THIRD EDITION

# PLASTICS FILMS

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Structural Wrap Exhibit 1039
Structural Wrap v Stormseal
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Page 1

# Plastics Films

## Third edition

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*With two chapters by*

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# Preface to the Third Edition

This edition has been extensively revised and updated in order to take account of advances in materials and conversion processes. The section on vacuum and gas packaging, for example has been expanded to include work on controlled/modified atmosphere packaging while the chapter on thermoforming has also been expanded and rewritten, with extra sections on control of wall thickness, automatic operation and solid phase pressure forming.

The chapter on health safety has been completely rewritten. The theory and the legislative aspects have both been updated, while new aspects include microwave cooking, irradiation and modified atmosphere packaging. The chapter on organolepsis has been extensively updated, particularly on newer techniques involving computers.

Finally, a new section has been appended on additives for plastics films in order to give a technological background to complement the health safety factors of additives.

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# 1 Introduction

Although the title of this book is 'Plastics Films' the subject of regenerated cellulose film has also been included because of its historical and present day importance. Regenerated cellulose is not a 'plastic' because at no stage in its manufacture is it capable of being moulded to shape. However, as a film it has a great deal in common with plastics films and it acts as an excellent reference point when properties and applications of plastics films are discussed.

The borderline between film and sheet may also need some clarification. There appears to be no hard and fast rule, but a convenient and widely accepted definition is that film comprises material up to 250 $\mu$m (0.010 in) in thickness whereas thicknesses above that figure refer to sheet. Some people tend to look on rigid material as sheet and flexible material as film but this is not so satisfactory as a practical definition. Materials such as unplasticised PVC and cellulose nitrate are fairly rigid even at thicknesses down to 70 or 80 $\mu$m (around 0.003 in), whereas low-density polyethylene is not really rigid even at thicknesses around 300 $\mu$m (0.012 in).

The subject of plastics film is already vast and is still growing rapidly so that a great deal of selection and condensation has been necessary to keep the subject within the bounds of this volume. Its aim has been to provide as full a background as possible to the student of plastics so that he may be in a position to consult the extensive literature on the subject. It is also intended to be a guide to the user or prospective user of plastics films, and to the worker in other fields of polymer technology.

## 1.1 HISTORICAL BACKGROUND

The first commercially successful plastics film was cellulose nitrate. It had some excellent properties, such as clarity, strength, resistance to moisture and dimensional stability but it also had one serious drawback, namely, flammability. As a film it has now been displaced by newer materials although as a sheet it still has at least one large application, namely, table tennis balls.

The most important development in films was the production of regenerated cellulose. The first process for dissolving cellulose and subsequently regenerating it was discovered by Schweitzer and formed the basis of his cuprammonium rayon fibre process. Cuprammonium films have also been made but are not so important commercially as those made by the Xanthate process. This was discovered in 1892 by three English chemists, Cross, Bevan and Beadle. A method for coagulation and regeneration of xanthated cellulose was patented by Stearn in 1898 and small commercial quantities of film were produced by John Chorley in Manchester a year later. However, the person chiefly responsible for the commercial development of equipment for the continuous production of cellulose film was J. E. Brandenberger, a Swiss chemist, and patents were first issued to him in 1911.

First applications for regenerated cellulose film were as decorative wrappings for luxury or semi-luxury goods. The development of heat sealable and moisture-proof grades (by means of coatings) meant that the film could be used as a protective wrapper and from then on its growth rate increased by leaps and bounds.

Cellulose acetate film was developed first, in 1909, as a 'safety' photographic film because of the dangers attached to the use of cellulose nitrate. Since then it has developed as a wrapping film where 'breatheability' is required (as in fresh produce packaging), in print lamination for the covers of journals, maps, etc., and in the manufacture of window cartons.

Of the films so far mentioned, regenerated cellulose was the almost unchallenged leader up to about 1950 since cellulose acetate was too expensive for the large tonnage packaging uses. The first film to challenge the supremacy of cellulose film was polyethylene but other, more recent, films such as polypropylene, PVC and polyethylene terephthalate have also either eroded cellulose film's markets or developed new ones of their own.

A calendered grade of polyethylene mixed with polyisobutylene was produced as early as World War II and was used for the packaging of Mepacrine tablets for the Services. In 1946, an



extrusion process was developed, followed by a chill roll casting method in 1948. The latter had a better gloss and transparency than the extruded grades then available but was unsuitable for bag making purposes because of a serious tendency to block. A year later, a blown tubular film was made available which could be converted into bags although its clarity was poor by today's standards. Initial applications were mainly confined to industrial packaging, such as covers for equipment packed inside wooden crates, the packaging of electrical resistors and as drum liners. The development of prepackaging for fresh produce gave a boost to the use of polyethylene film because of its combination of transparency and high strength. When, eventually, high clarity grades of polyethylene film were developed, new markets opened up in the fields of display packaging such as textiles, woollens, soft toys and similar items. During this time, polymer costs were steadily falling and eventually polyethylene film became the cheapest transparent film available. Today, one of the largest tonnage outlets for polyethylene film is the heavy duty sack for fertilisers, peat, polymer granules and various chemicals. The strength of polyethylene is exemplified by the fact that a sack for 50 kg (1 cwt) of fertiliser has a thickness of only 200 $\mu$m (0.008 in).

Although it has many advantages, low-density polyethylene film is limp compared with regenerated cellulose film and special machinery had to be developed before it could be used for high-speed packaging. A more challenging competitor to regenerated cellulose was polypropylene with its good clarity and stiffness as well as good barrier properties. This film was introduced around 1959.

Other plastics films have made their debut since then but none of them has had the impact of polypropylene, mainly because of their high price relative to polypropylene. However, many have established their own special niche in the market place by virtue of some special property or other. The importance of plastics films today can be seen from the *Table 1.1* which gives consumption figures for some of the main films in the U.K. in 1979.

Up to the beginning of the 1970s the story of plastics films was one of steadily reducing prices, leading to a gradual replacement of more traditional packaging materials such as paper. Since 1973 the continuing heavy increases in oil prices have sharply reversed the downward spiral of polymer prices and have greatly reduced the rate of increase in plastics consumption. The growth of plastics films has not been halted completely, however, because there are valid technical reasons, in addition to economic ones, for using them in a wide variety of applications. When considered from a performance

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**Table 1.1**

| *Film* | *Consumption (tonnes)* |
|---|---|
| Low-density polyethylene | 300 000* |
| High-density polyethylene | 22 000 |
| Polypropylene | 34 000† |
| PVC | 40 000 |
| Regenerated cellulose | 47 000 |

* includes heavy duty sacks (65 000 tonnes).
† includes film tape used for woven sacks (9000 tonnes).

point of view plastics are still competitively priced in relation to other materials.

## 1.2 SOCIO-ECONOMIC CONSIDERATIONS

Reference has already been made to the economics of plastics films but there is also a socio-economic consideration which is becoming more important as time goes on. This is the use of energy in manufacturing processes. More strictly this should be looked at in terms of a total energy equation involving the energy used to produce the article to be packaged, the possible percentage loss if the product was sold in the unpackaged state and the energy used to produce the particular protective package. Such equations tend to show that in most cases the energy used in producing the packaging material is fully justified. In addition, the energy used in producing a plastics film bag or wrap is an order of magnitude less than that of a glass container (first use), a tinplate can or an aluminium container (to package an equivalent weight of foodstuff). As an example of the justification for packaging, 1 kg (2.2 lb) of potato crisps is estimated to consume 10 MJ (0.095 therms) of energy in its manufacture. Coated, oriented polypropylene bags, or bags made of coated cellulose film (to contain 1 kg—2.2 lb of crisps), would probably consume only about 0.3 to 0.35 MJ (0.003 to 0.0035 therms). The spoilage of unpackaged crisps would be 100% within a very short space of time and thus the packaging is fully justified. The energy consumption for a glass bottle (also able to hold 1 kg—2.2 lb of foodstuff) would be nearer 9 MJ (0.085 therms) on initial manufacture but this drops to about 0.5 MJ (0.005 therms) for subsequent reuse (reflecting the energy used in washing).

Another factor which has a bearing on economics is availability. Most plastics are derived from oil and, as this is a non-renewable resource, prices must obviously rise as the resources dwindle.



However, not all plastics are derived from oil. Cellulose (from trees and other plant life) forms the starting point for a range of plastics including regenerated cellulose and cellulose acetate films. Attention is also being directed increasingly towards a wide range of renewable resources including seaweed, sewer waste, field crops, etc. One important monomer—ethanol—can be derived, via the fermentation of sugars, from plant juices, cellulose and starch, while methanol (an important source of formaldehyde) can be obtained from agricultural residues or from municipal solid waste. Sugar itself has also been investigated as a feedstock for plastics. Economics is still a major barrier but this will change as the non-renewable sources become even more scarce.

It should not be forgotten that oil is not the only non-renewable resource available for plastics manufacture. Coal was widely used once and may well be again, so giving more time to develop renewable resources.

## 1.3 LEGISLATION

A large percentage of plastics films is used in packaging and this means that plastics films are widely affected by an increasing amount of legislation. One aspect of legislation is dealt with in Chapter 11 but there is also increasing pressure from consumer groups and governments concerning the impact of packaging on the environment. In the E.E.C., the Environment and Consumer Protection Service has set up a Packaging Working Group. This has already shown a very anti-packaging bias and although its initial attention has been concentrated on the use of returnable and one-trip containers for beverages it will probably move to other areas of packaging (including films) in due course. In the U.K. a Waste Management Advisory Council (WMAC) was set up in 1974 and went on to form a Packaging and Containers Working Group. WMAC was disbanded late in 1980 but not before the Working Group had produced an excellent report on returnable and non-returnable beverage containers. In order to present a coherent reply from industry to the growing criticism, leading U.K. packaging manufacturers, producers of packaged goods and retail organisations formed the Industry Committee for Packaging and the Environment (INCPEN) in 1974. Later, in 1976, the Waste Management Advisory Council indicated to INCPEN that, to avoid legislation, industry should consider producing a draft code of practice for packaging. INCPEN eventually produced a draft U.K. Code which was then discussed with the CBI, various consumer and

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environmentalist organisations, Pira (Research Organisation for the Paper, Printing and Packaging Industries) and observers from various government departments. The final Packaging Code was published in May 1978. The Code has eight points, the last of which reads: 'The package should be designed with due regard to its possible effect on the environment, its ultimate disposal and to possible recycling and reuse where appropriate.' The operation of the Code is supervised by the Packaging Council which includes members representing manufacturers of packaging, packers of consumer goods, distributors, consumer organisations, environmentalists and trade unions, meeting under an independent chairman.

Some of the main factors concerned with the packaging film/environment interface are discussed in Chapter 25.

# Part 1
# Film-Forming Materials

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# 2
# Polyolefins

The polyolefins form an important class of thermoplastics from any standpoint but they are particularly important as film formers since they include low and high density polyethylene and polypropylene. Low density polyethylene film constitutes the major portion of the total film market but high density polyethylene and polypropylene are by no means minor components.

The polyolefins which will be dealt with in this chapter are low density polyethylene, high density polyethylene, polypropylene and poly(4-methyl pentene-1). Ethylene–vinyl acetate copolymers will also be dealt with here because the film-forming polymers contain ethylene as the major constituent. Ionomers, although based on ethylene, are discussed in a separate chapter since their structure and properties are sufficiently different to merit separate treatment.

In the case of polyethylene, the low density and high density polymers will be considered separately although a broad spectrum of polyethylenes is now available, due to co-polymerisation of ethylene with small amounts of other olefins such as butene-1, or by blending of the two types of polyethylene.

## 2.1 LOW DENSITY POLYETHYLENE

The first high-molecular-weight polymer of ethylene was produced by Imperial Chemical Industries Limited in 1933, during a pure research programme devoted to the effects of extremely high



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pressures on chain reactions. Special equipment was developed to withstand these pressures which were of the order of thousands of atmospheres. During an investigation of the reaction between ethylene and benzaldehyde, a white powder was produced and was identified as a polymer of ethylene.

The experiment was repeated using ethylene alone but this led to explosive decomposition of the ethylene and the apparatus was badly damaged. Two years passed before any further work was carried out but in the meantime improved apparatus had been developed.

What happened next owed a great deal to chance but was turned to good account. A fall of pressure occurred during a repeat of the experiment using ethylene alone and fresh ethylene was added to restore the pressure to its original value. At the end of the experiment about 8 g of a white powdery solid was obtained and identified as polyethylene. The success of this particular experiment was traced to the fact that the ethylene added to restore the pressure had, quite by chance, contained just the right amount of oxygen to initiate the polymerisation reaction. The element of chance had, in fact, entered at a still earlier stage because the pressure drop was apparently greater than could be accounted for by polymerisation and there must, therefore, have been a leak in the apparatus.

Low density polyethylene was first used in the electrical industry, particularly as an insulating material for underwater cables and, later, for radar. The development of polyethylene film came during World War II by calendering of a polyethylene–polyisobutylene blend and later, in 1946, by extrusion.

The polymerisation of ethylene can occur over a wide range of temperatures and pressures but most commercial high pressure processes utilise pressures between 1000 and 3000 atmospheres and temperatures between 100 and 300°C. Temperatures higher than 300°C tend to cause degradation of the polyethylene. The first initiator, as we have seen, was oxygen but other initiators and modifiers have also been used. The concentration of oxygen is critical. The process is highly exothermic and one of the earliest difficulties was the removal of excess heat from the reactors.

The ethylene is highly purified and then led over a reduced copper catalyst in order to remove any traces of oxygen. The precise amount of oxygen necessary to act as an initiator is then added and the gases are compressed in multi-stage compressors. They are then pumped into the reaction vessel by specially designed compressors. Two main types of reactor are in use, namely, the autoclave and the tubular. In either case, provision must be made for the close control of catalyst concentration, pressure and temperature. Any

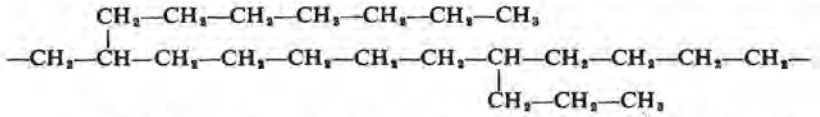


unconverted ethylene is separated from the molten polymer and is recycled. The polymer is then extruded as a continuous ribbon, solidified by cooling (usually in a water bath) and cut into granules. Film grades are usually given a further homogenisation by processing in an internal mixer, a refiner or a screw extruder.

The simplest structure for the polyethylene molecule is a completely unbranched chain of $-CH_2-$ units as shown.

$$-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-\text{etc.}$$

The vigorous nature of the high pressure process, however, militates against the straightforward process of chain growth and a great deal of chain branching occurs which has an important bearing on the properties of low density polyethylene. Both short and long branch chains are produced, examples of which are shown below.



It will be noticed that each branch chain contains a terminal methyl ($-CH_3$) group. A convenient way of characterising branching is by the number of methyl groups per 100 carbon atoms and this can be done by infra-red spectroscopy.

The occurrence of these branch chains prevents a close packing of the main polymer chains and this accounts for the fact that the process just described produces low density polyethylene.

### 2.1.1 PROPERTIES

The structure of the low density polyethylene molecule also affects properties other than density. One important property is that of crystallinity. The great length of polymer chains means that a certain amount of entanglement normally occurs and this prevents complete crystallisation on cooling; there are thus disordered areas between the crystallites. The structure of a partially crystalline polymer is shown in *Figure 2.1*.

Areas where the chains are parallel and closely packed are largely crystalline while the disordered areas are amorphous. These crystalline areas are known as crystallites. When the polymer melt is cooled slowly, the crystallites may form spherulites consisting of spherically symmetrical aggregates of crystallites plus amorphous polymer.

*Figure 2.1* shows molecules passing through both ordered and

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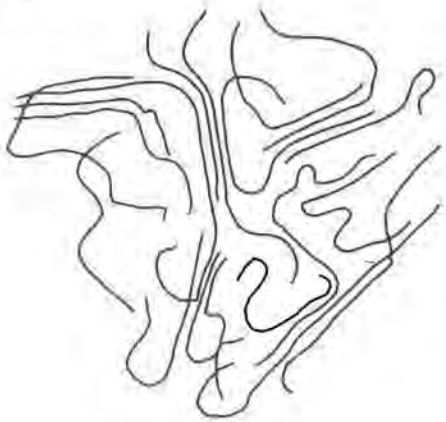

*Figure 2.1*

disordered states and this was once widely believed to be the case. More recent work seems to point to the fact that the molecules fold on themselves in a parallel arrangement to form lamellae. Crystallisation spreads as other molecules align themselves into position and also start to fold. The spherulites mentioned earlier occur due to irregularities in molecular structure which cause the crystalline growth to occur in more than one direction. The presence of chain branching will tend to reduce the possibility of an ordered arrangement and so reduce the crystallinity. The crystallinity of low density polyethylene usually varies between 55 and 70% (compared with 75–90% of high density polyethylene). The other property of importance which is affected by the chain branching is softening point. The fact that the chains cannot approach so closely to each other means that the attractive forces between them are reduced and less energy, in the form of heat, is necessary to cause them to move relative to each other and thus flow. The softening point of low density polyethylene is slightly below the boiling point of water and so the material cannot be used where boiling water or steam sterilisation are involved.

Low density polyethylene is a tough, slightly translucent material and is waxy to the touch. The density can vary between about 0.916 g/cm$^3$ and 0.935 g/cm$^3$. It can be blow extruded into tubular film or extruded through a slit die and chill-roll cast. The chill-roll casting process gives a clearer film but even blown film can be produced with good clarity with improvements in cooling of the bubble. Low density polyethylene film has a good balance of properties such as tensile strength, burst strength, impact resistance



and tear strength. In addition, it retains its strength down to quite low temperatures (around −60° to −70°C). It is a good barrier to water and water vapour but is not so good a barrier to gases. It is not suitable, therefore, for the packaging of products susceptible to oxidation.

It has excellent chemical resistance, particularly to acids, alkalis and inorganic solutions. It is, however, sensitive to hydrocarbons and halogenated hydrocarbons and to oils and greases. The effect is one of absorption followed by swelling. The swelling is less for polyethylenes of high molecular weight. Certain polar organic chemicals can cause environmental stress cracking of low-density polyethylene. This is a phenomenon which can be caused by chemicals which normally would not attack or dissolve the polyethylene. In the presence of stresses, however, these same chemicals cause surface cracks or even complete failure of the material. Typical stress cracking agents are detergents, some essential oils, vegetable oils, benzaldehyde and nitrobenzene. The incidence of stress cracking can be greatly reduced by the use of high-molecular-weight grades of polyethylene.

By the use of suitable additives it is possible to produce low density polyethylene film with high slip (low coefficient of friction) and low blocking tendencies. Build-up of static electricity can be a problem but again the use of additives can give film with much improved properties in this respect. It is odourless and tasteless and is widely used in food packaging applications. One disadvantage of low density polyethylene film is its relatively low softening point and the material cannot, therefore, be steam sterilised.

Low density polyethylene film is easily heat sealed and gives good, tough welds. It cannot be sealed by high frequency methods since it has a very low loss tangent. Sealing by means of adhesives is difficult because of the low absorption characteristics of low density polyethylene and the use of water or solvent based adhesives is restricted. Hot melt adhesives (especially those based on polyethylene and polyisobutylene blends) can be used but are expensive and show little advantage over direct heat sealing.

Printing of low density polyethylene film can be carried out successfully by a variety of methods provided that the surface is treated beforehand. This pre-treatment is necessary because of the inert, non-polar nature of the film surface which makes it very difficult to achieve a good key, and is described more fully in Chapter 14.

Flexographic printing methods are the most popular for low density polyethylene film but gravure and silk screen methods are also used. Although low density polyethylene has excellent

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dimensional stability with respect to changes in ambient humidity conditions, it is easily stretched so that 'snatching' should be avoided while running through the printing machine otherwise bad register will be obtained.

The addition of starch to low density polyethylene produces a material of some interest in the field of biodegradable plastics. Such polyethylenes normally contain between 10% and 40% of starch by volume. In moist soils they are said to lose half their strength in about 12 months and to break down totally in 5 years but the latter is strictly true only for the starch content. The remaining framework of polyethylene will probably embrittle and break up. Dispersal or absorption into the soil could well follow.

Starch-filled polyethylenes can be processed on conventional equipment. The main use at present is for carrier bags although another application for degradable film is for mulching of some agricultural crops such as tomatoes.

### 2.1.2 USES

The high tonnage usage of low density polyethylene film is a good indication of the very large number of applications which have already been developed for this material. The overwhelming proportion of these uses are in the fields of packaging, building and horticulture and agriculture and are therefore dealt with in the appropriate chapters.

## 2.2 LINEAR LOW DENSITY POLYETHYLENE (LLDPE)

In recent years there has been a spate of process development aimed at producing low density polyethylene either by *low* pressure gas phase polymerisation or by liquid phase processes similar to those used for producing high density polyethylene. Although the result of these newer processes is indeed a low density polyethylene there are still differences between the conventional low density polyethylene and the new polymers. These latter are known as linear low density polyethylenes (or LLDPE) and are similar in structure to high density polyethylene but with slightly longer and more numerous side chains.

A typical LLDPE gas phase process is that of Union Carbide Corporation. The process is based on a fluidised bed of polyethylene. Ethylene is fed in at the base of the fluidised bed and



the resultant polymer is taken out continuously, keeping a constant fluidised bed level within the reactor. The temperature is relatively low (about 100°C) while pressures are markedly lower (689–2068 kN/m²—100–300 lb/in²) than is the high pressure gas phase process developed originally by ICI. The efficiency is lower than in high pressure gas phase processes, being about 2% polymerisation per pass, compared with 15–30%. However, plant size can be greatly reduced by eliminating much of the equipment necessary in high pressure operation and the capital costs are also much lower. A somewhat similar process is the stirred bed system. A Ziegler type catalyst is used and a higher percentage polymerisation is achieved.

There are basically two types of liquid phase process, namely, slurry and solution. One slurry process is that of Phillips Petroleum which uses a chromium catalyst and operates at a temperature of 100°C and pressures between 689 and 4826 kN/m² (100 and 700 lb/in²). The polyethylene is produced in particle form. Solution processes have been developed by Du Pont and by Dow Chemical, using a Ziegler type catalyst. Operating conditions are around 180–250°C and 2757–4137 kN/m² (400–600 lb/in²). Additives can be incorporated directly in these processes.

The properties of LLDPE will vary according to the particular process employed in the same way that the properties of LDPE or HDPE vary. However, a major feature of LLDPE is that its molecular weight distribution is more narrow than that of LDPE. In general, the advantages of LLDPE over LDPE are improved chemical resistance, improved performance at both low and high temperatures, higher surface gloss, higher strength at a given density and a greater resistance to environmental stress cracking. In film form, LLDPE shows improved puncture resistance and tear strength. Typical figures for puncture resistance at a thickness of around 75 $\mu$m (0.003 in) are 0.4 ft lb/in$^2$ (834 J/m$^2$) for LDPE and 0.9 ft lb/in$^2$ (1877 J/m$^2$) for LLDPE. Similarly, the tear strengths about 350 gf (0.77 lb.f) for LDPE and 1050 gf (2.31 lb.f) for LLDPE (mean of machine and cross directions). At a density of 0.92 g/cm$^3$ the melting points of LDPE and LLDPE are 95°C and 118°C respectively.

LLDPE has been used for the manufacture of heavy duty sacks where its higher percentage elongation and ultimate tensile strength make it particularly suitable. Its higher melting point also opens up the possibility of hot fill applications, one suggested use being for cement sacks.

LLDPE is also making inroads into the stretch wrap market because of cost/performance improvements. One disadvantage is that LLDPE has considerably less inherent cling than other stretch

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films like PVC and EVA. One way of overcoming this is by the incorporation of cling additives. Another is to eliminate the need for cling by such devices as closure by mechanical crimping. LLDPE is also being used in stretch wrapping in the form of a laminate with other plastics films. One example is a triple laminate with conventional LDPE as the outer layers and an inner core of LLDPE. The advantages claimed here are a greater tear and puncture resistance and a higher tensile strength and elongation, compared with LDPE. The overall thickness can, therefore, be reduced and the stretchability is greater. The film weight per pallet load can, therefore, be reduced with a consequent cost saving. Other films have been developed that are based on blends of LLDPE with other polymers such as EVA. It should be noted that in shrink wrapping (as opposed to stretch wrapping) the lower hot melt strength of LDPE makes it the more suitable material.

The differences in molecular structure affect the rheology of the two materials. LLDPE is more viscous at extrusion shear rates and requires greater power to extrude. In addition, a wider die gap is required when extruding 100% LLDPE in order to prevent melt fracture. For best results some minor modifications have to be made to the screw and die gap of extruders designed for ordinary LDPE. Equipment has been designed to handle LLDPE, while another approach is the use of additives that allow the extrusion of LLDPE without the occurrence of melt fracture.

## 2.3 IRRADIATED POLYETHYLENE

Work on the irradiation of polyethylene has shown that hydrogen gas (with small amounts of methane, ethane and propane) is liberated and the polymer becomes increasingly insoluble due to cross-linking of the molecule by C—C bonds. Increasing irradiation leads to yellowing and, eventually, the polyethylene becomes a dark ruby red colour. At first the polyethylene becomes more flexible but later it turns harder and eventually becomes quite brittle.

Irradiated polyethylene film has been produced by passing ordinary low density polyethylene film continuously through a high energy electron field. This converts it to an infusible film, which, with appropriate stabilisers, will withstand prolonged ageing at 105°C or short term exposure at 230°C.

The process slightly reduces gas and water transmission rates and the film has good clarity. Tear strength is good, both tear initiation and tear propagation being high.

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## 2.4 HIGH-DENSITY POLYETHYLENE

Following ICI's discovery of low density polyethylene, the next most important step came in the early 1950s when Professor Ziegler, in the course of work on organometallic compounds, discovered catalysts which enabled the polymerisation of ethylene to be carried out at near atmospheric pressures and temperatures. At about the same time, two other low pressure methods were developed in the U.S.A. by Phillips Petroleum Company and Standard Oil of Indiana.

These discoveries were significant not only because of the different manufacturing techniques involved but because the products themselves were found to be different from the conventional polythylene in several important respects.

The catalysts used by Professor Ziegler stemmed from his work on organo-aluminium compounds and the first to give satisfactory results was a combination of aluminium triethyl and a titanium derivative such as the tetrachloride. The active catalyst is actually a reaction product of the two materials since neither will polymerise ethylene to high molecular weight products if used alone.

The Phillips process utilised such catalysts as partly reduced chromic oxide supported on steam activated silica–alumina, while the Standard Oil of Indiana process made use of nickel oxide on charcoal.

The principles involved can be seen by reference to the Ziegler process. The catalyst system is suspended in a liquid hydrocarbon through which the ethylene gas is passed. The pressure is near atmospheric and the temperature is around 50–75°C. Polyethylene settles out as a granular powder and the resultant slurry is stirred until the viscosity becomes so high as to interfere with efficient dispersion. The mixture is then passed through working up and solvent recovery stages. In general, the sequence is one of catalyst deactivation, catalyst decomposition and removal, solvent recovery, drying, extrusion and granulation. The efficient removal of catalyst residues is extremely important as the electrical properties of the polymer may otherwise be severely affected. One method used is to add dry hydrochloric acid gas which forms alcohol soluble complexes with the titanium (this being the more difficult metal to remove). After preliminary washing with alcohol, the polymer is well washed with water. The resultant slurry is filtered or centrifuged and then dried.

The Phillips process operates at higher pressures (2750–3450 kN/m$^2$ —400–500 lb/in$^2$) and higher temperatures (100–175°C). The liquid medium is usually cyclohexane and at these temperatures the

polyethylene dissolves and is removed as an approximately 10% solution. The catalyst is removed quite simply by centrifuging. The polyethylene is obtained by cooling, pelleting and drying.

More recently (during the late 1960s) Union Carbide Corporation introduced a gas phase process for the manufacture of high-density polyethylene, based on a catalyst system developed by them. Ethylene, a small quantity of hydrogen, catalyst and comonomer (if used) are fed continuously to a gas phase reactor where polymerisation takes place at about 1960 kN/m² (286 lb/in²) pressure and at a temperature within the range 85–100°C. The reactor is discharged to a product receiver where any unreacted ethylene is recovered and recycled to the reactor. The polymerised product is transferred from the receiver to a product purge tank and then through a gas lock valve to a conveying system which takes it to the storage silos. From the silos the product is withdrawn for mixing, extrusion and granulation. Because gas phase polymerisation requires no solvent, there is no need for separation of solvent from the polymer, nor for solvent recovery. The catalyst efficiency is also claimed to be sufficiently high for residual catalyst removal to be unnecessary. There is, therefore, no need to wash and dry the polymerisation product and so there is no recovery of washing solvent and no effluent.

### 2.4.1 PROPERTIES

The linear structure mentioned earlier is closely approached by the polyethylenes produced by low pressure processes. Some branch chains are formed but these are short and are not so many in number. Copolymers of ethylene with, for example, butene-1 are also produced by low pressure processes in order to introduce controlled amounts of branching into the essentially linear molecule. Densities of the copolymers are around 0.945–0.95 g/cm$^3$ whereas those of the linear homopolymers are around 0.96 g/cm$^3$.

High density polyethylene film is stiffer, harder and has a less waxy feel than low density polyethylene. It can be made by blow extrusion or slit die extrusion (with chill roll casting or water quench) but with blow extrusion a rather milky, translucent film is obtained.

The softening point of high density polyethylene is higher (about 121°C) and so it can be steam sterilised. The low temperature resistance is about the same as that of the low density polymer. Tensile strength is higher than that of low density polyethylene as is the bursting strength but impact strength and tear strength are both



lower. Because of their linear nature the high density polyethylene molecules tend to align themselves in the direction of flow and the tear strength of the film is much lower in the machine direction. This difference between machine direction and transverse direction tear strength can be accentuated by orientation to give a built-in tear tape effect.

The permeability of high density polyethylene is lower than that of low density polyethylene by a factor of about 5–6 times, its moisture vapour barrier properties being particularly good. In fact, of the films in common use its moisture vapour barrier properties are only surpassed by those of the vinyl chloride/vinylidene chloride copolymers.

The chemical resistance of high density polyethylene is also superior to that of low density polyethylene and, in particular, it has a better resistance to oils and greases. The solubility in organic solvents is reduced with increasing density, as is the permeability to solvents.

High density polyethylene is subject to environmental stress cracking in the same way as low density polyethylene but the effect can be reduced, again, by using high molecular weight grades where there is likely to be a problem.

### 2.4.2 USES

As with low density polyethylene the applications for high density polyethylene are largely in the fields covered by the applicational chapters, namely, Packaging, Film Fibres and Synthetic Papers.

## 2.5 POLYPROPYLENE

Early attempts to polymerise propylene using the high pressure process gave only oily liquids or rubbery solids of no commercial value. Later work by Professor Natta, in Italy, was directed towards the use of Ziegler-type catalysts. He found that if in the Ziegler catalyst system, aluminium triethyl plus titanium tetrachloride, the titanium tetrachloride was replaced by titanium trichloride, a stereospecific catalyst was formed which yielded crystalline high molecular weight polymers of propylene. A stereospecific catalyst is one which controls the position of each monomer unit as it is added to the growing polymer chain, thus allowing the formation of a polymer of regular structure from an asymmetric monomer unit such as propylene. This work constituted a major breakthrough in

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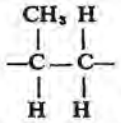
polymer technology since this was the first time that polymers with a regular spatial structure had been produced synthetically.

Basically Natta's polymerisation of propylene is similar to the Ziegler process for the preparation of high density polyethylene. The gas, under a pressure of about 100 atmospheres, is led into a reaction vessel in which is a well-stirred dispersion of catalyst in a liquid hydrocarbon. The temperature is kept low enough to ensure precipitation of the polypropylene as it is formed. Stirring is continued until the polymer content is between 35 and 40%, when the slurry is pumped to a flash drum where the unreacted propylene is removed and recycled. The slurry is then centrifuged to remove the liquid hydrocarbon.

Catalyst removal from the polymer is carried out by extracting with a weak solution of hydrochloric acid gas in methyl alcohol. After removal of the extractant, the polymer is washed with water to remove the acid, steam distilled to remove solid traces, dried, extruded and pelletised.

More recent work has made it possible to produce a type of polypropylene by gas-phase polymerisation methods.

The basic structural unit of polypropylene is:



and is thus similar to that of polyethylene with a methyl group substituted for one of the hydrogen atoms. The polymerisation of

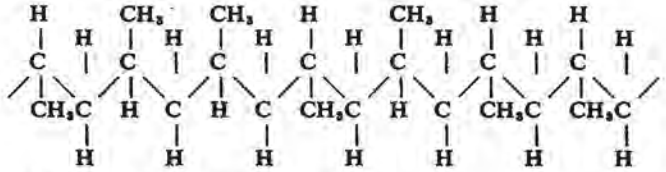


*Figure 2.2. Atactic polypropylene*

propylene without the aid of stereospecific catalysts produces haphazard linkages to give a rubbery or oily polymer with what is known as an *atactic* structure with a random distribution of the methyl groups on either side of the chain, as shown in *Figure 2.2.*

The regular crystalline polymer produced by stereospecific catalysts is known as the *isotactic* form, the name stemming from the original idea that the methyl groups were always situated along the same side of the polymer chain. In fact, the carbon atoms



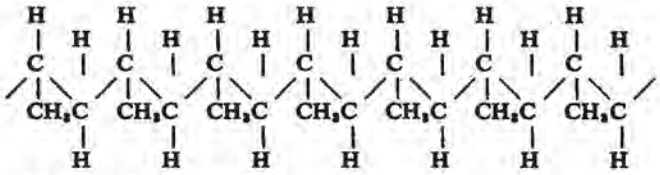


*Figure 2.3. Isotactic polypropylene*

arrange themselves into a helical chain with the methyl groups on the outside. *Figure 2.3* shows a 2-dimensional representation of the isotactic form. Two other forms are the *syndiotactic* and *stereoblock* polymers (*Figures 2.4* and *2.5* respectively).

The regular helices of the isotactic form can pack closely together whereas the atactic molecules will have a more random arrangement. Stereoblock polymers with infrequent inversion will behave very much as an isotactic polymer.

Some atactic polymer is produced even using a stereospecific catalyst system and the degree of isotacticity can be measured by extraction of the atactic molecule with n-hexane in which it is soluble. Both isotactic and stereoblock polymers are insoluble.

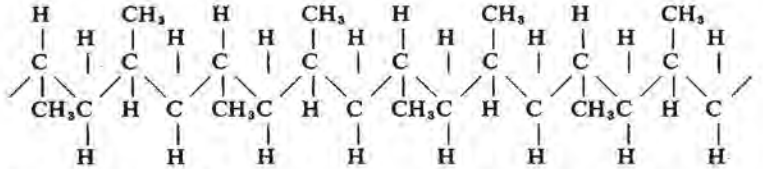


*Figure 2.4. Syndiotactic polypropylene*

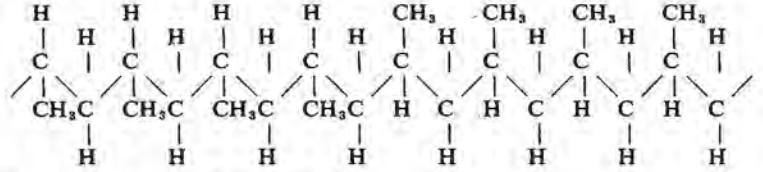


*Figure 2.5. Stereoblock polypropylene*

### 2.5.1. PROPERTIES

Polypropylene has a lower density than low density polyethylene (0.90 g/cm$^3$), is harder and has a higher softening point.

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Polypropylene film can be manufactured either by blow extrusion or by slit-die extrusion with subsequent cooling by chill-roll or water bath quench. The position is complicated by the fact that both methods have been used to produce a range of films which vary in the amount of orientation built into the film. Commercially, the films of most interest are slit-die extruded cast film with no orientation, biaxially oriented film with more or less equal orientation in the machine and transverse directions, and biaxially oriented films with unbalanced orientation. It is also possible to produce uniaxially oriented polypropylene, but this has a special significance in the manufacture of fibres, and is dealt with in Chapter 24. The various methods for producing biaxially oriented films are described in Chapter 8.

## Cast film

Cast polypropylene film has good transparency and gloss but increasing thickness makes it more and more difficult to effect rapid cooling and thus prevent the growth of larger spherulites which cause haze (see Chapter 10). There is, therefore, a consequent loss of clarity with increasing thickness.

The tensile strength of cast polypropylene is about twice that of cast low density polyethylene, but the tear strength is only about half. The elongation at break is high for cast polypropylene film and it can be cold drawn. One limitation of cast polypropylene film is its low impact strength at low temperatures (below about 0°C).

The permeability of cast polypropylene film is slightly higher than that of high density polyethylene, but much lower than that of low density polyethylene. The chemical resistance of polypropylene is good and, in particular, it is more resistant to oil and greases than the polyethylenes. Polypropylene is not subject to environmental stress cracking.

## Biaxially oriented film

Because of the wide variations possible in the extent of orientation in the two directions there is obviously a wide range of properties available. The balanced film has a tensile strength, in each direction, roughly equal to four times that of cast polypropylene film. Tear initiation is difficult, but tear resistance after initiation, is low. The elongation at break is also low because it has already been fully drawn. Biaxial orientation improves the gloss slightly and greatly reduces haze so that the oriented film has a greatly improved clarity over that of the cast film.



Biaxial orientation also improves the barrier properties of polypropylene film and its low temperature impact strength. Although both moisture vapour and gas barrier properties are improved by biaxial orientation, the gas barrier properties are still not as good as those of regenerated cellulose. However, coated grades of oriented polypropylene are available which are very much better in this respect. Coated grades were originally developed to improve heat sealability because shrinkage tends to occur when the highly stretched film is heated. The provision of a lower melting point polymer as a coating is one way of solving this problem. One coating which has been developed is acrylic based and does not add anything to the barrier properties of OPP film. However, it does provide a relatively wide sealing range of 45°C and it adds sparkle and good machine slip characteristics. Its hot-tack seal strength is good enough for it to be widely used for the vertical form/fill/seal packaging of light weight products such as snack foods. Heat seal coatings that are also barriers to water vapour and gases are based on PVDC. Here, again, there are various categories. The first has a fairly wide heat seal temperature range (33–45°C) with improved oxygen barrier properties. Both one or two sides coated films are available. The one side coated films are used as laminating substrates for use with other OPP films and cellulose films, to package snack foods and confectionery. The two side coated films are used in unsupported form for bags and carton overwraps. The second category has superior gas barrier properties but a narrower sealing range (28°C). Because of this such films are used as laminating substrates with other materials for the controlled or modified atmosphere packaging of coffee, processed meats and natural cheese. The third category of films have acrylic coatings on one side and a PVDC coating on the other. Such films provide a degree of gas and aroma barrier together with lap sealability.

Coextrusion is the other route to heat sealability. Most coextruded OPP films consist of two or three layers. The major component is the core ply which usually consists of virgin homopolymer and some regrind. One or both sides of the core may be covered with a PP-rich copolymer, or an ionomer, or a vinyl acetate-modified PE layer. PP-rich copolymers of propylene and ethylene are used for their good hot-tack seal strengths and excellent finished seal strengths. Ionomer is used because of its wide sealing range and grease resistance, while vinyl acetate-modified PEs provide good anchoring properties in coating, metallising and laminating operations. Some properties of typical coated and coextruded OPP films are shown in *Table 2.1.*

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**Table 2.1.** OPP FILMS—COATED AND COEXTRUDED

| | *Coextruded* | *PVDC coated* | *Acrylic coated* | *Metallised* |
|---|---|---|---|---|
| Haze (%) | 3.0 | 3.0 | 3.0 | – |
| Heat seal temperature range (°C) | 88–150 | 120–150 | 110–150 | – |
| Oxygen permeability ($cm^3/100\ in^2/d/atm$) | 160 | 1–3 | 150 | 4–18 |
| Water vapour transmission ($g/100\ in^2/d$) | 0.3 | 0.3 | 0.3 | 0.1–0.3 |

### Highly transparent film

Highly transparent blown polypropylene films have also been developed as direct competitors to regenerated cellulose film in areas of retail packaging where the prime need is consumer appeal, i.e. good surface gloss, high clarity, crackle, etc. The strength of such films is not so high as that of normal orientated polypropylene but this is seen as an advantage in some retail packaging where complaints are often made that plastics packs are too strong and difficult to open.

The process consists in extruding a tube downwards from a rotating spreader die and water cooling it after a short (300–500 mm—12–20 in) passage through air. The tube passes through a calibrator just below the water surface. The blow-up ratio is very low (less than 1:2). The preferred polymers are those with a higher than usual atactic and heptane soluble content.

### Pearlised polypropylene

Another PP film development is pearlised OPP. One variant is a gassed, expanded foam, oriented film which offers opacity and increased yield because of its lower density. In the U.K. it is widely used for wrapping confectionery and biscuits and is replacing glassine and foil tissues for these applications. Opaque OPP films can also be formed by other methods. In one method, homopolymer PP resin is mixed with a small amount of particulate matter, and a thick sheet is extruded and then oriented by the tenter frame process. The PP pulls away from each particle, thus creating an air-filled void. After heat stabilisation the OPP film is similar to a micropore foamed film. In another process, the material is produced as a filled film

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without voids, the opacity being a direct result of the amount of particulate material added.

In the film having air-filled voids the whiteness and opacity are created partly by the encapsulated particles but, to a greater degree, the opacity is also caused by light rays being reflected by the PP cell walls and by the air within each cell. The refractive index of the air is less than that of the PP and it is this difference that creates the opacity.

#### 2.5.2 USES

Many of the uses of polypropylene film (both cast and biaxially oriented) are in the field of packaging while the uniaxially oriented film is used for fibres. There is one field in which oriented polypropylene film is being increasingly used and that is print lamination. Included here is the covering of maps, charts, covers of technical journals and covers of paper-back books. Cellulose acetate is also used in this field, but polypropylene is cheaper because of its lower density and is also dimensionally stable in conditions of changing humidity. One disadvantage of polypropylene film is that special adhesives are usually necessary for good adhesion.

## 2.6 POLY(METHYL PENTENE) (TPX)

Methyl pentene polymers are a class of polymer based on 4-methyl pentene-1 as the principal monomer. This is copolymerised with other monomers using Ziegler type catalysts when an isotactic polymer is formed. Unlike polyethylene and polypropylene it is a very transparent polymer having a clarity nearly equal to that of acrylic sheet. It has the lowest density of any commercially available plastic ($0.83\ g/cm^3$) and a softening point higher than that of polypropylene. The melting point is 240°C but it is still form stable up to about 200°C. It has good chemical resistance but its permeability to moisture vapour and gases is high.

No uses have yet been developed commercially for the unsupported film, but it has been used as a coating on paperboard to give heat resistant disposable trays suitable for cooking and serving foodstuffs.

## 2.7 ETHYLENE/VINYL ACETATE COPOLYMERS (EVA)

Theoretically the proportion of vinyl acetate in ethylene/vinyl acetate copolymers can vary from 1 to 99% but commercially

available products to date have normally had less than 50% of vinyl acetate. Of these, the ones with 21–50% vinyl acetate are used as additives for waxes and adhesives and the copolymers with useful film-forming properties lie in the range 1–20% vinyl acetate. It seems logical therefore, to treat the film-forming EVA copolymers under the heading of polyolefins.

EVA films can be made by either blow extrusion or chill-roll casting methods. Cast film has the better optical properties but blow extrusion gives a tougher film and is the simpler method for the production of shrinkable film. Because it has a high elasticity, excessive tension should be avoided during haul-off.

### 2.7.1 PROPERTIES

The properties of EVA films vary according to the percentage of vinyl acetate in the molecule but in general the material compares with low density polyethylene as follows:

(1) Its heat seal temperature is lower.

(2) Its impact strength is higher.

(3) Its elasticity is greater.

(4) It has a greater resistance to environmental stress cracking.

(5) Its permeability to moisture vapour and to gases is higher.

(6) Its flexural life is greater.

(7) Its low temperature properties are better.

(8) EVA is tacky and has a greater tendency to blocking than has low density polyethylene.

(9) EVA's slip properties are worse, i.e. its coefficient of friction is greater.

(10) EVA can be sealed by high frequency heating but more power is needed than for PVC.

(11) Its printability is better.

(12) Its filler retention is higher.

Films with up to about 7–8% vinyl acetate may be considered as modified low density polyethylene, but the films with around 15–20% vinyl acetate are more like flexible PVC, with the added advantage that their flexibility is inherent and does not depend on added plasticisers which can later be leached out.



## 2.8 POLY(BUTENE-1)

Butene-1 is the next step up from propylene in the olefin family and is polymerised with the aid of Ziegler type catalysts. Its behaviour on crystallising from the melt is unusual inasmuch as the tetragonal crystalline Form II which is first obtained changes over a period of three to six days to the more stable hexagonal Form I. The transformation is accompanied by an increase in density, rigidity, strength and hardness. There is also an increase in crystallinity from about 30% to about 50%.

Polybutene film is normally prepared by blow extrusion but it can also be chill-roll cast. The unusual behaviour on cooling does not adversely affect film production.

### 2.8.1 PROPERTIES

Polybutene gives a tough film with good tear resistance, tensile strength, puncture resistance and impact strength. Its performance in these respects is superior to that of low density polyethylene which it resembles in density (0.915–0.92 g/cm$^3$). The melting point of polybutene is similar to that of high density polyethylene (125°C). Polybutene retains its strength properties at elevated temperatures to a greater extent than does low density polyethylene and this makes it particularly suitable for hot-fill packaging applications. At the other end of the temperature range, polybutene embrittles at about −35°C.

Polybutene has similar chemical properties to those of low density polyethylene, in general, but it has a much better resistance to environmental stress cracking. It is a good barrier to moisture vapour, but is not a particularly good barrier to gases.

Polybutene film can be heat sealed to give strong seals whether the seals are made in-line after extrusion, when the film is in Form II or later when the film has changed to Form I. Polybutene can be printed with the type of flexographic equipment used for polyethylene film, after pre-treatment.

### 2.8.2 USES

Polybutene film has been used in the U.S.A. for milk pouches but its toughness makes it a strong contender for industrial packaging or for tarpaulins.

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## 2.9 MELT FLOW INDEX (MFI)

The concept of melt flow index is so widely used that no discussion of the polyolefins is complete without it. The MFI is an indirect measure of the molecular weight of the particular polymer and is important to the converter because of the differences in processability between polymers of the same chemical type but with different molecular weights. We have also seen that the liability to environmental stress cracking is dependent on molecular weight.

The melt flow index is a measure of the melt viscosity of the polymer which in turn is related to the molecular weight. It is measured using the apparatus shown in *Figure 2.6* which is basically an extrusion plastometer with a standard orifice. The weight, in grammes, of the material extruded in 10 min under a constant dead weight and at a constant temperature is called the Melt Flow Index. A low melt flow index corresponds to a high melt viscosity and since melt viscosity is directly related to the molecular weight of the

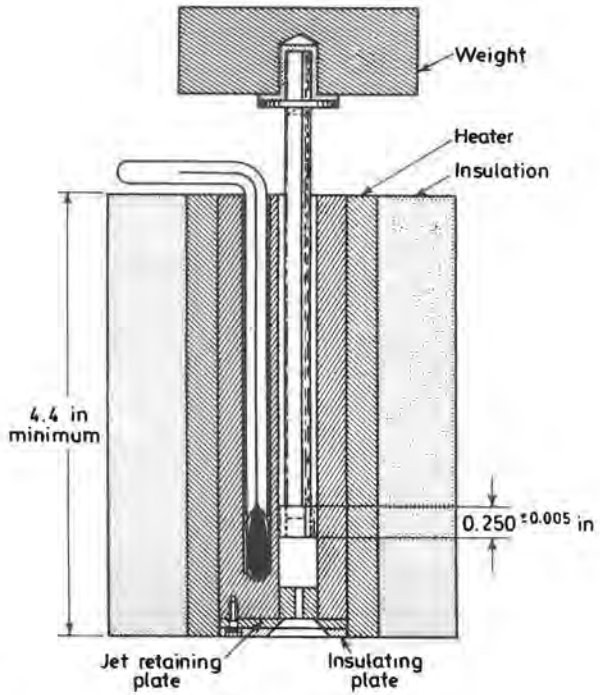


*Figure 2.6. Apparatus for determining Melt Flow Index*



polymer a low MFI corresponds to a high molecular weight and vice versa. A strict relationship obviously only applies to polymers of the same chemical constitution, but it also is restricted to polymers of the same density since density also affects melt viscosity. In the case of the polyethylenes and EVA the standard temperature is 190°C but for polypropylene the temperature is 230°C in order to allow for its higher melting point.

The relationship between melt viscosity and MFI is a logarithmic one. Thus, for a MFI of 0.2 the melt viscosity of a low density polyethylene (density 0.92 g/cm$^3$) is 300 000 P, while for a MFI of 2, it would be 30 000 P. Similarly a MFI of 20 corresponds to a melt viscosity of 3000 P. Extrusion processes, such as film making, require high melt viscosities and so low MFI grades are used.

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# 8
# Manufacturing Methods

## 8.1 EXTRUSION OF FILM

There are fundamentally two different methods of extruding film, namely, blow extrusion and slit die extrusion. The former method produces tubular film, which may be gusseted or lay-flat while the latter results in flat film. If desired, lay-flat film can be slit to give flat film. The equipment for film extrusion consists of an extruder, fitted with a suitable die, equipment to cool the molten film, haul-off machinery and a wind-up unit. Blow extrusion and slit die extrusion vary in the design of die used and in the type of cooling. The haul-off and wind-up equipment is also different.

The design and operation of the extruder up to the die is the same for both methods, however, and will be briefly described here before considering the different types of film manufacture. The basic extrusion process is designed to convert, continuously, a thermoplastics material into a particular form, in this case film. The basic sequence of events is as follows:

(1) Plasticisation of the raw material in granule or powder form.

(2) Metering of the plasticised product through a die which converts it to the required form (i.e. tubular or flat).

(3) Solidification into the required form.

(4) Winding into reels.



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Processes (1) and (2) are carried out in the extruder, whilst (3) and (4) are ancillary processes.

A typical extruder is shown in *Figure 8.1* and consists essentially of an Archimedean screw which revolves within a close fitting, heated barrel. The plastics granules are fed through a hopper mounted at one end of the barrel and carried forward along the

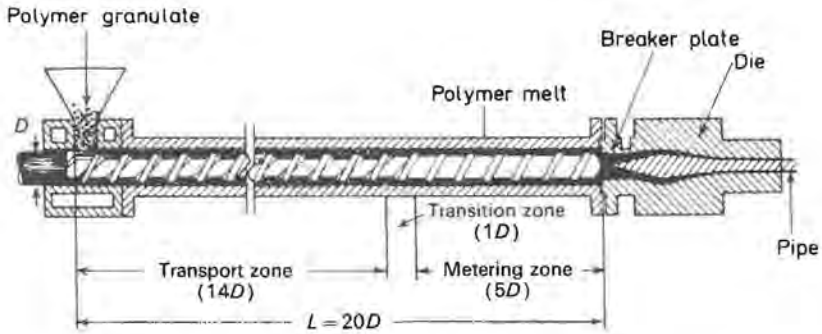


*Figure 8.1. Scheme for a typical single-screw extruder ($L/D = 20$) shown extruding pipe*

barrel by the action of the screw. As the granules move along the screw, they are melted by contact with the heated walls of the barrel and by the heat generated by friction. This frictional, or exothermal, heating is appreciable and in modern high speed machines it can supply the whole of the heating required for steady running, external heating being required only to prevent the machine from stalling at the start of the run when the material is cold. The screw then forces the molten plastic through the die which determines its final form. The most important component of the extruder is the screw and different designs of screw are used for extruding different polymers. Extruder screws are characterised by their length to diameter ratio (commonly written as $L/D$ ratio) and their compression ratios. The compression ratio is the ratio of the volume of one flight of the screw at the hopper end to the volume of one flight at the die end. $L/D$ ratios most commonly used for single screw extruders are between about 15:1 to 30:1 while compression ratios can vary from 2:1 to 4:1. An extruder screw is usually divided into three sectors, namely, feed, compression and metering. The feed section transports the material from under the hopper mouth to the hotter portion of the barrel. The compression section is that section where the diminishing depth of thread causes a volume



compression of the melting granules. The main effect of this is an increase in the shearing action of the molten polymer due to the relative motion of the screw surface with respect to the barrel wall. This improves the mixing and also leads to an increase in frictional heat and a more uniform heat distribution throughout the melt. The function of the final section of the screw is to homogenise the melt further, meter it uniformly through the die and smooth out pulsations.

Just prior to the die is fitted a breaker plate supporting a screen pack consisting of a number of fine or coarse mesh gauges. The screen pack filters out any contamination which might be present in the raw material. This is particularly important in the case of thin film extrusion where even the smallest of contaminating particles could cause holes or even breaks in the film. The screen pack also increases the back pressure in the extruder and this improves the mixing and homogenisation of the melt. The screw is usually cored for steam heating or water cooling. When the maximum amount of compounding is required, the screw is cooled. This improves the quality of the extrudate but slightly reduces the output.

Correct design of the head is important and should promote streamline flow of the material with no 'dead spots' where material could stagnate and so decompose due to overheating. This is particularly important in the case of PVC where the degradation point of the material is close to the temperature necessary for adequate flow.

A fairly recent development in extruder design has been the use of venting or degassing zones in order to remove any volatile constituents from the extrudate before it emerges from the die. This is achieved by releasing the plastic melt from the state of compression to which it has been subjected, whereupon the water and other volatiles will vaporise and cause the melt to froth. In effect, two screws are used, in series and separated by the degassing zone. The first has three sections, namely, feed, compression and discharge, the latter having a shallow thread and normally running full. The second screw has a degassing section, fed by the discharge section of the first screw, followed by a discharge section of its own. The degassing section has a deeper thread than the final section of the first screw and thus the polymer suddenly finds itself in an increased volume and hence is at a lower pressure. Frothing occurs as the volatiles are released from the melted polymer which is again compressed and then fed to the die. The volatile vapours are released either through a vent-hole in the top of the extruder barrel, or through the hollow of the screw via a hole drilled in the trailing edge of one of the flights in the degassing section. In each instance, a

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vacuum is sometimes used to assist in extraction of the vapour. Vacuum hoppers are also sometimes used, particularly for dry-blend powders to reduce porosity, when the screw must be sealed at the thrust bearing in order to prevent rearward polymer leakage.

Multi-screw extruders, particularly twin-screw extruders are also available and have their own advantages and limitations. In general, multiple-screw machines are more expensive and because of their more complicated construction are likely to be less sturdy. A more positive transport of the molten polymer is possible, however, and better mixing is obtained. By virtue of their positive pumping action, multiple-screw extruders produce less shear heat and this makes them very suitable for materials that are heat sensitive, have low coefficients of friction or must leave the die at low extrusion temperatures.

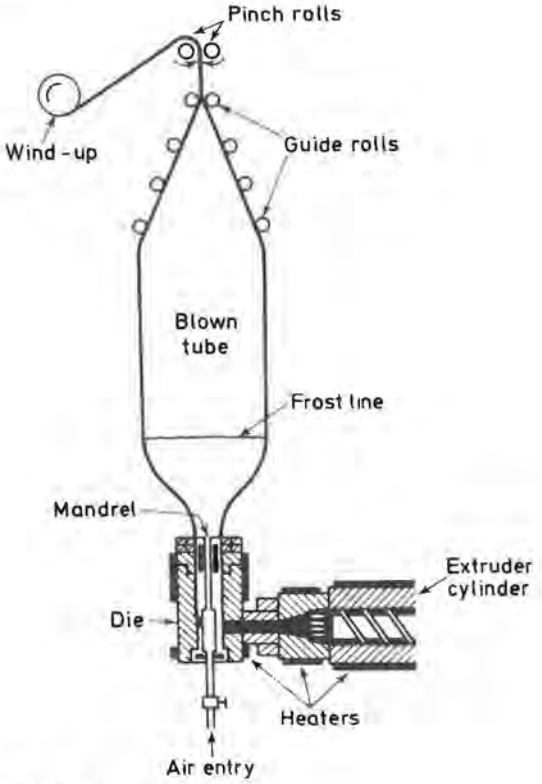


*Figure 8.2. Blown film extrusion*



### 8.1.1 BLOWN FILM EXTRUSION

A typical set-up for blown film extrusion is shown in *Figure 8.2*. In this instance the molten polymer from the extruder enters the die from the side but entry can also be effected from the bottom of the die. Once in the die, the molten polymer is made to flow round a mandrel and emerges through a ring shaped die opening, in the form of a tube. The tube is expanded into a bubble of the required diameter by an air pressure maintained through the centre of the mandrel. The expansion of the bubble is accompanied by a corresponding reduction in thickness. Extrusion of the tube is usually upwards but it can be extruded downwards, or even sideways. The bubble pressure is maintained by pinch rolls at one end and by the die at the other. It is important that the pressure of the air is kept constant in order to ensure uniform thickness and width of film. Other factors that affect film thickness are extruder output, haul-off speed and temperatures of the die and along the barrel. These must also be strictly controlled.

As with any extrusion process, film blowing becomes more economical as speeds are increased. The limiting factor here is the rate at which the tubular extrudate can be cooled. Cooling is usually achieved by blowing air against the outside surface of the bubble. Under constant air flow conditions an increase in extrusion speed results in a higher 'frost' line (the line where solidification of the extrudate commences) and this leads to bubble instability. Increasing the air flow gives more rapid cooling and lowers the 'frost' line but this is limited in its application because too high a velocity of the air stream will distort the bubble. Various designs of air cooling rings have been worked out in order to produce improved cooling without these attendant difficulties and one such design (designed and patented by Shell) is shown in *Figure 8.3*. It consists of a conically shaped ring provided with three air slits, the airstreams from which are so directed and regulated that the space between the bubble and the ring decreases gradually towards the top of the ring. This gives improved cooling by increasing the speed of the airstream. The design also results in a zone of under-pressure at the top of the ring and this greatly improves the bubble stability.

Blown film extrusion is an extremely complex subject and there are many problems associated with the production of good quality film. Among the many defects which can occur are variations in film thickness, surface defects such as 'orange peel', 'apple sauce' or 'fish eyes', low tensile strength, low impact strength, hazy film, blocking and wrinkling. Wrinkling is a particularly annoying problem because it can be costly, leading to scrapping of a roll of

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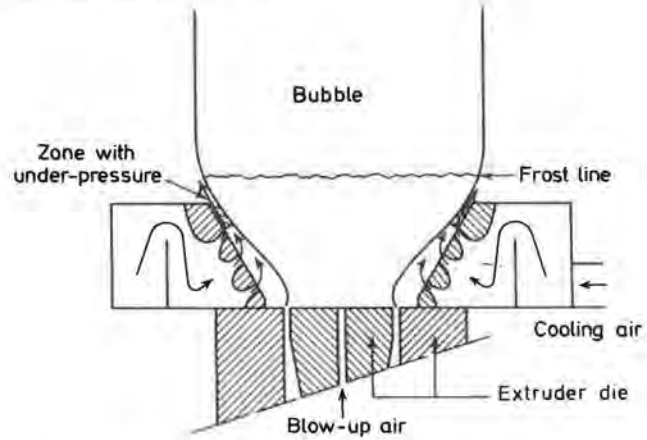


*Figure 8.3. Shell cooling ring*

film, and because it can arise from such a wide variety of causes that it is likely to occur even in the best regulated extrusion shop. If the film is too cold when it reaches the pinch rolls, for instance, it will be stiff and this may cause crimping at the nip and wrinkling. One way of raising the film temperature at the nip rolls is to raise the melt temperature but this can lead to other troubles such as blocking. In fact, this is illustrative of the whole subject of film blowing inasmuch as compromises are often necessary to achieve the best balance of properties. Wrinkling can also be caused by the die gap being out of adjustment. This causes variations in film thickness and can lead to uneven pull at the pinch rolls. Another cause of wrinkling may be surging from the extruder or air currents in the extruder shop. Both of these factors can cause wobbling of the film bubble and thus wrinkling at the wind-up stage. The film bubble may be stabilised by supporting it with horizontal stationary guides or the whole extruder may be protected from stray air currents by a film curtain. Other causes include non-alignment of the guide roll and the pinch rolls, or non-uniformity of pressure across the face of the pinch rolls.

Among the surface defects mentioned earlier, 'fish eyes' are due to imperfect mixing in the extruder or to contamination. Both of these factors are controlled by the screen pack which not only screens out contaminating particles but improves homogeneity by increasing the back pressure in the extruder. 'Orange peel' or



'apple sauce' are also surface defects caused by inhomogeneity of the molten polymer.

Since low density polyethylene forms by far the greatest percentage of all film made, it will be useful to consider the influence of the various polymer parameters such as melt flow index and molecular weight on the film properties. Impact strength, for instance, increases with molecular weight (i.e. with decreasing melt index) and with decreasing density. Heavy duty sacks, for instance, are normally made from polyethylene grades having densities between 0.916 and 0.922 g/cm$^3$ and melt indices between 0.2 and 0.5. For thinner technical film as used in building applications or waterproof lining of ponds, higher melt indices have to be used because of the difficulty of drawing down very viscous melts to thin film. Melt indices of between 1 and 2.5 are more usual, therefore, and impact strengths are less than for heavy duty sacks. Clarity is, however, improved. Where a good balance of properties is required as in the medium clarity/medium impact grades, slightly higher densities are used (0.920 to 0.925 g/cm$^3$) and the melt index is varied between 0.75 and 2.5. For high clarity, a high density and a high melt index are required since increases in both these properties cause an increase in see-through clarity, a decrease in haze and an increase in gloss. High clarity film will, of course, have a relatively poor impact strength because of the high melt index and such film should not be used for packaging heavy items.

### 8.1.2 SLIT-DIE EXTRUSION (FLAT FILM EXTRUSION)

In flat film extrusion the molten polymer is extruded through a slit-die and thence into a quenching water bath or on to a chilled roller. In either case the essence of the process is rapid cooling of the extruded film and cooling is, therefore, applied within a very short distance of the die lips (usually between 25 and 65 mm—1.0 in and 2.6 in). This short distance is also dictated by the necessity to reduce 'necking' of the film web, with consequent loss of width. In the chill roll casting method, the melt is extruded onto a chromium plated roller, cored for water cooling *(Figure 8.4)*. The rapid cooling leads to the formation of small crystallites and this gives a clearer film.

Where the quench bath method is used, the water temperature should be kept constant for best results. At constant extrusion temperature, lower quench temperatures improve slip and anti-blocking properties while higher quench temperatures give film that is easier to wind without wrinkles and with better physical properties.

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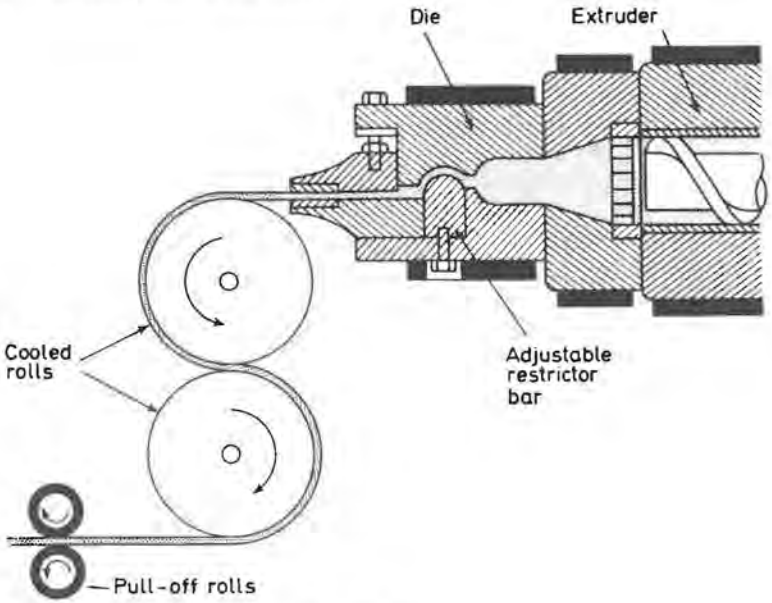


*Figure 8.4. Film casting (slit-die extrusion)*

Slit-dies for flat film are wide in comparison with the diameter of the extruder head and this means that the flow path to the extreme edges of the die is longer than to the centre. Flow compensation

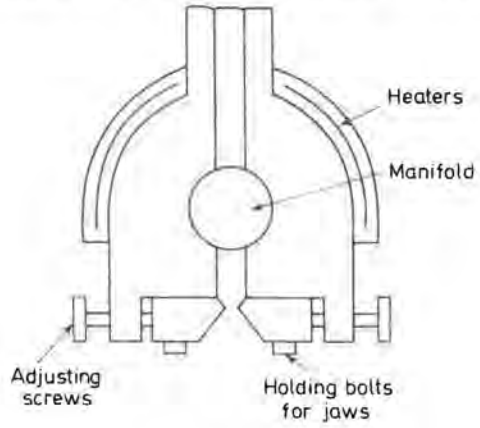


*Figure 8.5. Cross-section of manifold-type die for film*



is usually obtained by a manifold die, a cross-section of which is shown in *Figure 8.5*. It consists of a lateral channel (or manifold) of such a diameter that the flow resistance is small compared with that offered by the die lips. The manifold can only be efficient in its task of flow compensation if the viscosity of the melt is fairly low so that higher temperatures are necessary for flat film extrusion. This limits the use of the manifold die to materials of good thermal stability while another consequence of the higher extrusion temperature is the necessity for a heavier screen pack in order to maintain satisfactory back pressures. The inside surface of a flat die has to be precision machined and well polished since the slightest surface imperfection will result in striations or variations in gauge.

### 8.1.3 COMPARISON OF BLOW AND CAST FILM PROCESSES

Some of the advantages of the tubular film process are as follows:

(1) The mechanical properties of the film are generally better than those of cast film.

(2) The width of lay flat film is easily adjustable and there are no losses due to edge trimming. This latter is necessary for flat film because of the thickening of the film edge due to necking-in.

(3) Lay flat film is more easily converted into bags since it is only necessary to seal one end of a cut length to make the bag.

(4) The cost for making wide blown film is much lower than for wide cast film because the cost of chill rollers increases rapidly with width due to the difficulty of precision grinding longer rollers.

(5) A tubular film die is more compact and is cheaper than a slit-die producing film of comparable width.

(6) The tubular process is easier and more flexible to operate.

These advantages must be balanced against the advantages of the slit-die process which are as follows:

(1) Very high outputs can be obtained by slit-die extrusion units.

(2) Slit-die film normally has superior optical properties but it should be noted that special rapid cooling processes have been developed for tubular film, particularly in the case of

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polypropylene film. On example, the Shell Tubular Quench Process, will be described in more detail later.

(3) Thickness variation is usually less with slit-die extruded film.

### 8.1.4 WATER COOLED POLYPROPYLENE FILM

Among the advantages of the air-cooled tubular process mentioned above were cheapness, ease of conversion into bags and flexibility of operation. These factors have been largely responsible for the large scale penetration of low density polyethylene film into packaging markets. Polypropylene cannot be processed on the same equipment since the rate of cooling is inadequate to prevent the formation of large 'spherulites' (crystalline aggregates) in the film. This leads to the production of a brittle film, having a matt, opaque appearance. Clear polypropylene film can be produced by chill roll casting techniques but the equipment is expensive and is not normally

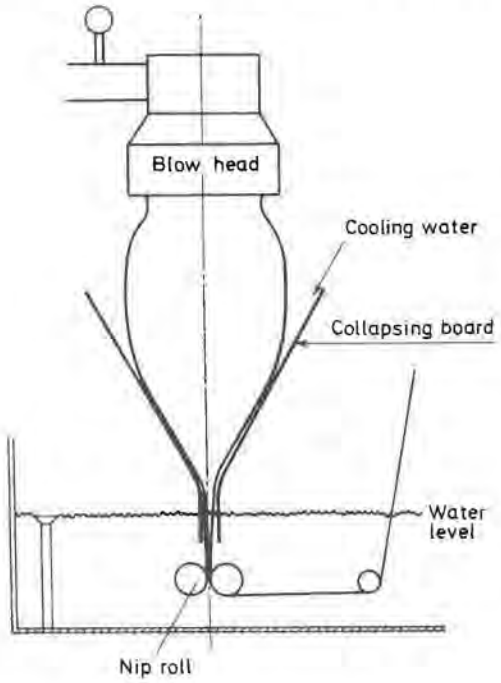


*Figure 8.6. Equipment setting for T-Q film extrusion*



economic at outputs below about 600 tonnes per annum. This has greatly hindered its penetration of the clear film packaging market.

Techniques of water cooling tubular polypropylene film, however, have opened up ways of producing clear film, with greater toughness and at no greater cost than cast polypropylene film. Among the different techniques commercially available is Shell's Tubular Quench (TQ Process) which involves downward extrusion of a tubular extrudate from an annular die followed by rapid cooling on water-covered converging boards. At the same time the tubular extrudate is inflated with air in the normal way to give film of the required lay flat width and thickness. The water film that runs down the converging boards shock cools the film and causes rapid crystallite formation and hence the formation of small spherulites with a consequent increase in clarity. The layout of the TQ Process is shown schematically in *Figure 8.6*. As with polyethylene, the blow up ratio influences the balance of molecular orientation between machine and transverse directions and this affects film impact strength, tensile strength and tear strength in the usual manner.

The properties of TQ polypropylene film are similar to those of the cast film. However, the ability to vary the blow up ratio allows a measure of control over the molecular orientation and this in turn can result in an improvement in mechanical properties compared with cast film where the orientation is essentially all in the machine direction of the film. The degree of orientation in the TQ Process is still low compared with that of a true biaxially oriented film and

**Table 8.1**

| *Property* | *TQ film* | *Cast film* | *Blown film (air cooled)* |
|---|---|---|---|
| Haze (%) | 3 | 4 | >20 |
| Gloss | 75 | 70 | 25 |
| Clarity (%) | 4–6 | 5–9 | — |
| Coefficient of static friction | 0.15–0.40 | 0.15–0.40 | 0.30–0.50 |
| Ultimate tensile stress (kg/cm²) | | | |
| MD | 500 | 450 | 190 |
| TD | 470 | 380 | 205 |

TQ film does not compete with it in properties. The production of biaxially oriented film will be dealt with later but a comparison of polypropylene film produced by chill roll casting, the TQ process and biaxial orientation is given in *Table 8.1*.

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The TQ Process is particularly valuable for outputs of film below the economic output of a cast film line (up to about 600 tonnes per annum). Costs are much lower and benefit from the great flexibility of the blown film process and the absence of edge trim waste.

Another process is the Dow-Taga process. In this the blown film goes through a hollow ring where it is coated with a film of water which flows from the ring and on to the film before it is collapsed. Different sizes of rings must be used to match changes in blow up ratios whereas with the TQ Process, no changes in equipment are needed when making different diameters of tubular film.

In a third process, developed by Kokoku Rayon and Pulp Co. Ltd. in Japan (now the Kohjin Co. Ltd.), the tube of polypropylene film, after it comes out of the die, is passed over a mandrel that extends down into a water bath. After cooling, the film comes out of the bath, still in tubular form. It is then dried and the tube collapsed between a set of rolls.

## 8.2 CALENDERING

In this process continuous sheet or film is made by passing heat-softened material between two or more rolls. Calenders were originally developed for processing rubber but they are now widely used for producing themoplastics (mainly flexible PVC) sheet and film.

In essence calendering consists in feeding a plastics mass into the nip between two rolls where it is squeezed into a film that then passes round the remaining rolls. It then emerges as a continuous film, the thickness of which is determined by the gap between the last pair of rolls. The surface of the film is determined by that of the last roll and can be glossy, matt or embossed. After leaving the calender the sheet is cooled by passing it over cooling rolls, and is then fed through a beta-ray thickness gauge (*Figure 8.7*) before it is reeled up.

The plastics mix fed to the calender may be a simple hot melt as in the case of, say, polyethylene but with PVC, a great deal of effort is put into the pre-calendering processes such as blending, mixing, gelling and straining. In addition to the polymer there may be inert mineral fillers (added to reduce the cost and modify the physical properties), pigments, lubricants (to assist in processing), stabilisers and plasticisers. The dry components (with the exception of the pigment) are loaded into a ribbon blender and agitated sufficiently to produce an even dispersion. If plasticisers are to be added they are sprayed into the powder mix during the initial period of



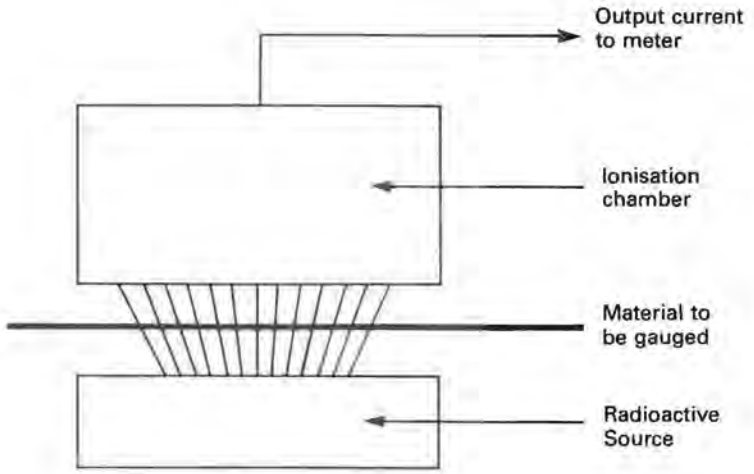


*Figure 8.7 Beta-ray gauge*

blending. When correct dispersion has been achieved the blend is removed via a valve at the base of the mixing chamber and weighed out into batch tins. If pigment is required it is added at this stage to each separate batch. The batch tins are then emptied into a primary mixer, such as a Banbury, and treated for about five to ten minutes at 120–160°C. The combination of heat and the 'kneading' action of the Banbury causes partial gelation of the mix. This partly gelled material is then passed to a two-roll mill and made to form a sheet round the front roll. This may be fed directly to the calender but for thin sheet or film a straining process is added to remove any coarse particles. A typical strainer consists of a single screw extruder with a filter screen directly in front of the screw. The screen consists of a fine stainless steel woven wire mesh backed up by a medium to coarse mesh for mechanical support, together with a perforated strainer plate.

Calenders may consist of from two to five hollow rolls (or bowls) arranged for steam heating or water cooling and are characterised by the number of bowls and their arrangement as, for example, I, Z or inverted L types. Four roll, inverted L and Z types are the most usual.

Very high forces have to be exerted on the rolls in order to squeeze the plastics to a thin film and these cause the rolls to bend giving sheet that is thicker in the middle than at the edges. Some

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ways in which the effect is counteracted are given below.

(1) The rolls can be 'crowned', i.e. they can be made with a greater diameter at the centre than at each end.

(2) The rolls can be crossed slightly, thus increasing the nip opening at either end of the rolls.

(3) A bending moment can be applied to the ends of each roll by having a second bearing on each roll neck and these are then loaded by hydraulic cylinders.

Z types have the advantage in this respect because bending of the rolls has no effect on the succeeding nip and so improves thickness accuracy. This is because alternative rolls are at right angles rather than in-line.

As mentioned earlier, thickness of the film or sheet leaving the calendar is measured using a beta-ray gauge (*Figure 8.7*). This gives an average reading of thickness over an area of sheet. Radiation from an isotope such as Thallium 204 is passed through the sheet and then collected in an ionisation chamber. The radiation received by the chamber is inversely proportional to the weight per unit area of the material being measured.

Calenders are of massive construction because of the large forces necessary to squeeze the plastics mass into a thin film. They call for high temperatures, with little tolerance across the rolls and high pressures, again with low tolerances. A large floor area is also needed because of the associated plant such as mixers, blenders, temperature control systems, haul-off equipment and other ancillary plant. Calendering is, therefore, a capital intensive process and calenders tend to cater for wide width film (around 1.8m—6.0 ft wide) because the cost is obviously proportionally less. However, these large machines tend to be used only for plasticised PVC because unplasticised PVC has a much higher melt viscosity which makes it harder to handle on rolls of this width.

A special calendering process known as the Luvitherm process was developed, therefore, to produce unplasticised PVC films. The PVC is flash heated up to 220°C while in contact with a specially designed aluminium roll and the hot film produced is normally oriented immediately after calendering in the high temperature zone. The calender unit is narrower than the large units described earlier and the output is lower. Special grades of PVC are used, with special stabilisers, and the compounding stage can be an extruder compounder feeding direct to the calender.

Calendering usually produces film with a better uniformity of gauge compared with that obtained by extrusion. A number of factors contribute to this, one of which is the great care paid to the engineering of the calender bowls (as mentioned earlier). The final gauge is very much dependent on the gap between the final two bowls whereas in extrusion the gauge is dependent more on blow-up ratios (in the case of tubular film) or draw down speeds (in the case of slit-die film). In addition, in an extruder cross-head die there may be a range of path lengths which lead to preferential flow and induce variation in gauge. In the tubular die process there are complicating factors such as the structures supporting the mandrel in the die. This also has an effect on the melt flow, leading to gauge variations.



Another advantage of calendering is that better mixing is obtained. The amount of energy available in a calendering line is very much more than in an extrusion line, so calendered film is less dependent on the uniformity of the feedstock.

The main advantage of extrusion for PVC is the much lower capital costs involved, so that shorter runs can be made at economic rates.

## 8.3 SOLVENT CASTING

Solvent casting methods are expensive but cellulose nitrate film was made in this way because of the flammable nature of the film. A casting solution is prepared by dissolving cellulose nitrate and camphor (as plasticiser) in a 70:30 ether/alcohol mixture using paddle mixers. After 8–10 h mixing the product is filtered through cellulose wadding and de-aerated in vacuo at a temperature just under the boiling point of the solvent.

The film casting is carried out on an endless belt, a smooth surface being obtained by depositing a layer of hard gelatine on a

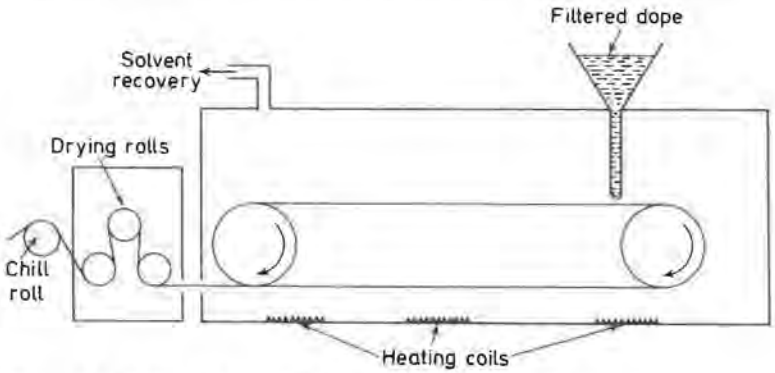


*Figure 8.8. Endless belt method of casting cellulose nitrate film*

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copper support. After being stripped from the casting surface the film is seasoned in a heated drying cabinet where it passes over a zig zag pattern of rollers. After a final passage over chilled rollers to cool the film, it is wound into reels. The general lay-out of a film casting process is shown in *Figure 8.8.*

Some cellulose acetate film is produced by solvent casting, as well as by extrusion, and solution casting has also been used for producing vinyl chloride/vinyl acetate copolymer films.

## 8.4 CASTING OF REGENERATED CELLULOSE FILM

Methods of dissolving and then regenerating cellulose date back to 1857 but the one which is the basis for the modern cellulose film was discovered by Cross, Bevan and Beadle in 1892. It was not until 1911, however, that Brandenberger patented the continuous manufacture of cellulose film. Uses for the film were restricted at first because of its high moisture vapour permeability but the development in 1927 of moistureproof grades opened up many new markets and cellulose film is still an important packaging material.

The basic raw material, cellulose, is obtained from wood pulp or cotton linters. After soaking in caustic soda for an hour, the excess alkali is pressed out. It is then shredded and allowed to age for 2–3 days and absorbs oxygen from the air. This reduces the length of the cellulose molecule chain and so reduces the viscosity of the solution during the next stage. Here the pulp is transferred to rotating churns and then sprayed with carbon disulphide. The solution is discharged into a tank and dispersed by stirring with dilute caustic soda solution. The resultant solution is known as viscose.

Cellulose film is made by filtering the viscose solution and allowing it to 'ripen' for 4–5 days. The ripening process consists of a slow hydrolysis the progress of which is followed by taking viscosity measurements. If ripening goes too far a gel is formed which is useless. Air bubbles in the solution are removed by drawing a vacuum and a film is formed by casting on to a drum or endless metal band, which revolves in the first of a series of tanks. The thickness of the film is regulated by varying the orifice at the base of the casting hopper or reservoir.

The first tank contains the coagulating solution consisting of sulphuric acid and sodium sulphate at a temperature of about 40°C. This solution not only coagulates the viscose but initiates its regeneration back to cellulose. The coagulated film is then led through further tanks by means of guide rolls. The tanks contain various



solutions designed to complete the regeneration, wash out acid carried over from the coagulating bath, remove any elemental sulphur, carbon disulphide, hydrogen sulphide, etc., and bleach the now transparent but still slightly coloured film. The film is then run through a bath containing glycerol or ethylene glycol which act as plasticisers and confer flexibility on the film. Finally it is passed through a drying oven and reeled up.

At this stage, the film is extremely permeable to moisture vapour and is not heat sealable and a subsequent coating treatment must be given if moistureproofness or heat sealability are required. A typical coating consists of dibutyl phthalate–plasticised cellulose nitrate, together with waxes and natural resins dissolved in organic solvents. Urea formaldehyde is also incorporated to anchor the coating and prevent it from floating off in damp conditions. The film is passed through the coating bath, dried to evaporate the solvent then passed through a high humidity chamber to restore the flexibility. Where even better barrier properties are required, a coating of polyvinylidene chloride is applied.

## 8.5 ORIENTATION OF FILM

Orientation of film by stretching it under heat is widely applied to films such as polypropylene, polystyrene, nylon and polyethylene

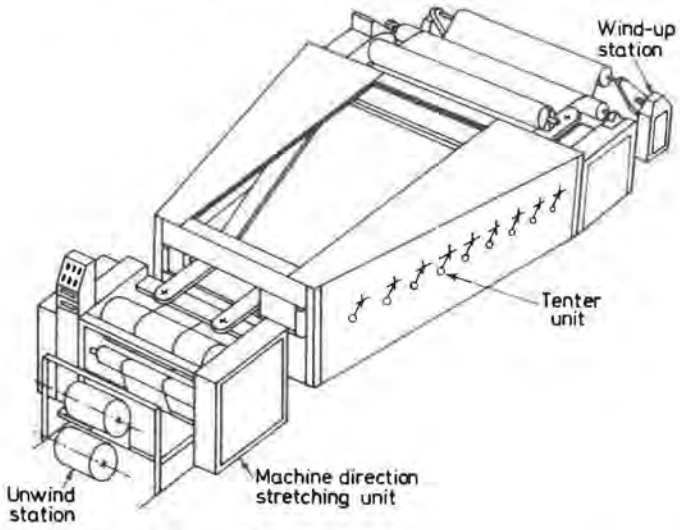


*Figure 8.9. Two-stage orientation—flat film*

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terephthalate to improve clarity, impact strength and, particularly in the case of polypropylene, its barrier properties.

Basic polystyrene film, for instance, in its non-oriented form is very brittle and has only a limited use as a dielectric in capacitors. When biaxially oriented (i.e. oriented in two directions at right angles), the film is quite tough and can be thermoformed into crystal clear tubs, trays and larger items such as cake covers.

The largest application of orientation techniques, however, is in the manufacture of polypropylene film and the various processes will be illustrated mainly with respect to this film. The main processes can be divided into linear and tubular. The principle of the linear type can be illustrated by considering the two stage process shown in *Figure 8.9*. Thick cast film of around 500–600 $\mu$m thick is made by the chill roll casting process described earlier in the chapter. This is then fed to a system of differential draw rolls, i.e. rolls running at gradually increasing speeds. These rolls are heated sufficiently to bring the film to a suitable temperature (below the melting point). Under these conditions, the film is stretched in the machine direction at a draw ratio which is normally between 4:1 and 10:1. After leaving the draw rolls, the film is fed into a tenter frame which consists of two divergent endless belts or chains fitted with clips. These clips grip the film so that as it travels forward it is

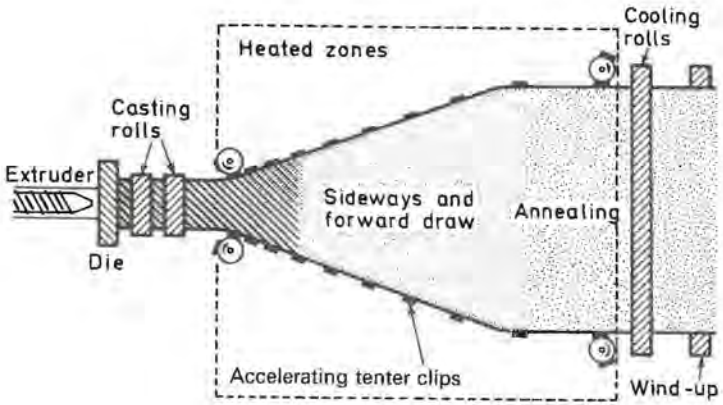


*Figure 8.10. Simultaneous orientation process using a tenter*

drawn transversely at draw ratios similar to those applied in the machine direction. The tentering area is also heated, with accurate



control of temperature, usually by passing the film through an oven. On leaving the tenter frame, the film is cooled by passing over a cooling roller, then reeled up. Systems are also available in which this sequence of operation is reversed, i.e. the tenter frame comes first, followed by the differential draw rolls.

The two operations can also be carried out simultaneously, as in *Figure 8.10*. The film is gripped by its edges as it leaves the casting rolls and is then moved forward at an increasing speed while being stretched transversely by the diverging grips. Mechanically, this type of operation can be carried out by a tenter frame in which the clips are moved by a screw of increasing pitch. The magnitude of the transverse draw would then be controlled by the angle of divergence of the clips, in the usual way, while the magnitude of the forward draw would depend on the rate of increase of pitch.

As indicated, orientation can also be achieved by tubular processes. Molten polymer is extruded from an annular die and then quenched to form a tube. The wall thickness of the tube is controlled partly by the annular die gap and partly by the relative speeds of extrusion and haul-off. The tube passes through slow running nip rolls and is then re-heated to a uniform temperature. Transverse drawing is achieved by increasing the air pressure in the tube, the draw ratio being adjusted by adjustments to the volume of entrapped air. The air is trapped by pinch rolls at the end of the bubble remote from the extruder and these are run at a faster speed than the first pair, thus causing drawing of the film in the machine direction. The tubular process is thus another method of obtaining simultaneous transverse and forward orientation.

A range of films is obtainable from the various methods, from a biaxially oriented film with balanced properties, i.e. the same draw ratio in each direction, via biaxially oriented film with unbalanced properties (different draw ratios in the two directions), to completely uniaxially oriented film (either in the machine direction or transversely). Uniaxially drawn films tend to fibrillate when stretched at right angles to the direction of orientation and this reduces their usefulness as packaging film. The phenomenon is, however, utilised in the production of film fibres and this subject is dealt with in Chapter 24.

If oriented polypropylene film is heated to about 100°C immediately after drawing, it will shrink unless it is restrained in some way. This can be prevented by a process of annealing or heat setting. The film is heated, under controlled conditions, and while held under restraint. After cooling, the film will not shrink if heated to below the annealing temperature and the film is said to be heat set. The physical and optical properties of the film remain unchanged.

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## 8.6 EXPANDED FILMS

Reducing the density of polymers by the creation of a cellular structure gives articles having a greater stiffness in bending for a given weight of polymer. The technique can be applied to extruded films as well as to moulded articles and has been so applied in the case of polystyrene and, more recently, the polyolefins.

The greater rigidity for a given weight of material is achieved because the rigidity of a beam is proportional to the cube of its thickness. For unit surface area, therefore, a film of double the thickness can be made from $X$ g of material if the density is halved. Doubling the thickness means an increase of two cubed, = eight, times the stiffness for a given modulus but the modulus varies linearly with density so that halving the density halves the modulus, giving a net increase of four times the stiffness. This can have very important economic advantages.

### 8.6.1 EXPANDED POLYSTYRENE FILM

There are two main methods for the production of expanded polystyrene film. The first of these starts with polystyrene beads which have been impregnated under pressure with a liquefiable gas, usually pentane. The film is blow extruded, using a twin screw extruder and the addition of a nucleating agent such as a citric acid/sodium bicarbonate mixture. The nucleating agent has been found to be necessary in order to give a fine cell size. As the molten mass leaves the extruder die head and the pressure is released, the material starts to expand. The blown bubble technique is used in order to take up the corrugations which occur during the expansion process. The bubble is normally blown horizontally for ease of handling during start-up since the material is hard and rigid, unlike polyethylene film. When the bubble is collapsed, the tube is cut at each side to give two flat sheets which are reeled up separately. This is necessary because the folded edges of the tube are a source of weakness due to the rigidity of the polystyrene.

The other method utilises ordinary polystyrene beads as feedstock and gassing is carried out in the extruder. The film is then blown as before. The extruder has to be constructed specially for this type of operation and it is only economically viable for large tonnage offtakes—of the order of 400 tonnes/annum. The extrusion of pregassed beads is cheaper at lower tonnages and has the advantage of flexibility since the extruder can be used for other work.



Control of sheet orientation in either operation is achieved, as usual, by adjusting the haul-off speeds and the blow-up ratio. The orientation should be as balanced as possible as any appreciable difference in strength between machine and transverse directions could lead to splitting of the sheet during subsequent thermoforming operations.

The density of the sheet as it leaves the extruder is usually about 80 g/l (5 lb/ft$^3$) but subsequent operations, such as blowing-up, and any stretching that occurs during haul-off, compress the sheet and so increase its density. The collapsing of the bubble and subsequent passage of the film through nip rollers also increases the density.

Where low density sheet is required it is passed under an infra-red heater just prior to reeling up.

### 8.6.2 EXPANDED POLYOLEFINS

These are made by adding a masterbatch to the normal granules and then blow extruding as usual. The masterbatch contains a blowing agent and processing aids. The blowing agent is a compound which breaks down at the temperature of extrusion to give nitrogen which expands the molten mass on extrusion. When the melt leaves the high pressure zone in the die, the gas diffuses to discontinuities in the melt and bubbles are formed. In expanding the melt the gas has to stretch the polymer in order to create a cell. The melt temperature has to be carefully controlled at this point, therefore, because it affects the melt strength.

Films produced in this way have some of the attributes of paper, e.g. appearance, handle, stiffness and some retention of creasing. Densities are of the order of 600 g/l (37.5 lb/ft$^3$).

## 8.7 PLASTICS NET FROM FILM

Nets are usually made by the knitting of mono- or multi-filaments or by direct extrusion processes giving nets with the crossing strands fused together at the point of contact.

It is also possible to produce a net from film by embossing and then stretching. The film splits in a regular manner and an open work pattern is produced. The technique is applicable to a large number of polymers, while other variables are the embossed pattern and the loading conditions.

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Outlets so far are in the surgical and medical fields, in dressings, and as adhesives between two layers of cloth which are fused together by heat. The regular spacing and porosity of the net remain while the laminated materials acquire excellent drape and resistance to washing or dry cleaning.

### FURTHER READING

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# 9
# Mechanical Properties

The properties of the various film forming materials have already been compared and contrasted. Selection of the best film for any particular use is a matter of matching these film properties against the end-use performance required. In packaging, for instance, it is the performance required by the product to be packaged in its particular marketing environment. The latter, it should be noted, includes the price at which the package can be sold.

In order to carry out this matching of properties against requirements, it is necessary to know what the various properties actually mean in practice and to have some method of quantifying them. The testing of film properties is also necessary for other reasons. Research laboratories must have some method of testing film properties in order to evaluate new products. The more efficient such an evaluation can be made, the more likelihood there is that the guesswork can be taken out of the decision as to whether the product is worth commercialising and, if so, for which market it is particularly suitable. Another objective of testing is to aid in process development. Test results can help in evaluating the results of changes in raw materials or processing variables, and can enable realistic manufacturing specifications to be set up.

There is a very wide range of criteria to be applied when considering the selection of a film for a particular purpose. In general, however, they fall into three broad groups. The first group covers those properties concerned basically with the strength of the film. These properties include tensile strength, impact strength, stiffness,



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bursting strength and tear strength. The second group of properties may broadly be classed as transmission properties and include permeability to gases, vapours and odours. Light transmission should also be included here and would cover properties such as 'see-through' clarity and haze. For convenience other optical properties like gloss are dealt with in this section.

Both of the groups already mentioned deal with those properties which are important to the final end-use performance. The last group includes properties which are more concerned with the performance of films on converting or packaging equipment. Examples of this sort of property are coefficient of friction, blocking, heat sealability and crease or flex resistance.

Some of the more important properties of plastics films are discussed in this and the next three chapters together with an outline of the various test methods used in their measurement.

## 9.1 TENSILE AND YIELD STRENGTH, ELONGATION AND YOUNG'S MODULUS

These four properties are considered under a single heading because the same equipment can be used for measuring each of them. To avoid possible confusion during the subsequent discussion, a few definitions are given below:

*Stress* This is the ratio of the force exerted on a body to its cross-sectional area,

$$\text{i.e.} \qquad = \frac{\text{applied force}}{\text{cross-sectional area}}$$

*Strain* This is a measure of change in the dimensions of the body when a force is applied to it and is calculated with reference to its original size. In tensile testing, strain is defined as:

$$\frac{\text{total elongation}}{\text{gauge length}}$$

*Gauge Length* Gauge length is the original length of that part of the test piece over which the change in length is determined. For films, this is usually taken to be the original distance between the test specimen grips.

Tensile strength (or more accurately, ultimate tensile strength) is the maximum tensile stress which a material can sustain and is taken to be the maximum load exerted on the film specimen during the test, divided by the original cross-section of the specimen. Yield strength is the tensile stress at which the first sign of a non-elastic deformation occurs and is the load at this point (known as the yield point) divided by the original cross-section of the specimen.



Elongation is usually measured at the point where the film breaks and is expressed as the percentage of change of the original length of the specimen between the grips of the testing machine. Its importance is as a measure of the film's ability to stretch.

Young's modulus, or the modulus of elasticity, is the ratio of stress to strain over the range for which this ratio is constant, i.e. up to the yield point. It is a measure of the force that is required to deform the film by a given amount and so it is also a measure of the intrinsic stiffness of the film.

Yield strength is usually more important than ultimate tensile strength, especially during the passage of the film through wrapping or printing equipment where a sudden 'snatch' could cause a non-reversible distortion and, hence, out-of-register printing.

During the unwind operation both yield point and elongation are important properties. If the elongation is high there is the danger of uneven stretching of the film unless special handling techniques are used. Too low an elongation should also be avoided as any sudden unbalance in the unwind operation could lead to breaking of the film. A certain amount of tension is necessary during unwind so that films with a low yield strength are in danger of being stressed beyond their yield point.

### 9.1.1 TEST METHODS

There are many types of tensile testing machines available but the basic principle of them all is that a film strip is held at one end by a fixed clamp and at the other end by a movable one. The clamps are then drawn apart and the tension in the strip is measured at various clamp separation distances. The load versus extension is measured by instruments and plotted on a chart. The film strip must be aligned vertically in the clamps so that the stresses are uniform across the width of the strip and parallel to the direction of loading. The upper clamp is usually suspended from a pivot and vertical alignment is more easily obtained if the strip is fastened in this clamp first. Self-aligning grips should be used in tensile tests although even these are not a complete answer to the problems of uneven loading. Both clamps should be tightened evenly so that no slipping occurs.

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The preparation of the test strips is also important. They should be cut cleanly with no nicks or other imperfections in the edges, otherwise failure may occur by tearing. The thickness of the test strips should be checked prior to testing and any which vary more than about 10%, over their length, should be discarded. Since most plastic films have different properties in the machine and transverse directions, the tests should be carried out on samples cut from each of these directions. Five to ten samples will normally be sufficient to obtain reliable results. The differences in tensile properties often have to be taken into account during conversion of the film into bags or other packages.

The various types of testing machine are characterised by their differences in the application of the load. They usually fall into one of the following categories, namely, constant rate of loading, constant rate of elongation and constant rate of powered clamp separation.

### Constant rate of load

One example of a constant rate of loading instrument works on the principle of the inclined plane. A tilting table has a carriage which moves down the table under the influence of gravity. The angle of the table is changed during the test to produce a constant rate of loading. This type of instrument is limited in its loading capacity and in the elongation it can accommodate and is now little used.

### Constant rate of elongation

The principle of this type of test is illustrated in *Figure 9.1*. The strip is clamped between the upper (fixed) grip, which is attached to a load weighing cell, and a movable grip driven at a constant rate, usually by an electric motor. The rate at which the powered grip moves can be preselected. Since the upper grip moves hardly at all, the rate of powered grip movement may be taken as the rate of extrusion of the film strip. Electrical signals proportional to the movement of the grip and to the applied load are fed to the axes of a recorder which then traces a load/elongation curve directly. Such machines are very versatile because of the combination of different drive speeds, recorder-chart magnification ratios and strain gauge sensitivities which can be used. They are also accurate since they are virtually free from frictional or inertial errors.



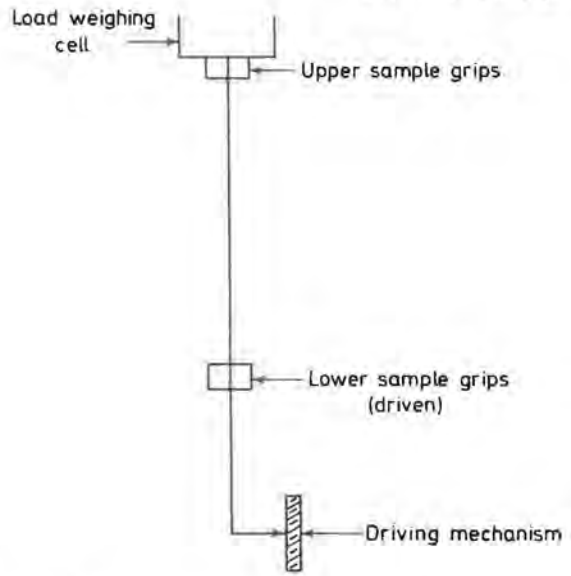


*Figure 9.1. Tensile tester—constant rate of elongation*

However, they are expensive and require expert maintenance and service.

### Constant rate of powered grip separation

Before electronic tensile testers were available a popular type of machine was one which uses a pendulum to measure the applied load. The lower grip is powered, as before, and moves at a constant rate. In this type of instrument, however, the upper grip also moves since it is attached to a weighted pendulum. The rate of separation of the grips and the rate of straining are both variable, therefore. Although this type of instrument is somewhat less accurate it is cheaper and is still in widespread use, particularly for quality control purposes.

A typical plot of stress against strain is shown in *Figure 9.2*.

The importance of the various tensile properties depends on the specific end-use requirements but some general observations can be made. The tensile strength, for instance, must be great enough so that the film will not break when subjected to the sort of load likely to be encountered in practice. In many cases the yield strength

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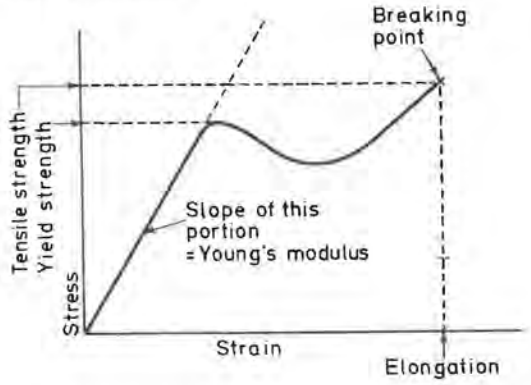


*Figure 9.2. Typical stress/strain curve*

may be more important than the ultimate tensile strength. This is because once the yield point has been reached, a large increase in elongation may result from a small increase in stress. In packaging uses, this can result in a tight wrap becoming loose. The yield strength is also important in handling on printing and laminating equipment. Up to the yield point, any elongation is reversible and the film will revert to its original strength when the stress is removed.

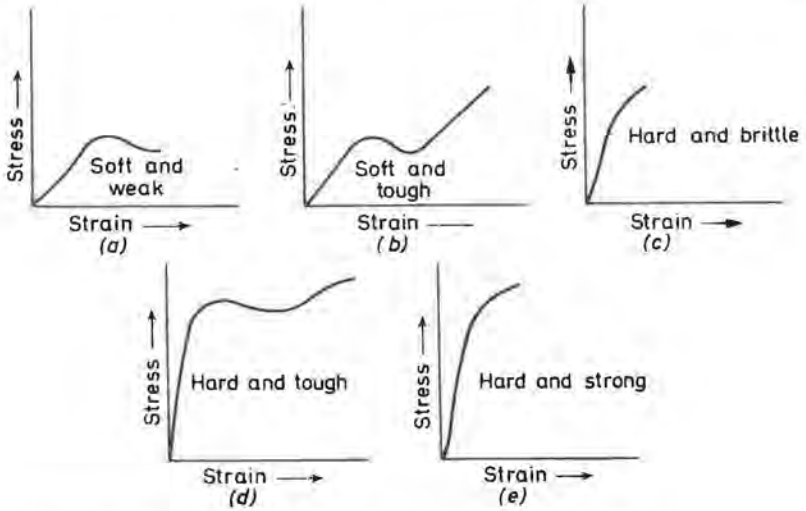


*Figure 9.3. Typical stress/strain curves obtained with polymers*



After the yield point, some of the elongation is non-elastic and there is always a residual elongation. A sudden snatch which leads to stresses greater than the yield strength will permanently stretch the film and lead to registration problems.

Films having a high elongation are sometimes used in order to relieve any stresses caused by an applied load and so reduce the risk of rupture. Under similar circumstances, films with low elongations would need to have fairly high tensile strengths to withstand any applied loading.

A great deal of information about the film can be obtained from the shape of its stress/strain curve. In addition to the numerical values for tensile strength, Young's modulus, elongation, etc., it is possible to obtain some idea of the toughness of the material by measuring the area under the curve. This area is a measure of the energy needed to break the test specimen and hence is directly related to toughness. Some typical curves are shown in *Figure 9.3* (*a–e*) and represent the following types of behaviour.

### Soft and weak

Soft and weak films have a low value for Young's modulus, coupled with a low tensile strength. The elongation at break is only moderate. As can be seen, the area under the curve is low.

### Soft and tough

These films have an appreciably higher area under the curve. The tensile strength is moderately high but Young's modulus is low as with soft and weak materials. The yield point is well marked and the elongation is high.

### Hard and brittle

As one would expect, the tensile strength and Young's modulus are both high. Brittle materials have no distinct yield point, however, and the elongation is low.

### Hard and tough

The high tensile strength, Young's modulus and elongation combine

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to give the large area under the stress/strain curve, thus justifying the adjective, tough.

### Hard and strong

Such films are intermediate in character between the hard and brittle, and the hard and tough materials, Although there is still no clearly defined yield point, the elongation and tensile strengths are both greater than for hard and brittle materials.

## 9.2 BURST STRENGTH

The burst strength of a film is the resistance it offers to a steadily increasing pressure applied at right angles to its surface under certain defined conditions. The burst strength is taken to be the pressure at the moment of failure of the film and is essentially a measure of the capacity of the film to absorb energy.

Bursting tests are usually based on those developed for paper. One such test is the Mullen Burst Test. The test is carried out by applying pressure to one side of a clamped disc of standard dimensions and the pressure required to burst the disc is recorded. The pressure is normally applied using a liquid medium, such as glycerol or ethylene glycerol, transmitted via a rubber diaphragm. Test results are affected by the speed at which the pressure is applied and by the diameter of the clamped disc. The lower the rate of pressure application and the smaller the diameter of clamped disc, the higher the bursting pressure.

## 9.3 IMPACT STRENGTH

Impact strength of a film is a measure of its ability to withstand shock loading. Such tests can, of course, be carried out on the finished package, one method being to fill, say, polyethylene bags with sand and subject them to controlled drop tests. The results of such tests cannot usually be applied to any other size or shape of pack, even if the same film is used. It is usual, therefore, to carry out impact tests on the basic film and some of these tests are described here.

One common method used to measure the impact strength of films is known as the Falling Dart method. The dart consists of a hemispherical head fitted with a shaft to which removable weights can be added, together with a locking collar to keep the weights in



place. The rest of the apparatus consists of a table, with a hole in the centre, over which are fitted grips designed to hold a sample of film without slipping. At the side of the hole a vertical pole is fitted. This supports an electromagnet which is used to drop the dart on to the film. The magnet can be moved up and down the pole to give any desired height of drop. A circular piece of film is placed in the grips, taking care that the film lies flat, without any creases or folds, and that it covers the whole of the surface of the grips. This is to avoid any slippage of the test sample which would result in too high a test result. The magnet is energised and the shaft of the dart (which is steel tipped) is attached to the magnet, via a centring hole. The magnet is then de-energised and the dart falls on to the film surface. If the film does not break, the operator should try to catch the dart on the rebound in order to avoid multiple impacts on the film. On the other hand, should the dart break the film and pass through the hole in the table, there should be some provision made for catching the dart and preventing damage to the head. This is because any nick or scratch on the dart head could cause anomalous results when dropped on to the next sample of film.

There are many ways in which the impact strength can be measured and expressed using the Falling Dart method. In one method the weight of the dart and the height of drop are adjusted to give rupture of all the film samples. The dart is decelerated by the film and the energy thus absorbed by the film sample is calculated. The original potential energy of the dart is known from its mass and its height above the sample while kinetic energy after impact can be calculated by measuring the time taken to pass two photoelectric cells placed immediately below the test samples. The photoelectric cells are connected directly with electronic timing devices. The energy absorbed is then found by subtraction of the residual kinetic energy from the potential energy of the dart and this is the impact strength of the film.

A simpler method is to drop the dart from a constant height and adjust its weight in equal increments from a minimum just too light to rupture the sample up to a maximum just heavy enough to cause rupture of all the samples. The weight at which 50% of these samples rupture, multiplied by the height through which the dart falls is taken to be the impact strength of the film. A convenient way of treating the results is the Staircase Method which needs a minimum of 20 samples.

Using some standard height, drop the dart and observe the result. If a failure is observed, the weight of the dart is reduced by a standard amount (say 5 g). If the drop does not rupture the film, then increase the weight of the dart for the next drop. Continue the drop impact

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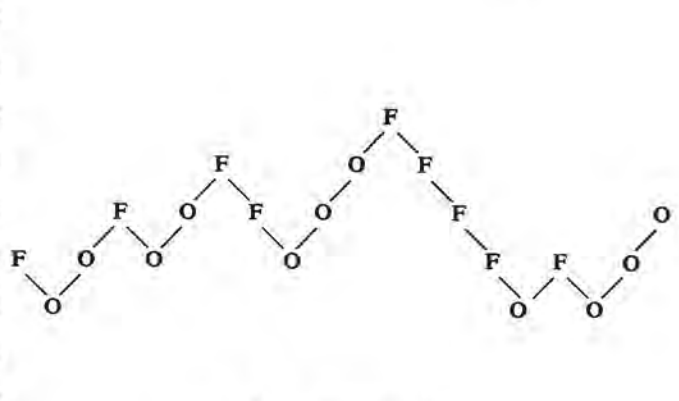
testing, decreasing or increasing the weight of the dart by the standard increment depending on whether the previous drop caused a failure or not. Record for each drop, the weight of the dart and the results of the test, i.e. failure or non-failure. The results can be recorded as follows:

Let O represent a non-failure, F represent a failure. Draw up a column of dart weights on the left hand side of the page and record the results of consecutive drops as they are obtained.




No. of impacts=20
No. of failures = 9

### Calculations of impact strength for staircase procedure

The impact strength is generally quoted as the weight to cause 50% failures × the drop height. The $F_{50}$ weight value can be calculated from the following equation:

$$\text{Impact weight} = \frac{(n_0w_0 + n_1w_1 + n_2w_2 + \cdots n_iw_i)}{n_0 + n_1 + n_2 + \cdots n_i} \pm e\,\text{g}$$

Where $n_0$ = Number of least frequent events at weight $w_0$ g
$n_1$ = Number of least frequent events at weight $w_1$ g
$n_i$ = Number of least frequent events at weight $w_i$ g
$e$ = Constant weight increment between weights $w_0$, $w_1$, etc.
If the least frequent event is a non-failure, use $+e$.
If the least frequent event is a failure, use $-e$.

In the example already shown, the calculations are based on failure as this was the least frequent event.



$$\text{Impact weight} = \frac{(3 \times 335) + (3 \times 340) + (2 \times 345) + (1 \times 350)}{3 + 3 + 2 + 1} - 5\,\text{g}$$

$$= \frac{1005 + 1020 + 690 + 350}{9} - 5\,\text{g}$$

$$= \frac{3065}{9} - 5\,\text{g} = 336\,\text{g} (= 335\,\text{g to nearest 5 g})$$

Another approach to the matter of impact testing is the use of a pendulum instead of the falling dart. The film is clamped vertically and struck by a pendulum which has swung from a known height. The residual energy of the pendulum after it has ruptured the film, is measured by a pointer on a calibrated scale or by an electric timer activated by a pair of photoelectric cells. The loss in energy is a measure of the impact strength of the film.

### 9.3.1 IMPACT FATIGUE

The pendulum test is based on the application of a force more than sufficient to cause failure of the film and to a certain extent this is also true of the Falling Dart test. However, in use it is likely that the film will have to withstand a series of impacts which, singly, are not sufficient to cause rupture. These smaller impacts may eventually cause failure by fatigue and this would be shown up by some repetitive impact test. Such tests are time consuming but equipment has been designed to carry out impact fatigue testing. One such piece of equipment consists of an inclined plane which holds a number of stainless steel balls. The incline can be raised to allow the balls to be dropped at various heights on to the clamped film. Balls of different sizes can be used and this, with the variation in drop height, gives a great number of possible variables. When failure of the film eventually occurs, a gate prevents any more balls falling on to the film.

## 9.4 TEAR STRENGTH

The usual tests for measuring tear strength actually measure the energy required for tear propagation rather than for tear initiation, as it is difficult to start a tear in most plastics films. More specifically, what is measured is the energy absorbed by the test specimen in propagating a tear that has already been initiated by cutting a small nick in the sample, with a razor blade.

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Tear strength is an important property of packaging films and a knowledge of both resistance to tear initiation and tear propagation, may be necessary. In heavy duty sacks, for instance, possible rough handling may demand that tears do not run from small snags or punctures incurred during transit. On the other hand, applications relying on a tear tape to give easy access to the contents, require ease of tear propagation in one direction.

One of the most common tests for measuring tear strength is the Elmendorf Test which, like so many other film tests, was originally developed for paper testing. The Elmendorf Test measures the energy required to propagate a tear through a specified length of film. The apparatus has two grips set side by side with only a small separation. One grip is stationary and is mounted on an upright on the instrument base. The second grip is movable and is mounted on a pendulum or a heavy sector of a circle. This pendulum is mounted on an almost frictionless bearing and swings on a shaft fixed perpendicular to the upright pillar. The sample of film is clamped in the two grips and a slit of standard dimensions is introduced centrally into the film using a razor blade. When the pendulum is released it swings down and tears the sample along a continuation of the slit. The energy required to complete this tear

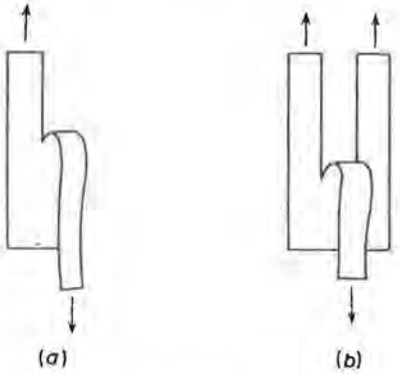


*Figure 9.4. Tear test specimens: (a) 'trouser' tear, (b) 'tongue' tear*

is measured on a scale attached to the pendulum by means of a pointer carried by the pendulum on its return swing. This indicates the residual energy in the pendulum and thus the amount of energy lost in tearing the film sample. The Elmendorf Tear Test is described more fully in ASTM D. 1922-61T.

Tear strengths can also be measured at slower rates of tear using



a tensile testing machine. Two possible types of tear test samples are shown in *Figure 9.4*.

In this type of test, measurement is made of the force necessary to keep the tear moving at a fixed speed. ASTM D. 1938-62T describes such a test. Tear propagation can also be measured on a tensile testing machine using a film sample cut to the shape shown in *Figure 9.5*.

When the sample is pulled between the grips of a tensile testing machine, a tear starts at the root of the 90° notch. For fairly flexible films both the load necessary to initiate the tear and to continue it

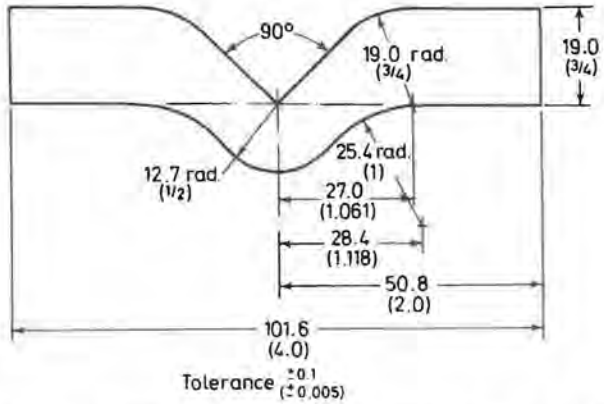


*Figure 9.5. Cutting edges of punch for tear strength test specimen. (Dimensions in millimetres with inch equivalents in parentheses)*

can be recorded. For brittle films, however, only the maximum tear initiation force is measured.

In all the tear tests described, samples should be cut from both machine and transverse directions as the tear strength can vary widely according to the direction of tear.

## 9.5 PUNCTURE PENETRATION TEST

Puncture propagation is also important, particularly in the handling or transit of shipping sacks. A test that measures the combined effects of puncture and tear is one developed by Patterson and Winn [*Mater.Res. Stand.2* (1962.396)]. A loaded carriage, fitted with a horizontally projecting spike, of standard tip and dimensions, falls from a fixed height on to a vertically mounted film sample.

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The top of the film sample holder is curved away from the rails so that when the sample is draped over it and clamped in place, the spike snags the film at a point which is always the same distance away from the sample edge. The carriage is guided by a pair of rails during the drop so as to standardise the manner in which the spike engages the film sample. The spike is 3.2 mm ($\frac{1}{8}$ in) in diameter and extends 39.6 mm (1.56 in) from the carriage face. The point is conical with a 30° included angle. The probe penetrates the film within a very short distance and the major contribution to the absorption of energy is found to be the resulting tear propagation. Arbitrarily, a minimum tear length of 39.9 mm (1.57 in) has been selected and if this is not reached then a heavier carriage is used and the test repeated.

The length of the tear is a measure of the energy absorbed by the film sample in stopping the carriage and spike as they move through the film. The potential energy of the carriage before it is released is equal to $m(h + x)$ where $m$ is the mass of the carriage, $h$ is the height of the carriage above the film sample and $x$ is the length of the tear. If the force exerted by the spike in tearing the film is $f$, then the work done on the sample is $f \times x$. Since the film brings the carriage to rest, the potential energy of the carriage is completely absorbed by the film so that $m(h + x) = fx$ and

$$f = \frac{mh}{x} + m.$$

## 9.6 STIFFNESS

Stiffness can be considered as the resistance of the film to distortion and, in particular, to bending. It is a compound property and depends on the thickness of the film, as well as the inherent stiffness of the material. Young's modulus is one measure of the inherent stiffness of a single ply film and the determination of this has already been described. There are also more direct methods of measuring stiffness, one of which is by means of the Handle-O-Meter stiffness tester. The test is a simple one and consists in measuring the force required to push a sample of film into a slot of a given width over which the film has been laid. The method is suitable mainly for thin film and the principle of operation is shown in *Figure 9.6*.

A sheet of film is placed on a metal plate containing a slot that extends the whole width of the plate. The width of the slot is usually 5 mm (0.2 in) but wider slots may have to be used with thick film. Machine direction stiffness is obtained by placing the film with the



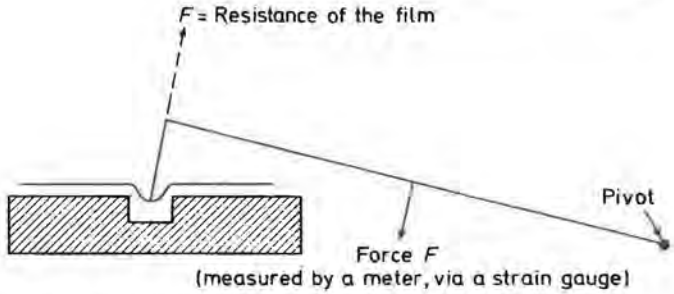


*Figure 9.6. Principle of Handle-O-Meter stiffness tester*

machine direction at right angles to the slot while transverse direction stiffness is obtained with the transverse direction of the film in a similar position. In operation, the equipment automatically lowers a horizontal bar through the slot against the resistance of the film. The force exerted on the bar is measured via a strain gauge and is indicated on a meter. The force first increases, reaches a maximum, and then decreases. The maximum value of the force, as indicated by the instrument, is taken as the Handle-O-Meter stiffness of the film.

The results may be affected by slip agents in the film and by electrostatic attraction (increasing the frictional resistance between the film and the base plate). Efforts have been made to reduce such effects by reducing the widths of the film sample so that it was not much wider than the width of the slot. However, the behaviour of the film in practice, on packaging machines, is probably more closely related to results obtained when they are affected by factors such as slip and electrostatic attraction. On the other hand, the dependence of stiffness on the cube of the thickness is obscured unless such extraneous factors are eliminated.

For thicker films, stiffness may be measured by treating a film strip as a beam. The test sample is placed on two supports, suitably spaced, and the resultant beam is loaded at the centre. The deflection produced for a given load is then measured. The test can be performed in other ways. Thus, the maximum load which the film strip/beam is able to support can be measured or the load necessary to produce a specified deflection can be determined.

One of the simplest tests for measuring stiffness is the cantilever test where one end of the film strip is clamped in a horizontal plane and the amount by which the film droops under its own weight is measured.

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Like most other properties already discussed, stiffness is usually different in the machine and transverse directions so that separate measurements must be made on strips cut in each of these directions. The main importance of stiffness is the influence it has on the performance of a film during its passage through the packaging machine. This is especially true for the feed section of such machines. After cutting a length of reel-fed film it is often necessary to push the cut edge forward to the next station on the machine. If the cut edge protrudes over a gap, drooping of the film will occur under its own weight. The extent of this droop will depend on the projected length (directly as the fourth power of the length projected), on the thickness of film (inversely as the square of the thickness) and on the intrinsic rigidity of the film. If the gap is bridged by a metal plate then the problem of 'droop' is replaced by problems concerned with the absence of slip, particularly with soft, sticky films. Such problems can be solved by the use of grippers to pull the film through instead of pushing it.

Stiffness may also be important to the final end use. Thus, in the packaging of woollen goods a limp film is preferred so that the softness of the contents can be appreciated without opening the package.

## 9.7 FLEX RESISTANCE

The resistance to repeated flexure or creasing is important in use. Some films are highly resistant whereas others will fail by pinholing or total fracture after bending only a few times. In essence the resistance to flexing is measured by repeatedly folding the film, backwards and forwards, at a given rate. The number of cycles to failure is recorded as the flex resistance. One method of measuring is known as the Schopper Folding Endurance Test and was originally designed for measuring the folding endurance of paper. A film strip (15 mm wide × 100 mm long—0.6 in wide by 4.0 in long) is held at each end by grips which keep the sample under a constant tension. A slotted metal strip is fitted over the mid-point of the sample and is driven back and forth by an electric motor at a rate of 120 double folds per minute until failure of the film occurs. The number of double folds up to the point of failure is recorded on a counter. Details of the Schopper test are given in TAPPI (Technical Association for the Pulp and Paper Industry) T.423m-50 (TAPPI Standard and Suggested Methods).

With some of the more tough and flexible polymer films, even a large number of flexings may not lead to fracture. In such cases



it may be worth running the test on various thicknesses since a thicker film may show failure at a relatively low number of flexings. Another point is that even if failure does not occur, certain properties of the film may be seriously impaired. Permeability may be increased, for example, or tensile properties may be reduced. The optical properties may also be seriously affected. One other way of testing crease or flex resistance, therefore, is to subject the film to a given number of cycles in the test equipment and then compare the relevant properties with those of the uncreased film.

## 9.8 COEFFICIENT OF FRICTION

The coefficient of friction is a measure of the ease with which the surface of one material will slide over another. Thus, films which are slippery and move easily over various surfaces have a low coefficient of friction. Referring to the diagram (*Figure 9.7*), $F$ = frictional force and is the force, parallel to the surface that resists the sliding motion. The ratio of the frictional force, $F$, divided by the normal force, $R$, is the coefficient of friction, $\mu$, when the forces are in equilibrium.

One of the simplest methods for measuring the coefficient of friction is by means of an inclined plane. The surface of the plane

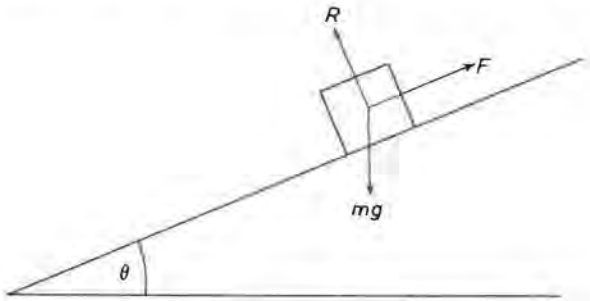


*Figure 9.7. R=normal reaction=mg cos θ; F=frictional force=mg sin θ; m=mass of object on plane; g=acceleration due to gravity*

is covered by a sample of film, as is the weight on the plane. The angle of the plane is slowly increased until the weight just starts to move when the various forces can be taken to be in equilibrium. The angle $\theta$ at this point is known as the angle of repose. The coefficient of friction $\mu$ then $= F/R = \tan \theta$. The coefficient of friction measured in this way is known as the static coefficient of

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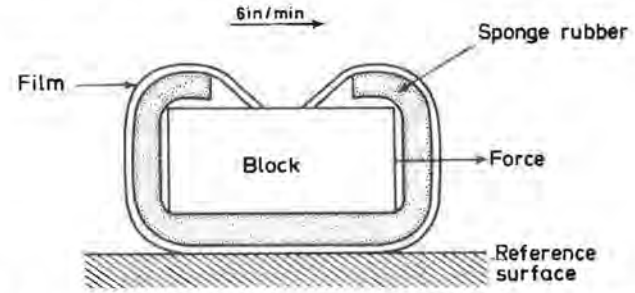


*Figure 9.8. ASTM apparatus for determining coefficient of dynamic friction*

friction. If the plane is set at an angle such that the weight moves easily, and the slope is then reduced until the weight just comes to rest, then the value measured for $\mu$ is known as the dynamic coefficient of friction. This is usually lower than the static coefficient although the two can also be equal. The value of the coefficient of dynamic friction is affected by the speed of movement of one surface over the other and the coefficient of friction may also be affected by humidity, temperature and the presence of static electricity.

A more satisfactory method of measuring coefficients of friction is by the procedure ASTM 1894-63, the principle of which is shown in *Figure 9.8*.

The apparatus consists of a sled, made from a metal block wrapped around with 3 mm ($\frac{1}{8}$ in) thick medium density foam rubber. The film sample is taped to the rubber in order to give the base of the sled a smooth, wrinkle-free surface. The complete sled weighs 200 g (7.05 oz). If the film/metal coefficient is to be measured, then the sled is placed on a smooth metal table, while the film is taped to the table if the film/film coefficient is required. Either the block or the table can be motor driven, the speed being kept constant at 150 mm (6 in) per minute. The horizontal force on the sled is measured by a spring balance or, preferably, a strain gauge. The sled is placed on the table lightly so that there is no risk of pressure causing an artificial bond between the surfaces. When the drive is started the original deflection of the load measuring device is noted and this is used to calculate the static coefficient of friction by dividing by the total weight of the sled. The average deflection is also noted and used to calculate the dynamic (or sliding) coefficient of friction.

Where the metal table is being used to measure film/metal coefficients, the metal surface must be thoroughly cleaned after each run. This is necessary because films which contain additives liable to diffuse to the surface may leave a smear on the metal.



The frictional properties of a film are important, both during its passage through printing or wrapping machines and after being made up into a bag, sack or overwrap. In general, one does not talk so much about high coefficients of friction as about low or high slip. High slip is normally required for a number of reasons. During the passage of a film, through packaging equipment of all sorts, it is subjected to a variety of forces including some which press the film tightly against flat metal surfaces. If the slip characteristics are low the passage of the film through the equipment can be arrested completely. The consequent strain in the film (particularly in a thin film) can lead to elongation or other distortion of the film which will affect register in the printing or bag making stages. High slip is also generally required once the package has been overwrapped since the finished packs have to slide over various surfaces as they are ejected from the machine.

The failure to slide during passage through a machine, mentioned previously, is known as seizure and the tendency towards this is not always shown by coefficient of friction data. This often arises because the coefficient of friction is determined at relatively low normal forces, compared with high localised forces which may occur in a packaging machine. Modifications of the standard friction test have been made, the main differences being the use of a sled modified to give a much greater loading normal to the surface, together with a reduction in the speed of movement. A satisfactory speed has been found to be 2.5 mm (0.1 in) per minute. In addition to measuring the magnitude of the tangential forces developed, provision is made for a pen trace to be made during the test. A trace which is fairly smooth and parallel to the surface indicates a surface with little tendency to bind. A sawtooth trace, however, indicates a surface which tends to stick and then slip and such a surface would be likely to give trouble on a packaging machine.

Frictional properties are also important in the manufacture of the film, especially when being wound up. Good roll formation, for instance, is dependent on the correct level of friction. Too much slip may cause telescoping of the roll during handling or transit whereas too little can cause buckling on the roll. There are, of course, occasions when a low slip value is a definite requirement. Heavy duty sacks, for instance, are often required to be stacked to heights of several metres and any tendency towards slip can be a possible danger.

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## 9.9 BLOCKING

A property somewhat akin to friction is blocking, which is the tendency of two adjacent layers of film to stick together, particularly when left under pressure for some time, as when films are stacked in cut sheets. It can also make bags made from layflat film difficult to open. Blocking is particularly marked in the case of films with very smooth surfaces which can come into very close contact with consequent exclusion of air. Other factors which affect blocking are static charges, surface treatment (such as printing pre-treatment) and storage conditions. Anti-blocking additives are often added to the film to reduce the tendency to blocking. These act by diffusing to the surface and forming non-adherent layers.

The degree of blocking is determined by the force required to separate the two layers of blocked film, when the force is applied perpendicularly to the surface of the film. In BS.1763: 1956, rectangular specimens are placed face to face between filter papers and glass plates, and a load of 6.895 $kN/m^2$ (1 $lb/in^2$) applied at 50°C for 24 h. After the film has cooled to room temperature, the sheet must peel under a specified static load. A different approach is taken in ASTM D1893-61T which assesses blocking by measuring the force required per inch of sheet to draw a 6.35 mm ($\frac{1}{4}$ in) diameter rod perpendicular to its axis at a rate of 127 mm (5 in) per minute between the adhering films, thereby separating them.

## 9.10 SUMMARY

The mechanical properties of a film or laminate are important both to the packaging operation and to the end-use. The problems in the case of the packaging operation have been complicated by the fact that plastics films were late on the scene and packaging equipment was originally designed to run using stiffer materials with better dead-fold properties such as paper, cellulose film, aluminium foil or combinations of these.

The first part of a packaging line that makes its demands on the web is the reel unwind. Constant tension devices are often used for controlling tension during the unwind but the elongation or extensibility of the film is still an important factor. Too high a figure can lead to uneven stretch while too low a figure, if coupled with shock-brittleness might lead to film breakage when a sudden snatch occurs.

The frictional properties of a film are important when the film comes into close contact with metal surfaces such as 'ploughs',



formers, guides, etc. which are used to preform tubes or to fold the wrapping material round the product. High slip (low coefficient of friction) is desirable but where low slip films are used then the metal surfaces which come into contact should be given a matt surface by sand blasting or some similar action.

Friction is also important when the film passes over free-running rollers. Too low a coefficient of friction would mean slippage instead of a positive drive of the rollers. Too high a coefficient of friction, on the other hand, could lead to wrap-around of the roller should there be a break.

Finally, stiffness is a factor in machine running whenever the film has to bridge a gap during its passage through the machine.

Mechanical properties of importance to the end-uses of a film include stiffness, a limp film being preferred for the packaging of woollen garments and similar goods.

If the film is to be used for making bags or sachets liable to rough treatment (especially when packaging heavy articles) then impact strength is important.

Tear propagation may be required to be high or low according to the particular end-use. Where tear tapes are to be incorporated then ease of tear propagation in one direction is desirable but for heavy duty sacks and similar applications, where puncturing during transit is possible, such propagation must be avoided.

The range of mechanical properties available is extremely wide when one considers possible combinations of plastics films, coupled with combinations using paper or aluminium foil. It is essential to be sure just what properties are essential at the design stage of any application. The dangers of under-performance are usually well understood but with costs becoming even higher, over-performance is equally to be avoided.

### FURTHER READING

BROWN, R. P. (ed), *Handbook of Plastics Test Methods, 2nd edition*, George Godwin (1981)

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# 10

# Physical and Chemical Properties

## 10.1 OPTICAL PROPERTIES

### 10.1.1 LIGHT TRANSMISSION

Light transmission is measured by means of a photoelectric cell. The intensity of a light source is measured by the cell, both with and without the interposition of the film sample. The light transmission is the ratio of the light intensity measured with the film to that obtained without it, and is expressed as a percentage. The figure for light transmission takes no account of the quality of the light transmitted by the film and it is possible that a blurred image might be obtained even when looking through a film with a high light transmission value. Such a film might be suitable for a tight overwrap but would be undesirable when the film is acting essentially as a window.

### 10.1.2 'SEE-THROUGH' CLARITY

A better guide to the quality of an image when viewed through a film is given by the property known as 'see-through' clarity. This indicates the degree of distortion of an object when seen through the film. In one test the optical definition of a standard well-illuminated wire mesh grid viewed through the test film is





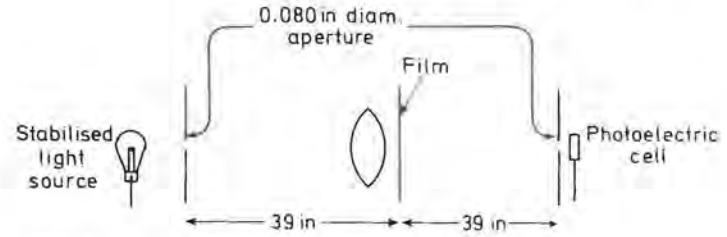


*Figure 10.1. 'See-through' apparatus*

compared with a set of eight standard photographs. These cover the range of clarities normally encountered in the material under investigation and the test sample is given a number corresponding to the standard it most closely resembles.

Another way of assessing 'see-through' clarity is based on the assumption that definition of an object is controlled by small-angle scatter. *Figure 10.1* shows the basis of the method.

A stabilised light source serves to illuminate a small (2.03 mm or 0.080 in diameter) orifice which then acts as the optical object. A large lens focuses this image on to a similar orifice placed in front of an electric cell. The distance between the orifices is 1.98 m (78 in) and the lens is placed midway between them. When a test sample of film is placed behind the lens, as shown, only light which is transmitted by the film with a deviation of less than 4 min will enter the photocell. The photocell reading, expressed as a percentage of the intensity of the incident beam, is the 'see-through' clarity. This figure is, of course, a measure not only of the distortion but also of the light transmission, and the 'see-through' clarity and the light transmission (determined as in the previous paragraph) must be compared in order to assess the effect of deviation alone.

### 10.1.3 HAZE

Haze can be taken as a measure of the 'milkiness' of the film and is usually of greater importance than 'see-through' clarity in the case of packaging films since these are usually closer to the contents of the pack. One cause of haze is surface imperfections of the film so that the amount of haze is not necessarily proportional to film thickness. The appearance of haze is caused by light being scattered by the surface imperfections or by inhomogeneities in the film. These latter can be caused by voids, large crystallites, incompletely dissolved additives or cross-linked material.

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Haze is measured by a technique specified in ASTM. D.1003 and in BS.2782: Part 5: 1970. It is defined in these standards as the percentage of transmitted light which, in passing through a specimen, deviates by more than 2½° on average, from an incident parallel beam by forward scattering from both surfaces, and from within the specimen.

A beam of light is passed through the film sample and on to the highly reflecting internal surface of an integrating sphere in such a manner that all the transmitted light is collected into a photoelectric cell. Next, the sphere is moved through a small angle so that the path of the light beam now falls on an extension of the

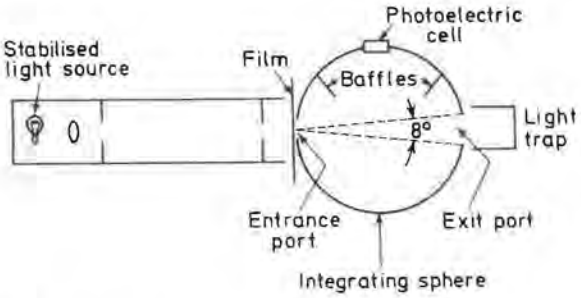


*Figure 10.2. Hazemeter*

sphere comprising a matt black surface that absorbs all the light transmitted straight forward along the path of the beam. Any light that is appreciably scattered in a forward direction is still gathered by the highly reflective internal surface of the sphere and into the photocell. The ratio of the second photocell reading to the first is a measure of the haze. The apparatus for the measurement of haze is shown diagrammatically in *Figure 10.2.*

### 10.1.4 GLOSS

Gloss is important to packaging films and is a measure of the ability of the film to reflect incident light specularly (i.e. as in a mirror—angle of incidence = angle of reflection). A high gloss will, therefore, produce a sharp image of any light source and will thus give rise to a pleasing sparkle on the film. Gloss is determined by a device that measures the percentage of the light, incident at an angle (usually 45°) to the surface of the film, that is reflected



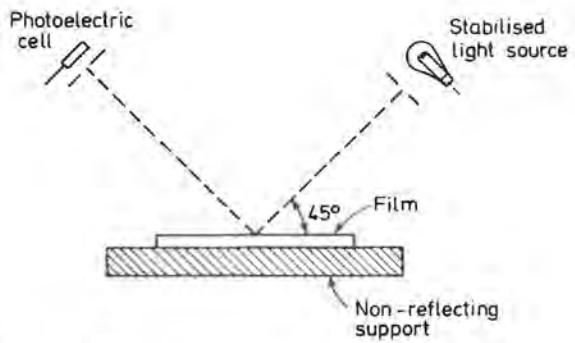


*Figure 10.3. Glossmeter*

at the same angle. The essentials of the standard test (BS 2782: Part 5: 1970) are shown in *Figure 10.3.*

The glossmeter is first calibrated by using an optically flat, highly polished, black glass plate of refractive index 1.52. This has a gloss value assigned to it of 53 units. A light trap, with matt black interior is first placed in position and the lamp switched on. The measuring device is then set at 0. The reference standard is next placed in position and the sensitivity control adjusted to give the correct reading for the standard. Finally, the test specimen is placed over the light trap and the new reading noted.

## 10.2 PERMEABILITY

In essence there are two mechanisms by which a gas or vapour can pass from one side of a plastics film to another. If the film is porous then the gas or vapour can flow through the holes. This effect is not usually present except in the case of very thin films. When porosity is not present then gases and vapours can still pass through the film by a process of solution (or absorption) and diffusion and this compound process is known as permeation. A full treatment of the permeability of gases and vapours through plastics is beyond the scope of this book. For this, and for further references, the reader is referred to an excellent monograph entitled, *Permeability of Plastics Films*, by B. J. Hennessey, J. A. Mead and T. C. Stening, and published by The Plastics and Rubber Institute.

Suffice it to say that where permanent gases are concerned, and under conditions of constant temperature and a constant partial pressure differential, a steady state will be achieved after a certain

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time has elapsed. The quantity of gas, $Q$, passing through the film is directly proportional to the difference in gas pressure on either side of the film, and inversely proportional to the thickness of the film. In addition, it is directly proportional to the time during which the permeation has been occurring, and to the exposed area. Thus we may write:

$$Q \propto \frac{At\,(p_1 - p_2)}{x}$$

where $Q$ = quantity of gas which passes through the film;
$A$ = the surface area in contact with the gas;
$t$ = time;
$(p_1 - p_2)$ = partial pressure differential;
$x$ = thickness of plastic.

This expression can also be put in the form of an equation, thus:

$$Q = \frac{P\,At\,(p_1 - p_2)}{x}$$

where $P$ is a constant for a specific combination of gas and plastic at a given temperature. The factor $P$ is variously known as the permeability factor (or 'P-factor'), permeability coefficient or permeability constant. It should be emphasised that the above equation applies only to steady state conditions.

The position with regard to vapours, including water vapour, is less clear. For one thing, the steady state condition is reached more slowly, while there may also be chemical interactions between the permeant and the plastics film.

The practical importance of permeability hardly needs emphasising. One of the prime functions of a packaging film, very often, is to act as a barrier to gases and vapours. Biscuits, for example, need to be kept dry, while conversely, cigarettes and tobacco need to be protected from moisture loss. The position with regard to the permanent gases is similar. Fresh produce needs to be able to lose carbon dioxide and pick up oxygen while fatty foods may go rancid if oxygen is not kept out. Many foods are packed in a vacuum and a good barrier is essential if this condition is to be maintained. The measurement of permeability is, therefore, important and standard methods are available for both water vapour and the permanent gases.



### 10.2.1 WATER VAPOUR PERMEABILITY

Tests for water vapour permeability are described in BS.2782: Part 5: 1970. Methods 513A and 513B are carried out by sealing test specimens with wax over the mouth of metal dishes containing a desiccant.

The dishes are weighed initially and then placed in a temperature and humidity controlled cabinet. Weighings are carried out at regular intervals and the gains in weight are measured. In Method 513A, the temperature of the cabinet is maintained at 25°C ± 0.5°C and the relative humidity at 75% ± 2%. These conditions are taken as representative of 'temperate' climates. For 'tropical' conditions the tests are performed at 38°C ± 0.5°C and 90% ± 2% relative humidity.

It may often be found preferable to carry out water vapour permeability tests on completed packages rather than on dishes. Test conditions are the same as above but the desiccant is contained in a heat sealed sachet instead of a metal dish. Weighings are carried out as before. In either case, the water vapour permeability is reported as g/m²/24h.

Where a quick indication of the potential barrier properties of a film is required, the film can be clamped in an instrument where one side of the film is exposed to a high humidity atmosphere while the other side is in contact with dry air. As water vapour diffuses in, it is detected by an infra-red absorption cell or by a resistor, the value of which is affected by changes in relative humidity. The instrument then measures the time required for a particular change in relative humidity as detected by the cell or resistor.

It should be noted, however, that difficulties can arise where hygroscopic materials are used (e.g. laminates based on regenerated cellulose or a cellulose-base film coated on both sides with a moisture barrier). Taking the latter as an example, the basic cellulose contributes little to the water vapour barrier properties, which are almost entirely dependent on the coatings (taken to be identical). The specimen is initially in equilibrium at 35% relative humidity and is then placed in an enclosure with saturated air (100% relative humidity) on one side and dry air (10% relative humidity) on the other. Under these conditions the initial rate of transmission of water vapour is dependent on the equilibrium relative humidity of the base film (35%), the relative humidity of the dry side (10%) and the water vapour transmission rate of the barrier layer separating them. After some time, the base film reaches equilibrium and the water vapour moving from the 100% relative humidity side equals that arriving on the dry side. As the two barrier materials are identical

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and have a much lower transmission rate than the base film, this will reach equilibrium at a relative humidity about midway between the wet and dry conditions, i.e. 55%. Under these conditions the transmission of water vapour will have increased above that in the initial conditions because the vapour pressure difference is due to a relative humidity differential of 45% (= 55% − 10%), compared with the initial value of 25% (= 35% − 10%). The transmission rate will, therefore, rise by a factor of about 1.8.

Similarly, a specimen where the base film is initially in equilibrium with a relative humidity *greater* than the final value will have a *high* apparent water transmission rate initially, and this will *fall* as the specimen approaches equilibrium. Hence, although rapid test instruments can measure transmission rates in a short time, the results may differ significantly from those obtained after dynamic equilibrium has been reached within the test cell. With non-hygroscopic barriers, results agreeing closely with the dish method can be obtained.

### 10.2.2 GAS PERMEABILITY

Measurement of gas permeability is carried out under controlled conditions of pressure, as well as of temperature and relative humidity. In essence the usual tests consist in making the film a partition between a test cell and an evacuated manometer. The pressure across the film is usually one atmosphere. As the gas passes through the film sample the mercury in the capillary leg of the manometer is depressed. After a constant transmission rate is achieved, a plot of mercury height against time gives a straight line. The slope of this line can be used to calculate the gas transmission. Gas permeability measurements are described in ASTM D.1434 and BS.2782: Part 5: 1970.

The foregoing method is known as the pressure increase method. Another common method is that of concentration increase. Two gases are used, a reference gas and the test gas. A partial pressure difference across the barrier material with respect to the test gas is created, without a difference in total pressure. Because the method of measuring the concentraton of the test gas can be specific to that gas even in the presence of other gases or vapours, equipment can be developed in which the relative humidity of both the test and the reference gases can be controlled. This is not possible where equipment has to be evacuated and is very important when determinations are carried out on barrier materials having a hygroscopic base. Various methods of measuring the concentration



change are used, including chemical analysis, gas chromatography and radioactive tracer techniques.

### 10.2.3 ODOUR PERMEABILITY

There are no standard tests for the measurement of odour permeability although it is an important characteristic in many cases. One method which can be used to compare the efficiency of several films as odour barriers is to make up pouches with each film. The pouches can be filled with some odoriferous material and then placed in separate clean glass bottles, sealed by crimping with aluminium foil. The minimum time for an odour to be apparent in the bottle can be measured and will give a rough ranking list of the test films. This ranking list may vary somewhat according to the type of odoriferous material used so that the substance to be packed should be used as the test material if possible.

## 10.3 DENSITY

The density of a film sample is most satisfactorily measured by means of a density gradient column as described in ASTM D.1505-60T or BS.2782: Part 5: 1970. A density gradient column is a mixture of two fluids of different density, the proportions of which change uniformly from the top to the bottom of the column.

The liquids are chosen for their densities but care must also be taken that they do not have an effect on the film under test. Ethanol–water, and methanol–water mixtures have both been used successfully, especially for measuring the density of polyethylene films. The column is established initially as follows. The two liquids are de-gassed by boiling and then mixed in such proportions as to give compositions having the required density limits at top and bottom of the column. These are placed in separate flasks. The flask containing the lighter mixture has a capillary tube outlet which runs to the bottom of the column. This flask is then stirred and is connected to the flask containing the heavier mixture. The density in the first flask thus increases linearly with time and so a column with a linear change of density is produced. If the filling is carried out slowly (over about three hours) and the column is surrounded with a temperature controlled water jacket the column will be stable for 2–3 months.

A series of calibrated glass floats, covering the required density range is then placed in the column. Film samples are cut and then immersed for $\frac{1}{2}$ min in, say, ethanol or methanol, and then introduced

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into the column by means of tweezers, taking care not to introduce air bubbles. After 3 h measurement is made, against a scale, of the heights of the floating samples and the markers against their respective densities. The heights of the floats are then plotted against their respective densities and the best-fitting curve is drawn through the points. From this curve, the densities of the film samples can be read. Samples on which measurements have been completed are removed at intervals by means of a slowly moving wire gauze basket.

Another method of determining film densities is also given in BS.2782: Part 5: 1970. A series of liquids of different densities is made up in stoppered glass vessels, maintained at a constant temperature of 23°C. Film samples are placed in each of the vessels, care being taken that no air bubbles are attached to the film. Observations are made as to whether the sample floats or sinks and a note is made of the densest material in which the film sinks and the least dense in which it floats. The densities of these two liquids are then rapidly determined. The density of the film under test will then lie between these two values.

## 10.4 HEAT SEALABILITY

The heat sealability of a packaging film is one of the most important properties when considering its use on wrapping or bag making equipment and, of course, the integrity of the seal is also of tremendous importance to the ultimate package. The heat sealability of a film has to be considered in relation to many other factors, including the available pressure, the dwell time, temperature and the rate of heat transfer of the sealing bars. Any test of the heat seal qualities of a particular film must, therefore, simulate the conditions under which the film will be used as closely as possible.

Heat seals can be made by a number of different methods, apart from the straightforward application of heat to the layers of film. Seals can be made, for instance, by high frequency heating (as with PVC) or by ultrasonic welding. However the seal is made, the strength is determined by measuring the force required to pull apart the pieces of film which have been sealed together. The force can be applied in such a way as to cause the seal to fail in shear or in peel. If other factors, such as the temperature, dwell time, and pressure used in making the seal are equal, then peeling a seal will give a lower figure than shearing it. Seals are normally tested in peel, therefore, as this is the way they are likely to fail in practice.

Two tests are in common use, the dynamic and the static. In both



tests a 25 mm (1.0 in) strip is cut through the heat seal. The dynamic test uses a sensitive tensile testing machine and the two free ends of the film strip are placed in the machine clamps. The force necessary to peel apart the two pieces of film is then measured. In the static test the strips are hung from a frame with one free end clamped and the other attached to a weight. The seals are examined at intervals for signs of failure. When recording the results of this test, the weight and the length of time the load was in operation are both noted.

Both of the above tests can, of course, be used for investigating the effect of changes in dwell time, temperature and pressure on heat sealing equipment if standard film samples are used.

## 10.5 DIMENSIONAL STABILITY

Dimensional stability is a desirable property in any film conversion process and particularly so in printing. Even small changes in film dimensions while passing through the printing process may lead to serious problems in print registration. In the finished package, too, dimensional stability is important. A reduction in dimensions of a film overwrap of the order of a few percent may be sufficient to crush a carton or cause rupture of the film. Conversely, a stretching of the film will lead to loosening of the wrap with creasing and wrinkling which, to say the least, are unsightly. Dimensional changes in a film may be caused by variations in either temperature or humidity. In some cases, a high humidity may cause a film to cockle.

Dimensional stability is normally tested by cutting film strips in both the machine and transverse directions, and then subjecting them to varying conditions and noting the percentage change in dimensions. Where possible, the test conditions should be closely related to the conditions likely to be encountered in conversion or end-use. If the precise conditions of end-use are not known then some arbitrary conditions can be used which will at least provide some measure of how the film will behave under changing conditions. For example, films which are sensitive to moisture may be exposed to a series of varying humidities at constant temperatures. The film strips should first be conditioned at some standard condition, say, 23°C and 50% relative humidity. After equilibrium has been reached the length of the film strips (or the distance between two previously scribed gauge markings) are measured. The strips can then be exposed to some high humidity, say 90%, for a specific period and the length remeasured. This could be followed

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by exposure to very low humidity (say 0–5%) followed by further measurement. Finally, the strips should be reconditioned at the standard conditions until equilibrium is again reached. If there is a permanent set, i.e. the strips do not return to their original length then this, too, is noted in addition to the changes at the various intermediate conditions.

An allied property, that of maximum shrinkage, is of interest in the case of heat shrinkable films. This can be determined by immersing marked film samples for 5 s in water (for temperatures up to 100°C) or in silicone 550 oil (for temperatures above 100°C). The temperature of testing is, of course, related to the shrink tunnel temperature in actual use.

## 10.6 WATER ABSORPTION

Water may be absorbed by a plastic film, either by direct contact or from the atmosphere. The effect varies considerably from film to film, ranging from negligible effect (as with the polyolefin films) to one of solution of the film (as with polyvinyl alcohol). Water absorption is measured by immersing a sample of film in water for a given time (usually 24 h) at a standard temperature and noting the change in weight.

## 10.7 EFFECT OF CHEMICALS

The effect of chemicals on a packaging film is obviously an important factor when assessing its suitability for containing a particular product. It might also, under certain circumstances, be important from an environmental point of view.

The normal test for chemical resistance involves subjecting a film sample to the chemical under test, usually by total immersion under specified conditions. Any change in appearance is noted at intervals as is the change in a particular property such as tensile strength.

It is not possible to generalise about the effect of specific chemicals so that tests should always be carried out where any doubt exists. Tests are particularly important in the case of mixtures even if information is available on the separate components.

One important phenomenon associated mainly with the polyolefins (although not polypropylene) is environmental stress cracking. This is caused by the action of stress in combination with particular chemical environments such as certain polar organic compounds.



The chemicals are normally without action on the plastic in the absence of stress but the combination of stress and chemical environment can cause cracking in a very short time. The use of high molecular weight grades has been found to reduce the effect to a great extent.

Where a film laminate is to be used for a particular package this should be tested as a whole since one effect of chemical attack might well be delamination. Heat seals should also be investigated in this way as changes which may be unnoticeable in the film itself can sometimes vitiate the strength of the heat seal.

## 10.8 EFFECT OF LIGHT

Prolonged exposure to light may bring about many undesirable effects in certain films. In particular, light may catalyse certain other reactions such as oxidation. Brittleness, loss of clarity, colour changes and surface imperfections are some of the undesirable effects. If a film is intended for applications involving continued use in sunlight it should contain stabilisers such as ultra-violet absorbers.

Tests are usually carried out by exposing samples of the film to light of a specified wavelength, or combination of wavelengths, for a given time and noting the effect on various properties such as tensile strength or the various optical properties. The intended end-use is of importance when assessing the suitability of the film as the type of radiation may be very different. In addition to the effect of sunlight it is important in many applications to know the effect of shop or display cabinet lighting. The screening effect of glass is also important when packs are to be on display in shop windows.

In the case of coloured films, exposure to daylight or artificial light may cause undesirable colour changes.

## 10.9 EFFECT OF TEMPERATURE

### 10.9.1 HIGH TEMPERATURES

One consequence of a high temperature on a thermoplastic film may be to soften it and if high temperatures are likely to be encountered during use then a plastic with an appropriately high softening point must be chosen. For boil in the bag packs, for instance, films with a softening point above the boiling point of water are required. High temperatures may also lead to other

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undesirable changes, especially in the case of plasticised film, where loss of plasticiser can be accelerated leading to brittleness of the film.

### 10.9.2 LOW TEMPERATURE

Low temperature behaviour of film is also important in many applications, including the packaging of frozen foods. Some films, such as polypropylene and unplasticised PVC, suffer a loss in impact strength at temperatures around 0°C although oriented polypropylene is very much better in this respect. Where low temperature use is envisaged, it is preferable to carry out tests on the actual package since any stresses and strains in the film may influence the behaviour.

## 10.10 FLAMMABILITY

Plastics films are no more hazardous than most other wrapping materials but it may still be important to assess the way in which a film will behave when exposed to a flame. Tests depend on the material to be examined but one typical method consists in igniting a strip of film bent to the shape of an inverted 'U'. The distance over which the strip burns is an assessment of its flammability.

## 10.11 SUMMARY

Most of the properties dealt with in this chapter are concerned with the end-use behaviour of the film. The exception is Heat Sealability which is important both to end-users and to the packaging machine performance.

The optical properties are particularly important in these days of self-service selling. Light transmission tests give no indication of image distortion and are, therefore, not so important for packaging films. Light transmission characteristics can influence the choice of film in horticultural applications. Where the choice of a packaging film is concerned then 'see-through' clarity, haze and gloss may be more relevant, especially when sales appeal is critical, because of the influence of these properties on the visibility of the contents and on the 'sparkle' of the film.

No individual plastics film is a complete barrier to water vapour or to gases. Measurement of permeability is important, therefore, as



an assessment of the protection likely to be given by a particular material. Complete impermeability is not always desirable, of course, and a knowledge of the exact permeability of the film is essential.

Good heat sealability usually means that packaging lines can be run at higher speeds. In addition, strong heat seals give packs that are less liable to leakage when roughly treated.

Finally, there are properties that can be grouped under the general heading of environmental resistance, i.e. resistance to the effects of light, chemicals and high or low temperature. These properties are relevant not only to packaging uses but also to building, agriculture and horticulture applications.

It should be re-emphasised that the performance requirements, in terms of physical and chemical properties, should be clearly stated so that the choice of film can avoid the extremes of failure in use, and over-packaging with consequent loss of profit.

### FURTHER READING

BROWN, R. P. (ed), *Handbook of Plastics Test Methods, 2nd edition*, George Godwin (1981)

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The relevant requirement in the Directive is that migration must not 'bring about an unacceptable change in the composition of the foodstuffs or a deterioration in the organoleptic characteristics thereof'. The U.K. version translates this as 'bring about a deterioration in the organoleptic characteristics of such food or an unacceptable change in its nature, substance or quality.' Obviously 'deterioration' requires further definition, which will presumably be derived from case law, which is not yet established.

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# 13
# Choice Criteria

Because there is no single film that will do every job it becomes necessary to make a choice. The best way to look at material choice is to consider the various properties that may be required for a particular end-use and then to look at the various materials available. Even with the wide range of materials available, however, it is often not possible to find one with all the properties required for a particular end-use. The answer lies in the use of composite materials formed by lamination or coating (see Chapter 19) and it is usually possible to obtain a composite film with almost any combination of desired properties, especially where aluminium foil or paper are considered as possible components. There are now thousands of composite films commercially available, in addition to the basic films, so that the choice facing the potential user can be a bewildering one.

The point at which any investigation must start is the question, 'What are the requirements for the envisaged end-use?' Once these have been determined, the choice of film (or laminate components) can be narrowed down to a relatively small number. The requirements for films to be used in building, agriculture and horticulture, etc., are usually straightforward compared with those for packaging materials so that the subject of packaging material choice will be dealt with here. The principles will, however, hold true in other end-uses.

Some of the main properties that have to be considered when looking at the various packaging end-uses are outlined below, followed by consideration of the main materials that can supply a particular property.



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## 13.1 PRODUCT REQUIREMENTS

The product requirements can best be assessed by compiling a check-list of questions about the product. The following series of questions are given as a guide, together with some comments on the points raised.

(1) Is a transparent or opaque package necessary? Opacity may be considered necessary because of the sensitivity of the contents to visible or ultra-violet light or because the contents are not particularly prepossessing. If baked beans were to be packed in a pouch, for instance, it is unlikely that a transparent pack would be required! If the main cause of any degradation is ultra-violet light then it is possible to use a transparent coloured film or a transparent film in which ultra-violet absorbers have been incorporated. Where visible light has to be excluded, an opaque ply must be added. Degradation by ultra-violet or visible light may simply cause discolouration of the product but it can also cause chemical deterioration, with potential hazards, when the product is a foodstuff or a pharmaceutical product.

On the other hand, some contents do add to the sales appeal of the package and transparency may thus be considered necessary. Transparency is also useful, sometimes, to show the type or quantity of the contents. In these instances it is usually possible to produce a transparent laminate that fulfils any other requirements such as strength or barrier properties.

(2) Are the contents sensitive to oxygen pick-up? Many food products, including biscuits, milk powder, potato crisps and other snack items, contain fats which are sensitive to pick-up of oxygen, with consequent rancidity, giving off-flavours and off-odours. It is obviously essential in these instances to incorporate an effective oxygen barrier in the laminate.

In some cases it is so important to keep the food out of contact with oxygen that vacuum packaging or gas flushing are used. Vacuum packaging increases the pressure differential between the inside of the pouch and the external atmosphere and an even more efficient gas barrier is thus required. The stresses on the pouch and on the seals are also greater and these, too, will affect the choice of material. The use of gas flushing usually entails replacement of the normal atmosphere in the pouch by carbon dioxide or nitrogen and this means that barriers to these gases are also required. Fortunately, good oxygen barriers are usually also good barriers to carbon dioxide and nitrogen, thus simplifying the problem. The question of seal integrity is particularly important so that a material having good heat seal properties is required.



(3) Are the contents hygroscopic or are they sensitive to drying out? In both these instances a good moisture vapour barrier is essential and seal integrity is again an important factor. Biscuits and snack items are examples of products requiring protection from moisture pick-up while cigarettes and tobacco are liable to dry out and become stale.

(4) Do the contents of the package give off gases? An affirmative answer may mean the use of a vented package as even films with high transmission rates are not usually able to transmit large quantities of gas because of the relatively small surface areas involved. The simplest way to vent a package is to punch a few small holes in the laminate or film, but this is a two-way process and if the entry of gases or moisture vapour is to be prevented then some form of non-return valve may be necessary.

(5) Is mechanical protection required? This is important when fragile items are to be packaged. The pouch or sachet then needs to be stiff and rigid in order to give some sort of mechanical protection.

(6) Is odour or flavour loss (or pick-up) likely to be a problem? There are many products that pose problems of this sort. Perfumes, or cosmetic products containing perfumes, need an odour barrier to prevent perfume loss, not just to prevent a weakening of the perfume but also because the residual perfume may be considerably changed in nature. Perfumes are complicated mixtures of a large number of different compounds, with a wide range of volatilities. These compounds are painstakingly blended to give the desired result and the preferential loss of one or two components can completely ruin the overall effect. Highly flavoured foods require an effective flavour barrier for similar reasons. With foods having a rather more bland flavour the problem is likely to be pick-up of odours or flavours from outside the package but the requirements of the film or laminate in terms of barrier properties are the same.

(7) Does the product require to be refrigerated during its distribution and storage? If refrigeration, particularly deep freeze, is required then components with good resistance to low temperature must be used.

(8) Does the product have to be processed in the package? This can entail sterilisation immediately after packaging or heating by the customer, as in boil-in-the-bag foods. A heat-resistant material is hence required.

(9) Is there likely to be any interaction between the product and the package components? There are many possible ways in which a packaging material can affect the product. Products having a high grease content can affect certain films such as polyethylene so that if such a film is required for its contribution to other properties it must

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be kept out of actual contact with the contents of the finished pack. Similar remarks apply to the use of untreated papers. Another possible chemical interaction is that between certain acids and alkalis and aluminium foil.

(10) What constitutes unsaleability for the particular product? This is sometimes very difficult to answer but it has an important bearing on the package selection. The trouble is that unsaleability may be due to one or more factors including changes in flavour, moisture content, texture and appearance. Since package cost is usually of extreme importance it is essential to pinpoint the most important factor in unsaleability and protect against that factor rather than spend too much money on other component plies designed to protect against things of far less importance. Is it permissible, for instance, for a slight loss of flavour to occur provided that the contents remain crisp? Conversely, would a slight loss of crispness be considered satisfactory provided that the flavour remained perfect? A different type of barrier material would be necessary for each of the two cases posed above.

(11) What length of shelf life is required? This is a most important question and should be answered realistically. Of course it is dangerous to take too low an estimate and so risk large-scale deterioration of the contents. It is equally wrong to take too high an estimate and risk pricing the product out of the market by paying for protection that is not needed.

## 13.2 MARKETING FACTORS

More information that will be of help in the choice of material can be gathered by compiling a check-list of questions concerned with marketing factors.

(1) What climatic conditions are likely to be encountered by the package? This, in conjunction with the nature of the contents, will have a large bearing on the barrier properties required.

(2) What system of distribution will be used? This may have a bearing on the barrier properties required and will certainly dictate the mechanical properties of the package.

(3) What type of retail outlet will the package encounter and are there any special display requirements? The latter may dictate the rigidity of the package.

(4) What package sizes are envisaged? The size of a package is relevant not only because of rigidity requirements but also because the surface area to volume ratios affect the permeation of gases and water vapour.



(5) Are easy opening features to be incorporated? This may affect the overall protection given by the package and may also affect the choice of film in terms of performance of the opening device. A tear tape fitment, for example, does not work very well if the film has a high resistance to tear propagation.

(6) What are the printing requirements? If scuff-proof printing is required, for example, this can be achieved by reverse printing a transparent film, such as cellulose acetate, and laminating this to a sub-strate giving whatever basic properties are required. Special effects can be achieved using aluminium foil. The high reflectivity of the shiny side of the foil is very effective in conjunction with plain or coloured transparent lacquers, while the soft satiny look of the matt side can be equally effective in enhancing the quality of the printing.

## 13.3 MACHINE REQUIREMENTS

The behaviour of the web on various packaging machines is also important and must be taken into account when choosing a film or laminate. Where twist wrapping is required, for instance, then paper or regenerated cellulose are still the best materials. Most plastics films retain enough 'elastic memory' to untwist again to a great extent. Aluminium foil also retains a 'twist' very well but is best laminated to paper or coated with polyethylene in order to increase its flexibility and tear strength. A similar situation arises when the web is required as a wrapper. Aluminium foil has extremely good 'dead fold' properties—i.e. it will retain the fold and does not need to be secured. Paper and regenerated cellulose are less good in this respect but are still satisfactory for most uses. Plastics films normally lack dead fold properties and folds must be secured by heat sealing.

For vertical form-fill-seal machines, such as the Transwrap, the wrapping material should have good slip characteristics otherwise breakage may occur due to frictional drag between the web material and the filling tube or forming shoulder. Where polyethylene is in contact with the filling tube it is necessary to incorporate a slip additive in the film. Thin, clinging films, such as polyvinylidene

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chloride, are unsuitable for this type of equipment because of frictional drag.

Again in the vertical type of machine the packaging material should have a high melt strength because the product to be packed is dropped down the filling tube on to the cross seal while the seal is still hot. Low density polyethylene is an ideal material for this purpose. However, if unsupported low density polyethylene film is used then the normal heat sealing bars must be replaced by impulse heat sealers (see Chapter 15).

The web in vertical form-fill-seal machines should normally be thin and flexible enough to withstand turning through very acute angles, during the formation of the tube, without creasing or breaking. Thus, regenerated cellulose film and low density polyethylene and laminates such as cellulose film/cellulose film and cellulose film/polyethylene are suitable, as is polyethylene-coated paper. The use of aluminium foil-based laminates is usually excluded because of the rigidity of the aluminium and its tendency to crease and crack.

In horizontal form-fill-seal machines, conditions are not so critical from the point of view of slip characteristics because a filling tube is not used. A high melt strength is still necessary although the question of the product dropping on to hot seals does not arise. This is because dwell times during the sealing operation are usually short and there are normally no cooling stations. The remarks made concerning materials for vertical form-fill-seal machines apply in much the same way to the horizontal machines except that the angles are usually less acute and the thinner types of aluminium foil laminates can be used. Low density polyethylene is not usually suitable as an unsupported film although some machines used for packaging textiles or bakery goods have been modified to take this material.

## 13.4 PROPERTIES AVAILABLE

Once the properties required by the packaging machine and by the product have been determined it remains to match these against the properties of individual plies. *Table 13.1* gives a summary of the various materials that can make a suitable contribution to the particular properties that may be required.

## 13.5 ECONOMICS

The question of material price obviously has a bearing on material



**Table 13.1**

| *Property required* | *Suitable materials* |
|---|---|
| Opacity | Aluminium foil, paper, pigmented plastics films (carbon black is the most efficient pigment) |
| Transparency | Regenerated cellulose, most plastics films (blow-extruded h.d. polyethylene—translucent) |
| Water vapour barrier | Aluminium foil, polyvinylidene chloride, regenerated cellulose (moisture-proof grades) high density polyethylene, polypropylene, low density polethylene |
| Gas barrier | Aluminium foil, polyvinylidene chloride, polyester, rigid PVC, nylon, regenerated cellulose |
| High temperature performance | Aluminium foil, nylon, polyester, high density polyethylene, polypropylene, paper (dry heat) |
| Low temperature performance | Aluminium foil, paper, low density polyethylene, high density polyethylene, ionomer, EVA, PVC, polyester, nylon, polypropylene (oriented), polyvinylidene chloride |
| Grease resistance | Aluminium foil, regenerated cellulose, nylon, EVA, high density polyethylene, polypropylene, polyester, cellulose acetate, PVC, polyvinylidene chloride, ionomer, greaseproof papers |
| Heat sealability | Low density polyethylene, ionomer, EVA, nylon, PVC (by high frequency sealers), high density polyethylene, polypropylene, polyvinylidene chloride |
| Printability | Paper, aluminium foil, regenerated cellulose, polycarbonate, polyester, cellulose acetate, nylon (ionomer, EVA, polyethylene, polypropylene—if pre-treated), (PVC, polystyrene—special inks) |

choice but it is not the only factor in the total economic picture. It must be remembered that total packaging cost is made up, *inter alia*, of the following:

(a) the package cost;
(b) storage and handling costs of the finished empty package;
(c) filling costs (including material wastage during setting up and running);
(d) storage costs of the filled package;
(e) transport costs for delivery of the filled package;

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(f) insurance costs during transport;
(g) losses due to spoilage or breakage;
(h) effect of the package on sales.

The actual package cost (item 'a') may often play only a minor part in the overall cost build-up and it would be wrong, therefore, to attach too much weight to the relative costs of the packaging materials being considered. To take just one example; the use of a material giving greater protection to the product could well save much more than any extra cost involved in its purchase.

Another factor to be considered is the specific gravity of the plastic. The price paid for the granules or powder is based on weight but the area of film (of unit thickness) will be greater for plastics of lower specific gravity. A slightly more expensive material with a lower specific gravity could, therefore, be cheaper in use.

# Part 3
# Conversion of Films

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to be lower. Other trends include the use of metals other than aluminium and the use of non-metallic materials. Silver, gold and zinc are already in use but consideration is also being given to the use of chromium, nickel/chrome alloys and stainless steel, because of their acid and alkali-resistant properties.

Among the non-metallic materials being considered, alumina and silica show promise as transparent, high barrier coatings while stannic oxide would be transparent and have anti-static properties.

# 15

# Sealing of Films

## 15.1 MECHANICAL METHODS

Although heat sealing of plastics films is the most common method used it is sometimes impractical for one reason or another. Where plastic bags are used in the home, for instance, it is the absence of heat sealing equipment which dictates other methods while in other cases it may be that the film does not heat seal readily, in spite of being a thermoplastic. Cellulose acetate is an example of this type of film.

One of the simplest methods of closing a plastics bag is with an elastic band or a wire tie and the latter is, in fact, used for fastening polyethylene bags for bread. Another method is to use staples for fastening. These are used particularly where a printed paper 'header' is attached to the bag and when a completely moisture vapour proof seal is not essential.

Heavy duty sacks can be stitched but such a seal is not usually sift-proof and the stitches can fail under stress. Cross-laminated film (see Chapter 19) is better in this respect because the lines of least resistance in each of the component films run at an angle to each other.

## 15.2 HEAT SEALING

Heat sealing, in one form or another, is the most common method of joining two pieces of film or for closing sacks, bags and sachets.



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After the development of coated grades of regenerated cellulose, where the coatings are fusible as well as moisture proof, methods of heat sealing these films were developed. These usually consisted of heated metal jaws—often patterned, by embossing, to give the seals extra strength. Heated wheels were also used to give band seals. When polyethylene film first appeared, similar methods were tried but were unsuccessful because polyethylene sticks to hot metal. In laboratory work and some commercial small runs, it was found possible to use heated wheels and metal jaws by inserting a sheet of plain (uncoated) regenerated cellulose film between the metal and the polyethylene but this was not really a convenient method. A more satisfactory solution was found to be the coating of metal jaw sealers with a silicone rubber or with PTFE.

There is another difference between polyethylene film and regenerated cellulose film which adds to sealing difficulties, however. The latter has an infusible substrate and only the coatings melt when heat sealing is carried out. Polyethylene film is completely fusible and so there is a danger of loss of strength because the sealing pressure causes flowing and thinning of the seal. In addition, the seal is still molten when the jaws are opened and the seal is left unsupported so that there is a danger of the seal being ruptured.

One early way round the problem was used to make bags from layflat polyethylene tubing. The end of the tubing was held by two pieces of cold metal so that about a centimetre of tubing protruded. A bunsen flame was played on the protruding film which quickly fused and gave a heavy bead seal to the tubing. The metal jaws had the function here of conducting the heat away from the rest of the film. The method was, of course, slow as well as a potential fire hazard. Another method of overcoming these difficulties is the use of an 'impulse sealer'. In an impulse sealer the jaws are of light construction and have attached to them a resistance wire or ribbon covered with PTFE, which is heated electrically. Because of their small heat capacity the jaws heat up quickly and cool quickly when the current is switched off. Alternatively, models are available with water cooled carrier bars. However, these have the drawback that under humid conditions, condensation may occur on the bar and this can affect the contact between the bar and the heating unit or lead to deposition of water onto the film.

The sequence in impulse heat sealing is as follows. The bag is placed between the jaws, the jaws are heated for a certain time (the current is usually switched on by the action of the jaws on a microswitch), the current is switched off (by a timer) but the bag is retained by the jaws until cool. The jaws are then opened and the bag is removed. The cooling cycle is usually pre-set with a sequence



timer and a red light is on during the heating and cooling cycle. Since the bag is held by the jaws while the seal cools there is no danger of seal rupture during withdrawal. There is a limit to the width of seal which can be made by impulse sealing because the wider the heating strip the longer it takes to cool and eventually the operation becomes uneconomic. However, even narrow impulse seals can be quite strong and are satisfactory for most uses.

Impulse heat sealers are intrinsically slower than heated jaw sealers because of the cooling sequence in part of the cycle. It is possible to incorporate various cooling methods in tandem with heated jaw sealers so giving heating and cooling without holding up the passage of the film during cooling. More specialised developments of the heated bar principle are rotary bar sealers and heated rotary band sealers.

When heat sealing laminated materials, it is generally preferable to use heated jaw sealers since laminates do not suffer from the disadvantages of single, fully fusible films. It is possible, therefore, to make use of the high speeds of the continuous heating method of sealing and embossed jaws can be used to give extra strength.

In general, a good heat seal, using heated jaw or impulse sealers depends on the temperature at the interface, contact or dwell time, pressure between the jaws and the nature of the film.

In the particular case of low density polyethylene film used on form, fill and seal sachet making equipment, the speed of cooling and the strength of the molten polymer are important factors. In the early days of such equipment, the filling speed was the rate determining factor but with increasing filling speeds, the limit is now set by the speed of sealing.

For materials sealing at the same temperature, the maximum speed of sealing is likely to be determined by the speed of crystallisation and this, in turn, is affected by density. The higher density grades crystallise at a higher temperature and so set up more rapidly. Of course, they also require higher seal temperatures but in practice sealing jaw temperatures are higher than the minimum required for a good seal and it is unlikely that a significant increase would be necessary for the high density grades.

Heat sealers have also been developed which work by applying a blast of hot air to the film surfaces. They are particularly useful for heavy duty sacks used for fertilisers or other products liable to cause contamination by powder of the two mating surfaces. Any dust particles are completely encapsulated by molten polyethylene and do not affect the heat seal strength.

Another method of heat sealing which is suitable for a range of thermoplastics films is hot wire sealing. The heat is applied by an

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electrically heated wire which serves to seal and sever the film in one operation in such a way that the seal is made on the trailing edge of one package and the leading edge of the next. It is used in bag and sack manufacture and in shrink-wrapping equipment. The seal so obtained is, of course, a narrow one and there is no bottom 'lip'. Such a seal may be quite strong in the sense of withstanding pressure from the contents but is susceptible to damage by large scale drop impacts.

Finally, a method of using infra-red radiation has been developed in Russia, with particular reference to the welding of PVC and low density polyethylene. Heating has been carried out using silicon carbide/clay rods with metallised ends for good electrical contact or a heating spiral of chromium steel wire in a glass tube. The efficiency of this method depends on the temperature achieved at the junction of the two pieces of film and this, in turn, depends on the amount of radiation absorbed by the material, part being reflected and part passing through. Maximum absorption for most plastics occurs at a wavelength of 3 μm and this corresponds to a surface temperature of 700°C. When thin films are welded, the rate of temperature rise and the final temperature are both dependent on the backing material on which the welding area lies. An appreciable amount of the incident radiation passes through the film and heats the backing pad which in turn heats the plastics film thus giving a better weld. Best results are obtained with compressed lamp black or black paper. Low speeds render this process uneconomic for commercial purposes but it is useful for hard-to-seal films such as PTFE.

### 15.2.1 SEALING OF ORIENTED FILM

The sealing of oriented films presents particular difficulties. When heated, the film naturally tries to return to its original, unstretched state in the vicinity of the heat seal and this leads to cockling of the seal. Highly oriented films are also liable to crystallise readily and if the cooling rate is slow then large spherulites are formed, giving brittle seals. Rapid cooling gives small spherulites and good strength at the seal. Secure clamping of the film and cooling of the areas adjacent to the heat seal can ameliorate these troubles but does not always cure them.

Another method which was designed especially for oriented polypropylene film is known as 'multi-point' sealing. As its name implies the heating jaws consist of a large number of very small points and the heating effect is, therefore, extremely localised thus preventing the tendency to shrinking of the whole heat seal area. Its disadvantage is that it is not a complete heat seal and air and moisture vapour can eventually diffuse through the seal.



Another more satisfactory method is to coat the oriented film with a polymer having a lower softening point and use the coating to effect the heat seal. Since the oriented film is not heated to its softening point the tendency to shrink is avoided. This method has the additional advantage that the oriented film gives support during the heat sealing operation provided that the heat seal temperature of the coating is far enough below the softening point of the oriented film substrate.

## 15.3 HIGH FREQUENCY HEATING

Films such as PVC and nylon 6.6 are difficult to heat seal by direct means because they tend to degrade at temperatures close to their softening point. Stabilisers have been developed which help in this respect but other methods of sealing are still preferable. For such materials one of the alternative methods of sealing is high frequency (or dielectric) heating.

The method works through the action of a high frequency current on the charged molecules of the plastic films. It is only applicable in those cases where the material is polar, i.e. it is capable of forming a dipole moment. Polyethylene, therefore, cannot be sealed by high frequency methods because it does not contain any inherent dipole moment. PVC, however, is polar and high frequency welding is widely used for the sealing of it. In essence, what happens is that the polar molecules try to align themselves with the oscillating high frequency field. Their rapid oscillation builds up internal friction which manifests itself as heat. This is sufficient to allow welding, especially under pressure. Because the heating occurs uniformly through the film there is not the same risk of over-heating occurring as when direct heat is used. In the latter case the surface temperature may well be too high before heat has penetrated to the centre of the film. In general, frequencies of around 50–80 MHz are used with outputs of up to about 25 kW. For very thin films it is essential to use the higher end of the frequency range and to lower the voltage. This precaution is taken to avoid 'flash' which occurs when the high frequency voltage is high enough to break down the insulation resistance of the film. In other words, since a given current produces a given amount of heat, it is safer to produce this current by using a high frequency and a low voltage in order to operate below the flash point.

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One advantage of high frequency welding is the ease in which a seal can be made through a liquid. An example of this is in the manufacture of shampoo sachets where a completely filled cushion type sachet is required. A continuous tube is filled with the liquid and the individual sachets are formed by sealing across the filled tube.

An advantage of more general interest is the fact that shaped welds can be produced very simply by using appropriately shaped electrodes. The manufacture of sachets shaped to provide a convenient cut-off portion for dispensing is one example of the use of shaped welds while another is the encapsulation of expensive and delicate parts for automobile and aero-engines. The parts are placed in a vacuum formed sheet of transparent, rigid PVC and a corrosion inhibitor added. A similar moulded sheet is placed on top and the assembly is welded by an electrode shaped to the component thus giving a transparent, rigid, hermetically sealed pack providing perfect protection for its contents.

A further advantage of high frequency welding is that heating occurs throughout the film. With heat sealing the seal interface only receives heat by conduction from the heated surface which must *ipso facto* be at a higher temperature, since thermal conduction is so poor.

Relevant variables in the high frequency welding process are the heating time, pressure and the power supply. Heating time may be larger than theoretical for thin films because of their greater heat losses (due to large surface area and small heat content). In such cases, buffers may be used to retain as much heat as possible. Pressures should not be so high as to cause thinning but must maintain good thermal contact between the film surfaces. A cooling period, while the films are still under pressure improves the strength of the final seal. The importance of the power supply has already been mentioned as when avoiding flash in the sealing of the film.

## 15.4 ULTRASONIC SEALING

This method of sealing depends on the vibratory energy of an ultrasonic head (known as the horn) being transmitted through two pieces of plastic film in contact. At the interface between them, the mechanical energy is converted into heat and produces an almost instantaneous weld. Briefly, the principle of the method is as follows. The vibratory energy from the horn radiates outward from the horn tip and is then transmitted through the plastic as a wave motion. There may be some reflection of energy at the interface of the two pieces of film but this is usually small because the joint is under



pressure due to the forces being applied at the horn. Most of the energy, therefore, passes through the lower piece of film. Here, the energy is reflected by the anvil on which the film is resting and tends to set the mating film surfaces vibrating against each other. Because of the high frequencies involved (about 18–20 kHz) the two surfaces are literally hammered together and the mechanical energy of motion is transformed into heat which melts the mating film surfaces.

The equipment consists of an ultrasonic generator feeding a 20 kHz signal into a transducer which transforms electrical energy into mechanical vibrations. These are amplified by means of the focusing tool or horn which, as already described, is in contact with the two pieces of film.

Ultrasonic welding is normally restricted to jointing thermoplastics of the same basic family. Members of the styrene family of plastics, such as basic and high impact polystyrene, ABS and styrene acrylonitrile give excellent results with ultrasonic welding and, in general, rigid plastics with a low melting point respond best to this method. It is a useful method for oriented films, including polyester film, because the high tensile strength of the oriented film is destroyed by normal heat sealing, whereas ultrasonic sealing produces little overall heating. Another advantage is that it can be used to seal packages containing greasy products because it can seal through surfaces contaminated by oils and greases.

In spite of the fact that normally only similar materials can be sealed by ultrasonic welding there are certain exceptions. One of these is the welding of plastics and paper or cloth. In these instances it is possible that bonding occurs because the high local pressure of the horn tip forces the fused plastic into the fibrous structure of the paper or cloth. In the case of plastics, ABS has been welded to acrylics and to polystyrene, the secret of success here being chemical compatibility and similarity of melting points.

Another example of the usefulness of ultrasonic welding is the sealing of multi-wall paper sacks with an inner polyethylene liner. The application is feasible because the heat is generated only at the welding interface and so the paper is not damaged. In ordinary heat sealing enough heat has to pass through the paper to melt the polyethylene and this may result in charring of the outer layer, especially when heavy gauges of paper are used. The main disadvantages of ultrasonic welding are, first, that sealing speeds are usually lower than those of heat sealing (although this may be overcome in time) and, second, possible health hazards due to the vibration. Some particularly sensitive people may be affected by ultrasonic frequencies and the upper level of audible frequencies

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which are also sometimes produced. Loss of hearing, headaches and cumulative tissue damage are possible through direct physical contact with ultrasonic devices so that operators should be provided with suitable ear protection and the equipment shielded with sound-absorbent material.

## 15.5 ADHESIVES

There is a tendency among plastics technologists to look upon adhesives as old-fashioned compared with ordinary heat sealing, let alone ultrasonics, infra-red and high frequency welding. In addition, there is the complication that plastics such as polyethylene and polypropylene have inert surfaces and are difficult to stick anyway. Nevertheless, adhesive sealing is still a very useful method of joining plastics, and can often be very much quicker than other methods. Inert plastics can be pre-treated in the same way as they are before printing, and a wide range of adhesives is now available for use with plastics.

Adhesive seals, of course, provide yet another answer to the problem of unsupported oriented films and are often used for polyester film. They are also useful where large area seals are required such as in block-bottom sacks, or for attaching valves to valved sacks. Finally, they are used for sealing plastics film and sheet to other materials such as fibreboard (as in blister packaging). Adhesives can be applied to plastics by similar methods to those used for other materials, including direct roll coating, direct roll kiss coating, reverse roll coating and air brush coating.

## 15.6 CHOICE OF METHOD

The choice of sealing method depends on many factors including the seal characteristics required, production speed required, the nature of the film to be sealed and the cost/effectiveness of the energy source or sealant. The effectiveness of the seal can be measured in a variety of ways, some of which are qualitative only but can be useful for production testing.

In the case of a simple sealed sachet, the exertion of hand pressure will show up any leakage by an escape of air. Another simple test is to insert a dyestuff on the inside of the seal and observe any leakage. A visual check under polarised light is also useful. Laboratory tests for assessing heat seal quality are described in Chapter 10 on 'Physical and Chemical Properties'.

# 16
# Wrapping equipment

Automatic wrapping machines for packaging materials were introduced around the end of the nineteenth century and the beginning of the twentieth, and were designed to use paper. When metal foils were developed as packaging materials they were readily accepted by the packaging industry because in addition to their excellent end-use performance properties they were stiff enough to be fed to automatic wrapping equipment in the same way as paper. In fact for many applications the foil was laminated to paper.

Regenerated cellulose film was a later arrival on the scene and posed new problems to the machinery designer. It was thinner than most wrapping papers, for instance, although it possessed reasonable rigidity. The biggest difference, however, lay in the need for the provision of temperature-controlled heaters to seal the film. In addition, end-folds had to be held in place during the sealing operation otherwise they tended to spring apart before a firm bond had been achieved. With adhesive sealing it was usually possible to use an adhesive with enough initial 'tack' to hold the folds in place until the adhesive had dried.

## 16.1 WRAPPING WITH THERMOPLASTICS FILMS

Thermoplastics films have added two main problems of their own to the list of machinery designers' difficulties. Many films are too limp to be handled by the type of equipment so successfully developed



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for paper and cellulose film, while the problem of heat sealing is complicated by the fact that the entire film thickness melts on heating, whereas heat-sealable grades of cellulose film have a fusible coating only. The main substrate is infusible and gives support to the molten material on the surface. The ways in which these problems are being solved are best explained by considering the basic functions of a wrapping machine and the main categories of machine available.

The basic functions of a wrapping machine include the following:

(1) Feeding the wrapping material.

(2) Forming the pack.

(3) Closing the pack.

The machine may also include labelling attachments, label imprinters, a splicing unit, photo-electric cell registration, and coding devices but these do not affect the main functions of the machine.

### 16.1.1 FEEDING THE WRAPPING MATERIAL

This section of the machine contains the reel of wrapping material together with some device for cutting the individual wrapper to size and positioning the resultant sheet centrally, ready to receive the product. It will also contain some device for maintaining correct tension in the web of wrapping material. Too little tension will cause the web to wander from the prescribed path and this can cause mis-cutting or bad positioning of the sheet. The problem with thermoplastics films is that too much tension may cause appreciable stretching of the film causing, again, incorrect sheet cutting, or mis-feeding. The magnitude of the problem varies with the nature of the film and with its thickness, as well as with machine design. On some machines, tension controllers similar to those used for cellulose film have been found adequate but on others it has been found necessary to fit a pre-feed or 'pay-off' device which provides a loop, or reservoir, of film. This is then used to feed the machine, so avoiding having to pull the film directly off the reel. Even with all precautions, the tension control of very thin, extensible films, still presents difficulties and these are aggravated by the presence of static electricity. It is usually necessary, therefore, to fit some form of static eliminator in such cases.

The feed section can itself be classified under one of three main categories:



(1) Feed sections where the web of wrapping material is pushed into position for cutting into a sheet.

(2) Feed sections where some form of gripping mechanism pulls the web into position for cutting.

(3) Machines where the motion is continuous and the product is enclosed by the film before the web is cut, giving the completed pack.

The first type of feed mechanism will obviously cause difficulties with thin, flexible materials. Buckling of the film often occurs and can lead to stoppages on the machine. The main cause of the trouble is hold-up of the leading edge of the film as it is being pushed over the bed plate or support rails when it approaches the cut-off position. The problem can be partly solved by reducing the area of the surfaces where the web has to slide, prior to cut-off, and by adding some form of positively driven carrier belt to take the web to the cut-off position.

The second type of feed mechanism normally gives much greater control over the web than does the first type. Gripper fingers close over the leading edge of the web and then pull it for a pre-determined distance. A guillotine knife cuts a sheet of film which is either transported by the gripper fingers direct to the wrapping station, or is positioned for transfer to a second set of grippers. The latter system is particularly useful if the design of the rest of the machine necessitates the sheet moving at right angles to its original path in order to reach the wrapping station.

The speed of a pull-feed machine is normally less than that of a push-feed type but only if the wrapping material is rigid. Limp wrapping materials, as we have seen, can cause misfeeds and jamming of the machine. The actual overall speed then achieved on a push-feed machine is much less than its rated speed.

The third type of feeding mechanism is best considered as an integral part of the whole machine since its continuous action makes it difficult to separate the various functions.

### 16.1.2 FORMING THE PACK

The product is pushed up into the sheet of wrapping material by an elevating table and the sheet is formed as a sleeve round the product. The ends are then folded and tucked over. If the wrapping material is so flexible that the overlapping ends of the sleeve sag, then the end folds will not be neat and the whole package will look untidy.

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Slip is a problem in the forming area because of the different interfaces involved and their varying requirements. Too high a slip between the product and the film may cause the sleeve of material to slide along the product but a high slip *is* required between the film and those parts of the mechanism which fold and tuck the film.

### 16.1.3 CLOSING THE PACK

Closure of the pack can be performed either by adhesives, labels, or by heat sealing. Although adhesives and adhesive labels are now available which are suitable for use with plastics films, the most common method of closing is heat sealing.

Heat sealing on automatic overwrapping equipment is based on two main principles, namely, resistance heating (heated metal jaws, plates or bands), and impulse heating, both of which were dealt with in the chapter on 'Sealing of Films'. Resistance heating is the most common, the simplest type of heater unit being a fixed metal plate (heated by a cartridge-type electrical heating element) over which the folded wrap is moved. Alternatives to the fixed heater plate include reciprocating and rotary heater units, the latter being more applicable to the continuous type of wrapping machine to be considered later. The advantage of reciprocating heaters over fixed heater plates is that they merely dab the folds of the package and so are less likely to disturb the folds by dragging. Another way of avoiding drag is to utilise heated plates or belts which move with the pack.

Other problems with heat sealing include heat transfer on fast machines where the dwell time is likely to be low (except in the cases mentioned above where moving platens or belts are fitted).

## 16.2 CONTINUOUS WRAPPING MACHINES

Such types of wrapping machines are particularly useful for the packaging of biscuits and sweet confectionery. A continuous tube of the wrapping material is formed round the product, the longitudinal seal being made by carrying the material past heater blocks, followed by cold rollers. The filled tube of material is kept moving by friction belt drives. The ends of each separate pack are sealed and cut simultaneously, usually by rotary crimping sealers.

The material feed problems mentioned when discussing the other types of wrapping machines are not normally encountered with continuous machines because the web of material is controlled at all



stages of the wrapping operation and cut-off only takes place when the product has been fully enclosed.

## 16.3 POUCH MAKING EQUIPMENT

The manufacture of separate bags and sacks is dealt with in Chapter 17. In this chapter we deal with the subject of pouches, where these are formed, filled and sealed on the same machine.

The difference between these machines and the overwrapping ones just considered is that on overwrapping machines the product acts as the former, whereas on pouch forming machines the wrapping material is formed round a metal tube and the product is delivered independently, through the forming tube.

In general, the most important film properties are tensile strength, flexibility and slip. Both tensile and flexural strength have to be high because the film is pulled around the forming shoulder at very

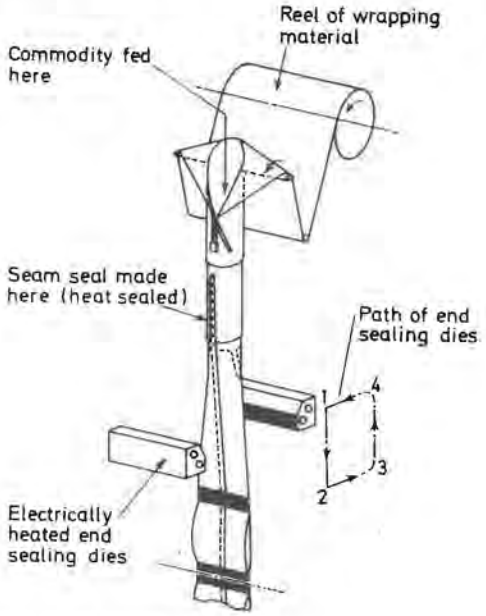


*Figure 16.1. Vertical pouch forming*

acute angles. The entry from the feed section to the forming section should be made as gradual as possible, commensurate with the need

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to maintain sufficient control of the web to avoid wandering. Good slip is essential to ensure smooth passage of the film over the forming shoulder. The action of a typical vertical pouch forming machine can be seen from *Figure 16.1*.

The web of film is formed by passing it around a vertically mounted forming tube and then sealed by a vertically mounted sealer bar. Heated crimp jaws are horizontally mounted, and close on the formed web of film, so giving a transverse seal which forms the base seal of the pack. A measured weight or volume of the product is then allowed to fall through the forming tube into the partially formed pack. The crimp heat sealing jaws, while still closed, descend drawing the pack and the web downwards by a pre-determined amount. They then open and return to their original position, at which point they close again to form the top seal of the pack and the bottom seal of the one following. A cut-off knife then separates the filled pouch from the web and the whole cycle is repeated.

This type of machine was originally developed for materials which remained inextensible when heated so that modifications were necessary for handling plastics films. Impulse sealers are used for the transverse seals and the heating and cooling cycle is completed

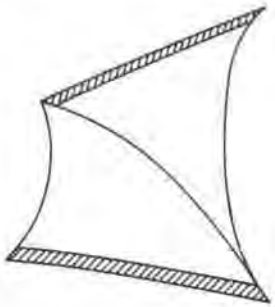

*Figure 16.2*

during the downward movement. The seal is sufficiently set, therefore, to withstand the strain when the product falls on to it. In addition, the vertical sealer bar is covered with PTFE to prevent the plastics web sticking to the heater surface.

If the second transverse seal is made at right angles to the first, a tetrahedral shaped package results (*Figure 16.2*).

Using a laminate of paper and low density polyethylene, such packs have found many applications in the packaging of liquids, including milk and fruit juices.



## 16.4 SACHET MAKING MACHINES

A range of machines is available which make sachets by passing the film over a triangular-shaped forming shoulder to give a folded film. In the horizontal version, vertical seals are made, giving a series of packets along the web of film. These are then cut into separate

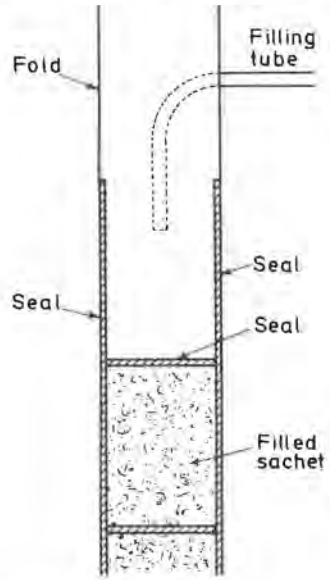


*Figure 16.3. Vertical sachet making machine*

sachets, opened, filled and finally closed by heat sealing along the top edge. The chief material requirement is rigidity, in order that the separated sachets should withstand the opening, filling and sealing operations.

In the vertical version, the folded film passes on both sides of a small diameter filling tube and is then sealed along three edges (i.e. one transverse seal and two side seals) and filled (*Figure 16.3*). The final closure is made at the same time as the bottom seal of the following sachet.

## 16.5 VACUUM AND GAS PACKAGING

Many products, particularly foodstuffs, need to be kept completely

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free from contact with oxygen during storage. The provision of a gas-proof wrapping material is not sufficient in such instances since there is usually enough residual air in the package to react with the contents. Three solutions are possible, namely, evacuation of air from the package, (vacuum packaging), replacement of the residual air by an inert gas such as nitrogen (gas flushing), and modified atmosphere packaging.

In the first method the packages are usually evacuated and then sealed in vacuum chambers, after they have been fabricated and filled. Several packages can normally be evacuated and sealed in the same chamber. Another possible way of evacuating certain packages, such as those made on vertical sachet machines, is to use a vacuum nozzle on the packaging machine. This type of vacuumisation is limited to granular products as there is a danger of powdered products being extracted at the same time as the gas is withdrawn.

When an inert gas is used, the product itself must usually be stored in bins or hoppers which have been evacuated and then flushed out with the inert gas. The chamber method may also be used for gas packaging, while the vertical pouch forming process shown in *Figure 16.1* can be used with gas flushing techniques provided that the product comes from pre-gassed hoppers.

### 16.5.1 MODIFIED ATMOSPHERE PACKAGING (MAP)

Modified atmosphere packaging is a method of packaging whereby the product inside the pack is surrounded by a controlled gaseous atmosphere. The air is evacuated from the package and is replaced by a mixture of gases. The exact composition of the mixture will depend on the nature of the product. The use of modified atmospheres to aid preservation of fresh produce is not new. For many years, now, farmers have been storing apples in modified atmospheres. Large cooler chambers holding batches of up to 200 tonnes of apples are used and the amount of oxygen is controlled by vents in order to preserve the particular type of apple being stored. Such storage is usually referred to as controlled atmosphere (CA). The concentrations of oxygen and carbon dioxide are monitored and regulated at the required levels by adding air or by removing carbon dioxide by 'scrubbing'. In the U.K. the use of modified atmospheres for retail packaging dates from 1969 when the technique was used for extending the shelf life of red meat. Modified atmosphere packaging places stringent barrier requirements on the packaging materials used, in terms of keeping the package gases in and preventing the ingress of unwanted gases.



The scope of the technique can probably best be seen by examining its use for certain types of product.

#### Fresh red meat

There are two main problems with red meat. One is bacterial growth, and this is tackled by including at least 20% carbon dioxide in the gaseous environment. This gas inhibits the growth of putrefying bacteria, provided that the temperature is kept between 0° and 2°C. The second one is that of maintaining the bright red colour that the consumer associates with freshness. Red meats contain a purple pigment called myoglobin. In the presence of air this changes to the bright red pigment, oxymyoglobin. This reaction is reversible. Further oxidation of oxymyoglobin gives a brown pigment—metmyoglobin—and this, slower, reaction is irreversible. If, then, the fresh meat is exposed to the normal atmosphere, it eventually becomes a brownish colour and loses its sales appeal.

Two gaseous mixtures that have been used successfully for the packaging of red meats are 20% carbon dioxide/80% oxygen, and 20% carbon dioxide/69% oxygen/11% nitrogen. Shelf lives of 7 days or over are possible, depending on the nature of the product. The presence of oxygen in the pack can have disadvantages in as much as off-odours may develop due to oxidation of fats.

The package is usually a thermoformed tray made from a PVC/PE laminate which gives a combination of good oxygen barrier and heat sealant. The lidding material is a laminate of PE film and polyester film coated with PVDC. The operation is a thermoform/fill/seal one, carried out on specially designed Multivac machines.

#### Cooked meats

Cooked meats are being packaged in atmospheres consisting of nitrogen/carbon dioxide mixtures. Bacon is one example, the advantages being better presentation and handling than with the usual vacuum pack. Shelf life is about the same in both instances. The bacon can be sliced thinner without the tendency to tearing when removed from the pack, and the rigid pack allows stacking without compression of the sliced product.

#### Fish

Fresh fish is especially susceptible to deterioration, both micro-biological and enzymatic. Various atmospheres have been used

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successfully, ranging from 80% carbon dioxide/20% oxygen at 3°C, to 40% carbon dioxide/30% nitrogen/30% oxygen at 0°–2°C. The presence of oxygen is considered to be necessary in order to prevent the growth of toxic anaerobic micro-organisms normally present in the waters. Shelf lives range from 4 to 9 days according to the composition of the atmosphere and the storage temperature.

## Cheese

Cheese has also benefited from modified atmosphere packaging. In one example, hard cheese has been packed in PP film. Under normal conditions the cheese had a shelf life of about 14 to 15 days, but packaged in a controlled atmosphere it can last for anything up to four weeks.

A different application is that of soft cheeses packed in nitrogen and carbon dioxide. The gases are absorbed by the product and the finished package has the appearance of a vacuum pack.

## Baked goods

The quality of baked goods is dependent on the maintenance of the original moisture content. However, high moisture content also stimulates mould growth. Chemical additives, such as benzoates or sorbic acid, retard mould growth, but such techniques are limited by regulations, consumer resistance and changes in flavour. Markedly reducing the oxygen content of the product environment or using elevated carbon dioxide contents permits high relative humidities with little or no mould growth. According to the British Flour Milling and Baking Research Association, when carbon dioxide is present at concentrations over 20% it exerts a highly beneficial effect on mould suppression. Below this figure the effect, though still present, is not so pronounced. Reducing the oxygen concentration alone has almost no effect on mould growth until the level is reduced below 1%. Neither elevated carbon dioxide levels nor reduced oxygen levels have a direct effect on staling; it is the ability to employ an elevated relative humidity that allows staling to be retarded.

The use of carbon dioxide differs from the use of inert atmospheres such as nitrogen. The latter only reduces mould growth at very high concentrations by virtue of reducing the oxygen to a very low level. The packaging of bread and cake in high carbon dioxide



concentrations (up to about 60%) has a suppressive effect on mould growth that increases with carbon dioxide concentration and with reduction in storage temperature.

Systems in use for the packaging of baked goods include Multivac twin-web thermoform/fill/seal and Rose Forgrove's horizontal form/fill/seal machine. In France, pizzas are packaged in sealed, thermoformed trays having a high oxygen barrier. Refrigerated shelf life is extended up to 21 days by the use of atmospheres consisting of 50% carbon dioxide and 50% nitrogen (i.e. oxygen free).

## Coffee

Another product that can benefit from modified atmosphere packaging is coffee. Freshly ground roasted coffee generates carbon dioxide and one packaging system combines modified atmosphere packaging with a valve. The valve allows the carbon dioxide to escape but provides a barrier against oxygen which would otherwise cause oxidation of the coffee. The coffee is packed immediately after processing and the pack is then flushed with an inert gas.

## Fresh fruits and vegetables

Fruits and vegetables are still living organisms after harvesting, taking in oxygen and giving out carbon dioxide. This process, known as respiration, works by burning the plant sugars in oxygen to release carbon dioxide, water and energy. Slowing down respiration by refrigeration reduces the amount of energy produced, and if there is not enough energy then the physiological functions depending on it slow down or cease. Such functions include ageing or senescence in leafy vegetables and ripening of fruits. Although refrigeration does slow down respiration it is not always suitable, for a variety of reasons. Bananas, for example, turn black at temperatures below about 14°C while cucumbers and tomatoes are discoloured or unevenly ripened at temperatures below about 7°C. In addition, some fruits are more susceptible to attack from microbes at low temperatures. These effects often only become apparent when the fruit returns to a higher temperature and begins to decay. In addition, some foods can lose texture and flavour at temperatures around freezing point.

The rate of respiration can also be lowered by limiting the amount of oxygen entering the pack. This slows the production of energy and, consequently, the processes of ripening or senescence. However,

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if a pack contains no oxygen at all, then the produce inside will start to respire anaerobically, giving undesirable by-products. Anaerobic respiration also produces energy, this time by converting sugars, such as glucose, into alcohols, aldehydes and acids. Apples, for example, produce ethanol (which gives them a 'cidery' smell) while cabbages produce lactic acid and smell like sauerkraut. It is not easy to keep a balance between starving fruit of oxygen to retard ripening and providing sufficient of the gas to avoid the generation of by-products. One of the important factors is the plastics film used to contain the produce. Oxygen levels in the pack depend on the ambient temperature and the respiration rate of the produce. They also depend on the oxygen permeability of the film. The situation is complicated by the fact that the relative humidity inside the pack affects the way in which the food modifies its atmosphere. This, in turn, depends on the water vapour permeability of the film and on the ambient relative humidity.

An example should serve to make the matter clearer. In an experiment, tomatoes were packed in a relatively oxygen impermeable film and stored at 20°C. After three days the pack had modified its atmosphere to one containing 5% carbon dioxide and 5% oxygen. The tomatoes used in the experiment were partly ripe and continued to ripen only when exposed to the air again. In another experiment, tomatoes were packed using less oxygen permeable films. These modified their atmosphere to one of only 1% oxygen and 14% carbon dioxide. Under these conditions the ripening process stopped completely and the tomatoes did *not* start to ripen again in the atmosphere and many were attacked by bacteria.

Rotting of fruit can also be caused by high humidity levels in the pack. In experiments using PVC film, packs were held at 20°C and 60% relative humidity. This raised the relative humidity inside the pack to about 90%, which is still low enough to keep microbial attack within normal limits. The use of PE films, which are less permeable to water vapour than PVC films, allowed the relative humidity to rise above 98%. The tomatoes packed in PE films were attacked by organisms such as *Botrytis cinerea* and quickly rotted.

When one takes into account the various factors involved, such as the type of produce, ambient conditions and the length of shelf life required, it should be obvious that no single answer exists in terms of plastic films. Normally the film must be tailor-made to suit each particular application and this has led to much development in the field of coextrusions.

Although modified atmosphere packaging is more costly its benefits are such as to justify the overall economics in many instances and commercial applications are growing appreciably. Estimates of



future growth range from 8% to 15% per annum. The benefits include the extension of shelf-life and this, in turn, allows for more efficient distribution, less product wastage and an attractive premium image. One of the growth areas at present is the packaging of salads. An important factor here is the provision of an anti-mist (anti-fogging) coating on the inside surface of the lidding film in order to maintain product visibility. Films used range from single films such as polypropylene to five layer coextruded films which include EVOH as a high barrier material. An interesting range of laminates is one in which the inner polyethylene ply is patterned so as to create channels from which the gas can escape. Other laminates used include some based on PET.

## 16.6 SHRINK WRAPPING

The technique of shrink wrapping goes back to 1930 when the ability of dampened plain cellulose film to shrink to a tight wrap on drying was utilised to provide decorative wrappings and to act as a pilferproof seal. The technique is still widely used today, especially for the wrapping of bottled drinks.

Later, in 1936, natural latex was used in France as a shrink wrap to pack perishable foods. The film was stretched and then allowed to shrink back on to the goods to be packaged. This technique has been extended using elastic plastics films such as low density polyethylene, EVA and thin plasticised PVC. The process is referred to as stretch wrapping to distinguish it from processes based on the use of heat shrinkable films. The latter technique is the one normally referred to as shrink wrapping and is dealt with in sections 16.6 to 16.10. Stretch wrapping is discussed in section 16.11.

Shrink wrapping began around 1948 with the wrapping of poultry for deep freeze storage. The film used was polyvinylidene chloride. A film bag was slipped over the bird, a light vacuum was drawn and the mouth of the bag sealed, usually with a wire tie. The bag and contents were then immersed in a hot water bath when the bag shrank tightly on to the contents. Apart from giving an extremely neat pack, shrink wrapping had the advantage that freezer burn (caused by intense dehydration of the surface of poultry) was prevented by the impermeable film, coupled with the close contour wrap. The latter also eliminated pockets in which ice crystals could form and obscure the contents.

The principle on which shrink wrapping is based is sometimes

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referred to as 'plastic memory'. In other words a film which has been stretched during manufacture (at a temperature above its softening point) and then cooled to 'freeze-in' the consequent orientation of the molecules, will tend to return to its unstretched dimensions when re-heated. The techniques of producing oriented films have already been described in Chapter 8. With most films other than polyvinylidene chloride, the temperature at which a suitable degree of shrinkage is obtained is above the boiling point of water so that hot-air tunnels have had to be developed for their use.

### 16.6.1 SCOPE OF PROCESS

The scope of shrink wrapping has expanded well beyond the original idea of contour wrapping frozen poultry although the shrink wrapping of items of food is still an important outlet. Because awkward shapes make little or no difference to the feasibility of shrink wrapping, the technique is particularly useful for the packaging of a premium offer with the product to which it is temporarily related. The equipment necessary for such a job is capable of handling subsequent offers within a fairly wide range of size and shape.

*Figure 16.4. Shrink-wrapped bottles*

Shrink wrapping is also advantageous in rounding off the contours of awkwardly shaped or complex sets of items so that they do not become dust traps when on display. However, one of the most rapidly developing fields open to shrink wrapping is the production of transit packs of cans, cartons or bottles, as an alternative to fibreboard cases. Cartons, of course, can be built up into a neat



stack which is easily shrink wrapped, but cans and bottles are normally first collated on one or two fibreboard or plastics trays, before shrink wrapping (*Figure 16.4*).

### 16.6.2 TYPES OF SHRINK WRAP

There are two main types of shrink wrapping, namely, the sleeve wrap and the all-round or perimeter-sealed wrap. In the sleeve wrap, a tube of film, greater in length than the product to be packaged, is made by sealing longitudinally (see *Figure 16.5*). When this is passed through the shrink tunnel, the extremities of the sleeve shrink around the ends of the product (*Figure 16.6*). Less film is used than in a complete over-wrap, and the holes at each end can be used for opening the pack. Sleeve wraps are particularly suitable

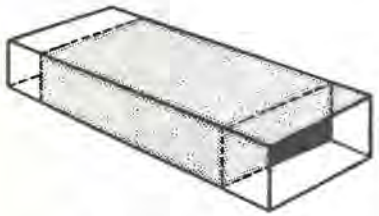

*Figure 16.5*

*Figure 16.6*

for securing premium offers or for making carry-home packs of, say, three or six unit packages, but they are also used for transit packs or one or two dozen cans or bottles. Another use for the holes at either end is as hand-holes for carrying. The all-round, or completely sealed, pack is a more efficient barrier against dust or moisture pick-up but it may be necessary to make a few micro-perforations in the film to allow the escape of entrapped air during the shrinking process.

With cans, a sleeve wrap may be preferable to a complete over-wrap because the cans could still hold residual moisture from the cooling water used after processing. In a complete wrap, condensation will eventually occur but with a sleeve wrap, the resultant ventilation should prevent this, provided that storage conditions are reasonably dry.

A sleeve wrap for holding, say, a premium offer and the product will require the use of film with a high degree of shrinkage in one direction only. For transit packs, where either a sleeve wrap or a

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perimeter wrap may be used, the type of film necessary will be dictated more by the proportions of the pack.

When a sleeve transit wrap is used, the shrinkage may be unbalanced to a small degree, but not to the extent indicated above for collating two fairly small items. Where the height of a pack is out of proportion to its length and breadth, the difference between machine direction shrinkage and transverse direction shrinkage should be at a minimum. For products requiring an all-round seal, the shrinkage should again be more or less balanced.

## 16.7 SHRINK WRAPPING EQUIPMENT

The equipment necessary for shrink wrapping transit packs of cans or bottles will usually consist of collating equipment, tray erector, tray loader, film wrapper and sealer, and a shrink tunnel, together with the necessary conveyors.

### 16.7.1 TRAY ERECTION

Plastic trays do not require erection because they are thermoformed in one piece. For fibreboard trays, either manual or mechanical erection may be used. However, for high speed lines manual erection can be expensive in terms of man-power, and mechanical erection will normally be used.

### 16.7.2 FILM WRAPPING AND SEALING

A range of equipment is available, from hand operated to fully automatic. Basically, however, there are two main types. One is used specifically for all-round sealing and utilises centre-folded film (i.e. film folded in half, in the machine direction) and an 'L'-shaped hot wire sealer. The object to be wrapped is placed within the folded film and the 'L' sealer brought down in front of it. This seals transversely in front of the pack (and also cuts the film), at the same time sealing the side of the pack (opposite to the fold). The pack then moves forward, another object is placed in the folded film and the operation is repeated. This seals the trailing edge of the first pack and the leading edge of the following one. Each subsequent operation of the 'L' sealer, seals the trailing edge of one pack, and the leading edge and side of the following one.

For sleeve packs the usual method is to use two reels of flat film,



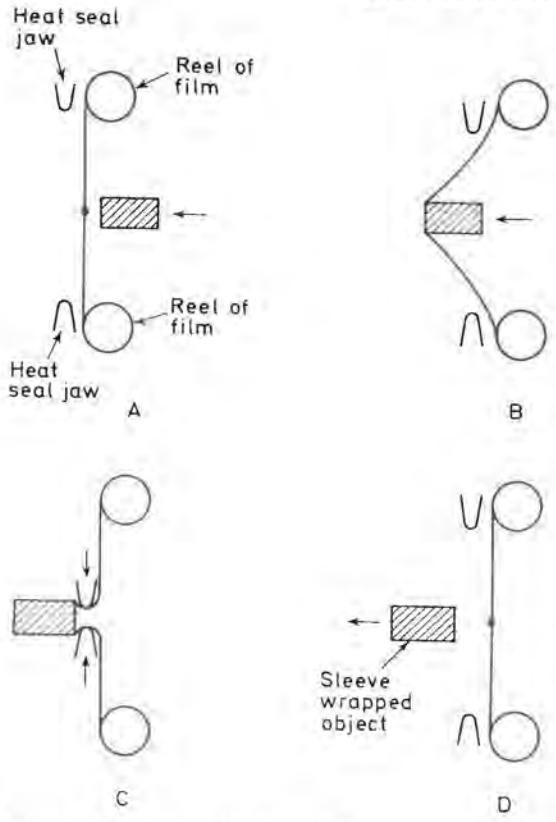


*Figure 16.7. Sequence of operations for sleeve wrap*

located above and below the sealing table. The ends of these two reels are first sealed together and the object to be wrapped is pushed through the curtain of film so formed, beyond the heat-sealing and cutting jaws. These are then operated to seal the pack, cut it from the web of film and re-form the curtain (*Figure 16.7*). If a complete overwrap is required, side seals can be added further along the line.

### 16.7.3 SHRINK TUNNELS

Shrink temperatures are often not far from the melting point of the film. Temperature control is an important factor, therefore. The normal means of heating a shrink tunnel is by hot air, and heat losses are minimised by fitting PTFE or asbestos curtains at each end of the tunnel.

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## 16.8 PROPERTIES OF HEAT-SHRINKABLE FILMS

In general, the orientation of a thermoplastics film improves its impact and tensile strengths, its clarity and its flexibility. Gas and moisture vapour permeabilities are also reduced in some cases. On the debit side, elongation is reduced and the heat-sealing range is narrowed.

### 16.8.1 SHRINK TEMPERATURE

The range of temperature over which a film will shrink is important commercially. Films with low shrink temperatures require simpler equipment and also pose fewer problems with the packaging of heat-sensitive goods. In addition, a film with a wide softening range is preferable to one with a fairly sharp melting point because the latter renders temperature control of the oven more critical.

### 16.8.2 DEGREE OF SHRINKAGE

The maximum amount of shrink available in commercially obtainable films varies from around 20% to around 75%. The percentage shrink of a particular film also increases with the temperature of shrinkage. Films with a steep shrink/temperature curve are more difficult to handle because of the closer temperature control necessary. Polypropylene, for example, has a steep shrink/temperature curve and a temperature variation of 10°C (i.e. $\pm 5°$ tolerance in the tunnel) could cause the degree of shrink to vary by up to 20%.

The degree of shrinkage necessary depends on the particular application. For tightening-up a loosely wrapped package only a very little shrinkage is necessary, whereas the contour wrapping of a complex-shaped article requires a high degree of shrinkage.

For printed films, the problem is not so much the total degree of shrinkage as the amount in different directions. Balanced orientation obviously gives the least distortion under normal conditions but there may be complications if the product is of irregular shape. In such cases the only course of action may be to choose a simple print design which is relatively unaffected by distortion.

### 16.8.3 SHRINK TENSION

This is the stress exerted by the film when it is restrained from shrinking at elevated temperatures. A certain amount of shrink tension is necessary in order to give a tight package but care must be taken when wrapping articles which could be crushed or distorted. High shrink tensions are really necessary only when the film is intended to become a structural part of the packing.



## 16.9 PALLET OVERWRAPPING

Shrink tunnels have been built which are large enough to accommodate complete pallet loads, and this has opened up a wide range of applications for shrink wrapping. The concept of shrink wrapping complete pallet loads was first developed for the packaging and transit of refractories. These are fragile and are often oddly shaped, thus making them extremely difficult to transport by normal methods. Using 150–200 μm thick, low density polyethylene film, a tough contour wrap can be obtained which is firmly anchored to the pallet. Other advantages of a shrink film overwrap for such pallet loads include protection against dirt and weather conditions, elimination of strapping damage, easy detection of pilferage, and a reduction in abrasion and crushing due to movement during transit.

The concept has since been expanded to include pallet loads of container glassware, bricks, and a wide range of products packed in sacks or fibreboard cases. Speeds of up to 300 packs per hour have been claimed. The shrink tunnels are usually heated by gas but electric ovens have also been used. Other heating developments include the use of a vertically reciprocating bank of heaters, and portable hot air heaters (rather similar to giant hair dryers).

## 16.10 GENERAL ADVANTAGES AND PROBLEMS

Many of the advantages of shrink wrapping have already been mentioned but a general summary may be useful. For the packaging of awkwardly shaped foodstuffs like hams, poultry, and so on, shrink wrapping provides a convenient and economical method for preventing freezer burn (in deep freeze storage) and for equipping the foodstuff with a second skin which protects it from contamination by dirt and bacteria. For transit packs of cans, bottles or cartons, shrink wrapping can often be cheaper than a conventional fibreboard case, as well as providing an attractive display pack. Two advantages of particular relevance to the retailer are the reduction in packaging material to be disposed of at the end of the day, and the fact that

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a shrink wrap takes up progressively less space on the warehouse shelf as the contents are removed, whereas a fibreboard case takes up the same amount of space whether full or empty.

However, there are still a number of problems which can arise under certain conditions. Some are a matter of user education but others are more technical. The latter can quite often be solved technically but not necessarily economically. With the packaging of cartons, for example, care must be taken where these are coated externally with wax or low density polyethylene. Bonding sometimes occurs between the shrink film and the carton coating, particularly if there are local hot spots in the tunnel. The trouble can usually be eased by reducing the dwell time in the tunnel and by tightening up the heat control.

Inconsistent results can sometimes be traced to temperature variations within the tunnel. This may not necessarily be due to the temperature control but may be caused by running the packs through with too little space between them. Sometimes, too, different temperature settings are necessary for the same film if it is to be used for different products. Cartons and cans, for example, will need different temperature settings because of their different heat conductivities.

One of the problems of transit shrink wraps is that of mixed loads, where shrink wrapped goods are carried in the same vehicle as, say, wooden boxes or metal containers. This problem can only really be solved by separate stacking.

The question of excessive shrink tension has already been mentioned. This can lead not only to crushing and distortion of flimsy cartons but may lead to trouble with items such as polyethylene bottles. If these are filled with a detergent, stress cracking may occur if the bottles are under stress. Even if the shrink tension of the film is not excessive, stress may be induced in the bottles when they are stacked. Where such bottles are carried in a fibreboard water case, the case itself usually takes part of the weight involved in stacking.

## 16.11 STRETCH WRAPPING

The principle of stretch wrapping, as mentioned earlier, is that the film is stretched around the article to be wrapped and is then heat sealed. The residual tension in the film gives a tight contour wrap (the simplest analogy is that of an elastic band).

The main films used in stretch wrapping are low density polyethylene, PVC and EVA, the choice depending on factors such as appearance (clarity, sparkle, etc.), protection required (gas barrier, water vapour barrier, etc.) and the susceptibility to damage by compression of the articles being wrapped.



One of the factors which initially held back the commercial development of stretch wrapping was the lack of suitable equipment and in the early days fragile items, such as cartons containing tea bags, were damaged by the excessive film tensions used. Suitable equipment is now available, however, and the advantages of stretch wrapping can be exploited. These advantages, *vis-à-vis* shrink wrapping, are dealt with below.

(a) Energy saving – This is perhaps the most obvious advantage, arising from the fact that no shrink tunnel is necessary in most cases. Apart from the savings in capital cost of a shrink tunnel, the savings in running costs can also be considerable. The direct savings in energy are also important.

When a sleeve wrap, extending beyond the length of the pack, is used it may be required to bring the ends in by shrinking. In such instances, a short end-closing tunnel may be used or the packs may be passed between two hot air guns. In either case, the energy used is less than in a normal shrink wrapping set-up.

(b) Savings on yield – It is often possible to use a thinner gauge for stretching wrapping. Typically, where a 50 $\mu$m film might be used for shrink wrapping, it can often be replaced by a 38 $\mu$m film in stretch wrapping.

(c) Savings in space – In general, stretch wrapping takes up less space than does shrink wrapping and this can lead to important cost savings. A typical figure would be 100 units of area for stretch wrapping compared with 160 units for shrink wrapping. With the high (and rising) costs of factory space this can also lead to appreciable cost savings.

(d) Installation and commissioning costs – These are usually less for stretch wrapping.

(e) Use of standard film – The use of stretch wrapping allows the use of standard film widths for a range of different product collations. This enables cost savings to be made in the ordering of film.

(f) Use of double wrapping – One technical advantage of stretch wrapping is in double wrapping, particularly in the overwrapping of pallet loads of pre-shrink wrapped packs. If the pallet loads are subsequently shrink wrapped there is the possibility of welding or laminating occurring between the pallet wrap and the film covering the individual packs. The use of dissimilar films can sometimes solve this problem but the use of stretch wrapping as the outer wrap solves the problem completely because no heat is used to obtain the final tension.

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### 16.11.1 TENSIONING OF THE FILM

For collation stretch wrapping, much of the equipment used is based on that developed for shrink wrapping. One of the main differences is that tensioning of the film is more important than in shrink wrapping so that adjustable torque units have to be fitted. In addition, packs have to be held in position to avoid movement during the stretching, clamping and sealing operations.

One way of stretch wrapping pallet loads is by spiral winding so that a standard width of film can be used, irrespective of the pallet load dimensions. Basically, pallet stretch wrap equipment consists of a turnable on which is placed the pallet load to be wrapped. To one side of this there is a vertical pillar, up and down which moves a carriage holding a reel of film. After placing the pallet load on the turntable the film is secured to the bottom of the pallet, the turntable is set revolving and a suitable number of turns of film is given to provide suitable anchorage. The film carriage is then taken up and down again until the requisite number of layers has been applied.

As mentioned earlier, one of the factors influencing the choice of film is the fragility of the objects to be wrapped. By this is meant the liability to deformation of the product or packs and this, in turn, governs the amount of tension which can be tolerated during wrapping. Of the three films already mentioned, low density polyethylene gives the highest initial stress for a given percentage deformation (when used in stretch wraps) while PVC gives the least. However, all give figures well above the initial stress of low density polyethylene shrink wraps. This is not the whole story, however, for the percentage stress retained after 24 hours also varies with the

**Table 16.1**

| | *Stretch wrapped* | | | *Shrink wrapped* |
|---|---|---|---|---|
| | LDPE | EVA | PVC | LDPE |
| Initial stress ($kg/m^2$) at 20% deformation. | 100 | 70 | 65 | 28 |
| Stress retained after 24 hours (%) | 55 | 60 | 30 | 95 |
| Stress retained after 24 hours (actual) ($kg/m^2$) | 55 | 42 | 20 | 26 |



different films and processes so that after 24 hours, PVC stretch wraps have slightly less retained stress than low density polyethylene shrink wraps and even EVA and low density polyethylene stretch wraps have a reasonably low stress.

Some typical figures for initial and retained stresses are given in Table 16.1.

## 16.12 SHRINK VERSUS STRETCH

These two techniques may, at first sight, seem to be completely competitive with each other, but in reality they are usually complementary. In fact, it is often a case of 'horses for courses', when choosing between the two for a particular application. In both techniques, the equipment available ranges from hand held to fully automatic systems and it is at the latter end that shrinkwrapping often shows up to advantage.

In palletisation, where shrink wrapping often *is* in competition with stretch wrapping, users will tend towards stretch wrapping installations if they have fairly uniform pallet loads at irregular or well spaced intervals. Where speed is important and load sizes vary, the tendency is to shrink wrap the pallets. One instance of this is the use of shrink wrapping by a leading U.K. ice cream producer. The company needed a machine that could wrap cartons of ice cream one minute and packages of choc ices the next. In other words what was wanted was a machine with the advantages of automation, coupled with the flexibility of intermittent and extremely low order runs. Another example of the use of shrink wrapping is in the wrapping of fork lift trucks. These are obviously of irregular shape but the use of a loose fitting cover, shrunk to shape by a hot air gun, gives a clear, tight, waterproof wrap in a few minutes.

Where the shape of the product and the type of operation lend themselves to stretch wrapping then cost and energy savings can tilt the balance of advantages quite considerably. Labour costs are roughly equal for both processes but capital costs for stretch wrap are lower, as are running costs. Stretch wrap equipment is available that is fully interlocked with a filled can palletiser and this is ideal for continuous running canning lines.

One of the developments in stretch wrapping is the use of LLDPE, because of cost/performance benefits. One disadvantage of LLDPE is that it has considerably less inherent cling than other stretch films such as PVC and EVA. One way of overcoming this is by the incorporation of cling additives. Another is to eliminate the need for

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cling by such devices as closure by mechanical crimping. LLDPE is also being used in stretch wrapping in the form of a laminate with other plastics films. One example is a triple laminate with conventional LDPE as the outer layers with an inner core of LLDPE. The advantages claimed here are a greater tear and puncture resistance, and a higher tensile strength and elongation compared with LDPE. The overall thickness can, therefore, be reduced and the stretchability is greater. The film weight per pallet load can, therefore, be reduced with a consequent cost saving. Other films have been developed that are based on blends of LLDPE with other polymers such as EVA. In these structures, the EVA gives the requisite cling.

It should be noted here that in shrink wrapping (as opposed to stretch wrapping) the lower melt strength of LDPE makes it more suitable than LLDPE.

# 17

# Bag and Sack Manufacture

The methods used for making bags from plastics film depend on:

(1) The nature of the film.
(2) Whether flat or tubular film is being used.

## 17.1 NATURE OF THE FILM

The most important influence that the nature of the film has on the choice of bag making method is the type of seal to be employed. The various types of sealing available for plastics films were discussed in Chapter 15 but the ones most likely to be used for film bags are adhesives, heat sealing and high frequency welding. In general, the division has been the use of adhesives for cellulose films (especially for film faced paper bags), heat sealing for polyethylene and polypropylene bags and high frequency welding for PVC. Adhesives are also likely to be used for films such as polyester where a big loss of strength occurs at the heat seals due to crystallisation. These rather rigid compartments are breaking down somewhat because of developments in adhesives for plastics such as polyethylene which enable the faster and more flexible machines based on adhesive sealing to be used for a wide range of films. Thus, heavy duty sacks with adhesive seals have been made from low density polyethylene as have small bags from high density polyethylene film.



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applications. The subject will be broken down, therefore, by considering the different plastics separately.

## 20.1 LOW DENSITY POLYETHYLENE

This particular polymer accounts for about 75% of the total usage of thermoplastics films in packaging, and over 56% of the total of thermoplastics films plus regenerated cellulose. It is thus the most important of the packaging films.

### 20.1.1 HEAVY DUTY SACKS

The biggest single outlet for low density polyethylene film is in the field of heavy duty sacks. The first products to be packed in these sacks in the UK in the early 1960s, were compound fertilisers. The existing package was a multi-walled paper sack, the usual construction for a 50 kg sack being five paper plies with an inner ply of 25 μm low density polyethylene. The main advantage seen for the all plastic sack was that the filled sack could be stored in the open air thus freeing expensive storage space for the farmer. In addition, the farmer could then buy fertiliser out of season and so qualify for an early delivery rebate. Finally, the plastics sacks of fertilisers could be kept in the fields where they would later be required, thus saving labour in distributing sacks from a central storage point. The original polyethylene sacks used 250 μm thick film and were dearer than the existing paper sacks. Nevertheless, work went ahead and a market now exists for over 80 000 tonnes/annum of low density polyethylene for sacks. The fertiliser sacks in particular are now cheaper than their paper counterparts and are only 200 μm in thickness.

There were many difficulties encountered during the development of this now very successful market and it is interesting to look at some of these. One of the first difficulties was that of handling. When the open mouth sack was filled and sealed it assumed a pillow-like shape which was difficult to stack. Stack instability was often thought to be due to a lower coefficient of friction for low density polyethylene, but in fact polyethylene on polyethylene has a higher coefficient than has paper on paper and it was soon recognised that the main trouble was the small area of contact with the pillow-shaped polyethylene sacks, against that given by the block-shaped paper sacks. One early solution that was proposed was to place the empty sack in a block shaped jig, fill, and seal all



but a small proportion of the seal. A vacuum was drawn in the sack and the seal completed. This gave a brick-like package but the taut film was easily punctured and the sack was then more floppy than the normally filled one. A more acceptable solution was found to be the provision of a few micro-perforations along the top of the bag. These holes allowed the air inside the sack to escape and the contents of the bags were consolidated under the influence of impacts during handling and movements on conveyor belts, etc. The holes were small enough not to let in moisture except in heavy rainfall. This meant that bags could not be stored under completely unprotected conditions, but a light tarpaulin or sheet of polyethylene film over a stack is sufficient for normal protection. This is still better than paper sacks which lose strength even under conditions where liquid water is absent but where the relative humidity is high. There are also many situations where filling equipment demands valved sacks so that these had to be developed for polyethylene sacks as well as for paper. Today, sacks are available with fitted valves (consisting of thin polyethylene flaps covering a slit aperture) and block bottom construction so that neither filling nor stacking is a problem.

Advantages of the plastic sacks, apart from outdoor storage and lower cost, include higher resistance to tear propagation and visibility of contents (where necessary).

There are now many other uses for low density polyethylene sacks in addition to the packaging of fertilizers. Peat is packed in such sacks, so is coal. Another large market is the packaging of plastics granules themselves. The market was slow to develop because of difficulties in stacking, palletisation and transport but the advent of block bottom, valved sacks has solved many of these problems.

### 20.1.2 SHRINK WRAPPING

Shrink wrapping is another large outlet for low density polyethylene film and one that is still growing. Shrink wrapping is based on the fact that a plastics film which has been stretched during its manufacture will revert to its original dimensions when heated. The plastics film is loosely sealed round the object to be packed, therefore, and then heated, when a tight transparent wrap is obtained. The first application for these techniques was in 1948, using a film bag of vinylidine chloride/vinyl chloride copolymer for the packaging of oven-ready turkeys for deep freeze storage. The turkey was placed in the bag, a vacuum drawn and the bag closed with a wire tie.

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The bag and contents were shrunk by plunging in a hot water bath. Shrink wrapping is now carried out using a heated tunnel (see Chapter 16). Low density polyethylene film has been used mainly in the field of transit packaging, where a shrink-wrapped package of, say, one or two dozen tins or jars, collated on one or two trays, is used instead of a fibreboard case. The mechanical protection given by the shrink wrap is not as great as that given by a well designed fibreboard case, but is usually adequate. There is also the psychological point that a shrink wrapped package can be seen to be fragile and is usually handled more carefully as a result. Other advantages of shrink wrapping, this time to the retailer who receives the goods, are:

(1) There is less packaging material to dispose of, after use.

(2) The package takes up progressively less space on the warehouse shelf as the goods are sold, whereas a fibreboard case takes up the same amount of room whether it contains one can or two dozen.

Low density polyethylene film is also used for the shrink wrapping of whole pallet loads. The tight, even wrap gives a more stable load than wrapping with paper plus strapping and, in addition, confers a large measure of weather-proofing on the load.

Other, miscellaneous applications for low density polyethylene shrink wrapping include rolls of wall paper, cucumbers and other awkwardly shaped objects. Low density polyethylene is used for all these applications, because it is cheap, tough, waterproof and has sufficient clarity for its purpose. In cases where a clearer or more sparkling film is required, then polypropylene or PVC are likely to be used.

Some of low density polyethylene's shrink wrapping markets are being taken over by stretch wrapping. Pallet wrapping is one market where there has been appreciable movement from shrink wrapping and some collation applications are now also using stretch wrapping techniques.

### 20.1.3 PRODUCE PRE-PACKAGING

Low density polyethylene is widely used in the pre-packaging of fresh horticultural produce. A tough film is required for heavy items, such as potatoes, while its use for green vegetables such as lettuces, brussels sprouts, etc., is due more to its moisture vapour barrier properties and its low cost. There are complications in the packaging of fresh produce, however. Respiration of the produce continues, after harvesting, so that the package must allow ingress of oxygen and egress of carbon dioxide. Although low density polyethylene is not a particularly good barrier to gases, its permeability is not great enough to allow the free transfer of oxygen and carbon dioxide required. In practice, a few small holes are punched in the film. These are sufficient to prevent a build-up of carbon dioxide in the bag but do not appreciably affect the total water vapour barrier properties and drying out of the produce does not occur. The ventilation holes often have another function which is to prevent condensation of moisture on the inside of the bag, with consequent loss of visibility of the contents.

In some instances the packaging of fresh produce has become more sophisticated—see section 16.5.1 on modified atmosphere packaging—and the question of film choice is more complex.



### 20.1.4 TEXTILE PACKAGING

Low density polyethylene has long been used for the packaging of textiles and similar items. In the case of woollen items, particularly, the soft feel of the film is an advantage inasmuch as the texture of the product can be felt by the prospective purchaser without opening the bag. High clarity grades are required, and the fact that the impact strength is lower, does not matter in this type of application. In some cases there has been a changeover to cast polypropylene film because of its better clarity and sparkle and it is likely that the tubular quench grades of polypropylene film, being cheaper than cast polypropylene in most cases, will accelerate the trend towards polypropylene. For larger items, such as blankets or bolts of cloth, it is likely that low density polyethylene will remain the preferred material.

Allied to textile packaging is the use of low density polyethylene film in laundering and dry cleaning. With dry cleaning, very thin film is used to protect the cleaned garment from dust pick-up and handling, and special equipment is used to dispense the film and place it round the garment while it is on a hanger.

### 20.1.5 FROZEN FOODS PACKAGING

The toughness of low density polyethylene at low temperatures and the fact that it can be formed into bags on a form/fill/seal basis has

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led to its use in frozen food packaging. The first use was for the packaging of frozen peas and was dependent on the development of individually frozen peas. Frozen peas were originally packed in cartons, the carton being filled and then frozen between plates. The peas were then received by the housewife as a solid block. In the case of the form/fill/seal bags, the peas are frozen in a blast of air and remain loose enough to be filled into a polyethylene bag formed from flat film round the filling mandrel. This type of packaging is cheaper than the carton and is preferred by the housewife because it is easier to use a portion of the peas and return the rest to the deep freeze.

The use of polyethylene film has spread to frozen soft fruits, brussels sprouts and other items able to be handled by this type of filling operation.

### 20.1.6 GENERAL FOOD PACKAGING

The general inertness of low density polyethylene film has naturally led to a widespread use in food packaging. A large tonnage of film is used for made-up bags sold direct to the housewife for use in the home, usually for the storage of food in the refrigerator.

Another market is for the packaging of sliced bread. Penetration of this market by low density polyethylene film was extremely slow, partly because of the low cost of the normal material—waxed paper—and partly because of the difficulty of handling a limp, totally fusible film as opposed to the stiffer waxed paper in which only the wax melted on heat sealing, the paper remaining as a rigid substrate throughout the operation. The penetration of low density polyethylene film into this field did not really begin until equipment was developed for packaging sliced loaves into ready-made-up bags. These were closed with a wire tie, thus overcoming the problems of heat sealing. The bags could be attractively printed, without register problems, while another plus point from the housewife's point of view was that re-closure was easily accomplished.

Interestingly enough, there is now a move back to waxed paper in some instances because many consumers look upon waxed paper as the traditional material for sliced bread. The return to this wrapping material would appear to be part of a general wave of nostalgia.

Low density polyethylene is also being used for the wrapping of sandwiches for retail sale and for a wide range of groceries, including sugar.



### 20.1.7 MISCELLANEOUS NON-FOODS

Low density polyethylene bags of various shapes and sizes are used for an incredibly wide range of goods, ranging from paper goods to hardware, from toys to domestic appliances and from records (the inner bag) to boots and shoes and leather goods generally. In thicker gauges, the film is used for making drum liners for a number of liquid and solid chemicals and as protective wraps inside wooden crates for heavy engineering equipment.

## 20.2 HIGH DENSITY POLYETHYLENE

One of the fastest growing outlets for high density polyethylene film in packaging is dealt with in Chapter 23 under the heading of 'Plastics Papers'. This is the use of high density polyethylene ultra-thin film for the wrapping of meat, fish, meat pies, cut flowers, etc., and as retail bags for supermarkets and chain stores as a replacement for the traditional paper bag. The advantages include much better barrier properties (particularly to moisture and greases), strength and lightness in weight.

One of the properties in which the high density polyethylene is superior to low density polyethylene is the softening point, which is above the boiling point of water. This makes it suitable for boil-in-the-bag foods and high density polyethylene has been used particularly for fish fillets, such as kippers and haddocks. The general advantages of boil-in-the-bag foods is that they are easy to prepare, eliminate washing up of messy saucepans and prevent cooking smells. The latter is particularly valid in the case of kipper and haddock fillets.

## 20.3 POLYPROPYLENE

Cast PP films (and blown non-oriented films) find their main outlets in various areas of textile packaging (including hosiery, shirts, sheets and blankets). Their use here is largely dependent on their superior clarity *vis-à-vis* LDPE, together with excellent sealing characteristics on side-weld overwrapping machinery. The use of non-oriented PP film for medical packaging is also growing, largely due to the use of medical disposables. Its relatively high temperature resistance allows its use in autoclaves where temperatures of 121–135°C are common.

These outlets are relatively small, however, and the large volume outlets require the superior properties of oriented polypropylene

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# 22
# Building and Construction

The building and construction industry is a very important one for plastics in general and accounts for about 25% of plastics consumption in the U.K. The film portion of this is relatively small in tonnage (though not insignificant) but is, nevertheless, interesting.

One of the most important roles played by the plastics films used in building is that of a moisture or moisture vapour barrier. Thus, polyethylene film is extensively used as a lightweight tarpaulin for covering up materials and equipment on site. Apart from being cheaper than the normal tarpaulin, polyethylene is much more easily handled due to its lightness in weight, although one might have reservations about this in a high wind! This lightness in weight also means that the polyethylene film has to be firmly anchored when in use. There is one further advantage in the use of polyethylene and that is its transparency which enables stored goods to be identified without removal of the covering.

Even more important is the use of low density polyethylene film as a weatherproof covering for building in progress. This can range from a simple covering at unfinished windows for buildings which are otherwise almost complete, to 'tents' covering the whole building. Such protection enables building to be carried on under conditions which normally bring it to an expensive standstill. The particular advantage of a plastics film such as polyethylene in this application is again the transparency which means that shelter from the rain, etc., is supplied without blocking out the daylight. The film may be attached to scaffolding or may be made up on a light framework.





Whichever method is used, the effect of strong winds must be taken into account.

The above uses, important though they are, do not count as part of the building's construction. Polyethylene and PVC films are used in such integral applications, however, the most usual being the damp-proof course on which are laid traditional brick walls. The function of the damp-proof course is to prevent moisture from the ground making its way through the foundation of the building and up the walls. Bitumenised felt was formerly used but low density polyethylene or PVC films are both cheaper and easier to use. Wall top membranes may also be made from the same film materials, while a similar use, where the plastics film's moisture barrier properties are utilised, is in window flashings.

An extension of the idea of covering an uncompleted building with a film structure on scaffolding or some other frame structure is the use of inflated structures. These were developed initially for military shelters which were only required as temporary shelters but because of this they had to be light in weight and portable so that they could be taken down and re-erected elsewhere. From these simple beginnings, large and complex prefabricated inflatable buildings have been developed with air lock access. The materials are usually laminates, of films such as polyester and PVC, in order to give the required strength. These structures are kept rigid by continuously running low pressure compressors. They are useful as warehouses, construction shelters, exhibition shelters and as swimming pool or tennis court enclosures. The selection of the right material for a particular type of shelter will depend on the climatic conditions to which it will be exposed, the rigidity required, allowable cost of the structure and the size. Other problems include the aerodynamics of the structure, and a compromise will probably have to be made between internal space requirements and the shape best fitted for aerodynamic stability. The problem of snow loading is a factor in some climates while other factors to be considered are anchorage requirements, any special requirements for doors, heating and ventilation equipment and detailed design as it relates to the distribution of load.

A more permanent variation on the theme of inflatable shelters has also been developed, initially as a combat shelter. Essentially it is a shelter which is carried in a type of rucksack until a suitable foundation is found. The shelter is then inflated and later sets hard by a chemical reaction. It consists of polyurethane between two layers of low density polyethylene film. The polyurethane foams when the structure is inflated to shape, then hardens and sets so fixing the shape permanently. This type of building, or something

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very like it, will most likely be used in the initial exploration of the planets. Light weight is essential, of course, while the other advantage is the fact that the shelters take up little space until they are inflated ready for use. The polyurethane used to set the structure into its permanent shape also offers the very important bonus of heat insulation so that the structures are almost ideal for the purpose. These film and polyurethane inflatable structures might also have a future use, much closer to home, as shelters for disaster areas such as those hit by tornadoes or earthquakes. Hundreds of these could be flown to the spot and erected in a very short time because of their light weight and low space requirements.

A different application of plastics films in the construction industry (though one which again depends on their moisture vapour barrier properties) is in the shuttering of concrete. Concrete is improved both in strength and in its surface qualities by the use of curing membranes and mould linings to back whatever shuttering is used. The even moisture retention given by such membranes, normally made from either PVC or low density polyethylene films, prevents surface flaking of the concrete forms.

A similar philosophy underlies the use of low density polyethylene film as an aid to the curing of concrete. Low density polyethylene film is placed over the concrete, soon after pouring, to control loss of moisture and retain the heat of hydration. The curing of the concrete is thus more even and more easily controlled, giving a stronger and more uniform structure. The technique is not usually applied to the curing of concrete roads in the U.K. since a brush-marked surface is required by the Ministry of Transport to reduce skidding. If the film is put on early enough to control curing it will also smooth away the fine brush marks. Low density polyethylene film is used in concrete road construction in other ways including use as a slip layer and for sealing the formation of the road. The formation is the base down to which the overlying material is excavated and it is sealed in order to prevent seepage of water into, or loss of moisture from it, between the time it is uncovered and the time the sub-base is laid. The sub-base usually consists of crushed stones or cement-treated gravel. Sealing was previously carried out with bituminous products but 125 μm polyethylene film is just as efficient and is lower in total cost. The polyethylene slip layer is used to provide a break between the poured sub-base and the main concrete surface to prevent the two layers keying into each other. This allows slight relative movement between the concrete surface and the sub-base with temperature changes or earth movements, etc., and thereby reduces internal stresses in the construction and, consequently, the tendency to crack formation. It does not matter



that the film slip layer may become punctured locally or lacerated by relative movements because it will already have served its purpose of preventing keying of the two layers. The film may be a simple layer of 125 μm thickness or may be two layers of 62 μm thick film, with or without a slip agent such as molybdenum sulphide, between them.

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Synthetic printing papers as a whole are still dearer than the traditional ones by a factor of around 2–3, but their superior properties often make their use economic. Engineering data sheets, for instance, can often justify the extra cost by virtue of longer life and being able to dispense with a protective folder. Where data sheets are kept in a loose-leaf binder, there is very much less chance of their being lost because of tearing at the punched holes. Finally, costs are often less than would be expected because of the possibility of using thinner gauges of film.

Thin PETP (and, to a lesser extent, thin polypropylene) has been successfully used in the manufacture of carbon 'papers' and typewriter ribbons. PETP has the better resiliency (giving good recovery after indentation) and has a very high strength.

# 24

# Film Tapes and Fibres

In Chapter 8 it was mentioned that one of the disadvantages of uniaxially stretched films was the fact that they tended to fibrillate and this militated against their use as film for packaging (or, for that matter, for building and horticultural uses). There is one vast field based on uniaxially stretched polyolefin films, however, and that is the film tape and fibre field.

Before studying this field of application in any detail, it will be helpful to define some of the terms used so that they may be referred to again without further explanation.

## Film tape

Water bath or chill roll cast, or blown film that is split into narrow tapes (usually 2 or 3.5 mm wide and 50 μm or 28 μm thick, respectively) and stretched under heat. Stretch rates are of the order of 7:1. Stretched film tape or film yarn are equivalent terms.

## Twisted film fibres

Water bath or chill roll cast or blown film that is split into wider tapes than the film tapes and again stretched under heat. Additionally, the tapes are then split by mechanical means into a coarse, fibre-like form. Stretch ratios are somewhat higher, being of the order of 10:1. Fibrillated film is an equivalent term.



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### Fine denier fibres

These result when the above process is taken still further, until a fine, soft, wool-like mass of fibres is obtained. Super fibrillated film is an equivalent term.

### Denier

This is the weight, in grammes, of 9000 m of the fibre in the form of a continuous filament. The SI unit is the tex, which is the weight in grammes of 1000 m of the fibre.

### Tenacity

This is a measure of tensile strength and is measured in mN/tex.

## 24.1 POLYMER CHOICE

Nylon and polyester fibres are normally too expensive for the types of market open to film fibres and tapes while another disadvantage in the case of film fibres is their reduced tendency to split, as compared with polypropylene and high density polyethylene. The choice between polypropylene and high density polyethylene is dependent on a number of factors. Polypropylene has a processing advantage because its tenacity is only slightly dependent on the melt flow index of the polymer so that relatively high melt flow grades may be used without appreciable loss of tenacity. High speed extrusion of the film is thus possible. Polypropylene stretched tapes also have a higher tenacity than those made from high density polyethylene even when low melt flow grades of the latter are used. The coefficient of friction of high density polyethylene is lower than that of polypropylene, too, and this can cause winding problems as well as stacking problems when the tapes are woven into sacks. In countries where high density polyethylene is used, it is usually its lower price that makes it attractive. Coextruded multilayer films are being investigated for some specific markets. One of these is for textured carpet yarns because of the latent self-crimping characteristics of the multilayer fibrillated yarns.

In the specific case of ropes, some interesting figures are given in *Table 24.1*. These show that polypropylene has only a marginally lower performance than nylon. However, nylon is distinctly more



expensive than polypropylene, especially on a cost/volume basis. The cost differential between polypropylene and high density polyethylene is not very high and in any case the monofilament

**Table 24.1** SOME PHYSICAL PROPERTIES OF ROPES

| Material | *Rope diameter* 8 mm Weight (kg/100 m) | Breaking load (kg) | Breaking length* (m) | Ratio of breaking length to manilla |
|---|---|---|---|---|
| Nylon (monofilament) | 4.2 | 1350 | 32 000 | 3.2 |
| Polypropylene | 3.0 | 960 | 32 000 | 3.2 |
| Polyethylene (monofilament) | 3.15 | 700 | 22 000 | 2.2 |
| Manilla | 5.4 | 540 | 10 000 | 1.0 |
| Sisal | 5.4 | 490 | 9 000 | 0.9 |

*Breaking load divided by weight per metre.

extrusion method is more expensive than the stretched tape method. The real difference in cost, then, is even smaller and is insufficient to compensate for the poorer performance figures of high density polyethylene. As mentioned earlier polypropylene has advantages in processing speeds and strength when both polypropylene and high density polyethylene are converted by the stretched tape method. Polypropylene also fibrillates readily on twisting whereas high density polyethylene does not.

## 24.2 PROCESS AND EQUIPMENT

The process for producing stretched film tape consists of the following stages:

(1) Production of the film.
(2) Slitting of the film to tapes of predetermined widths.
(3) Heating and orientation of the tapes.
(4) Winding of the stretched tapes on to a suitable spool.

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The preferred process is continuous but it may be separated into two stages whereby the film is wound onto a roll after extrusion. The roll is subsequently unwound, slit, stretched and wound onto spools. The biggest advantage of the two stage process is that the ultimate line speed is not governed by the extruder speed so that both extruder and stretcher can be run at optimum speeds. A wide range of equipment is commercially available for each of the above steps but the make-up of an optimum complete line will depend on a number of factors including size of plant, equipment available, cost of equipment, previous technology and the precise products to be produced.

### 24.2.1 FILM EXTRUSION

All three techniques mentioned in Chapter 8, namely, slit die extrusion with chill roll casting, slit die extrusion with water bath quenching and blow extrusion are suitable for the production of the basic film. There are, however, advantages and disadvantages attached to each one of these techniques.

Slit die film systems are generally reckoned to give higher line speeds since the film can be more efficiently cooled. Closer gauge control is also possible. Disadvantages include a greater amount of scrap due to the edge thickening which occurs in flat film extrusion. This is not, however, a factor when the film tapes are to be used for the manufacture of ropes since the thicker tapes can be used as part of the rope's central core. Of the two slit die methods, chill roll casting has the tighter control of film thickness but differential cooling of the two sides of the film makes it a less efficient process for thick film extrusion. Disadvantages of the water bath quenching method include a higher variation in thickness than in the chill roll casting method and the carry-over of water. Devices for the removal of excess water have, therefore, to be included. Possible methods include the incorporation of vacuum/heat dryers in the line.

Blown film equipment is cheaper than that for slit die extrusion. An important characteristic of blown polypropylene film is that some lateral orientation occurs during the blowing process. As this is never completely eliminated during the subsequent longitudinal orientation the final film tapes have a reduced tendency towards self-splitting. The strength is also reduced somewhat and the film has a softer feel than cast film. The softer feel is desirable in tapes for weaving and fibrillation, and especially for fabrics from fibrillated film because of the enhanced consumer appeal. The reduced self-splitting characteristics are also desirable, both for weaving (which is natural)



and for fibrillation because reduced splittability leads to a more controlled splitting, at least when a pin roller unit is used (see later section on fibrillation) and less post-fibrillation.

### 24.2.2 FILM SLITTING

The film is slit into tape of sufficient widths so that the stretched and oriented tapes will be of the required denier. Slitting is usually carried out using a slitter bar containing razor-like blades. During slitting the film should be under controlled tension for accurate cutting and this is best achieved by siting the slitter bar close to a roll or drag bar.

### 24.2.3 HEATING AND ORIENTATION

After slitting, the tapes are led into a pull-roll stand (or godet unit). This may consist of 3, 5 or 7 power driven rolls together with a nip roll, covered with neoprene or urethane rubber to prevent slippage. From the godet unit the tapes enter an oven, usually about 3–4 m (9.8–13.1 ft) long, fitted with accurate control of temperature and with special regard to uniformity of heating. Circulating hot air ovens are the most usual but infra-red heaters are also used and hot-plates (heating by contact) have been developed. At the other end of the heating unit is a second godet unit operating at a higher speed than the first. The ratio of the speeds of the first and second godet units is the draw ratio (7:1 for weaving tapes and 10:1 for tapes for fibrillating). Where tapes are to be used for woven carpet backing there may be sufficient heat generated, during the weaving process, to cause tape shrinkage unless the tapes are previously heat set. This relaxation and heat setting is carried out by running them through a second oven followed by a third godet unit.

Later types of stretching equipment are based on hot roll techniques. Blown or cast film is stretched in its full width on a unit consisting of pre-heated rolls, stretching rolls and annealing rolls. It is then wound up as wide stretched film which can be slit into tapes. Because the stretching is controlled over a very short distance only a slight reduction in film width occurs and thus a larger number of tapes can be produced from a given film width than with conventional methods based on slitting before stretching. Advantages of hot roll stretched polypropylene film include:

(1) High output.

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(2) Low splitting tendency.
(3) High tenacity.

One disadvantage is that output is limited by the high initial film thickness required. This is because the film thickness after stretching is directly proportional to the stretch ratio used. With a typical stretch ratio of 10:1 the initial film thickness would be approximately 400–500 μm and adequate cooling and pre-heating of such films is difficult.

#### 24.2.4 WINDING

The winding of tapes is more difficult than the winding of natural or synthetic monofilaments because of the added complication of possible twisting. This can reduce the tensile strength by 15–20% and must, therefore, be avoided. Another critical factor is tension which must be kept constant. Constant tension winders are available but are expensive. Constant torque winders are cheaper but require manual adjustment by the machine operator as the diameter of the wound bobbin increases.

## 24.3 FIBRILLATION

The film tape, manufactured as outlined earlier, can be fibrillated by mechanical splitting in a controlled manner to give a range of fine denier fibres. The three basic systems for fibrillating are:

(1) Pin-roller system.
(2) Castellated die system.
(3) Embossed roller system.

#### 24.3.1 PIN-ROLLER SYSTEM

The equipment consists of a roller which revolves at a peripheral speed higher than the linear speed of the film and which can incorporate up to approximately 30 000 needles in a series of bars; an assembly of rollers for adjusting the contact area of the tapes; and draw off rollers for adjusting the tension. As they revolve the needles split the tapes, forming a regular or irregular network pattern. The size of this network can be adjusted by altering the roller speed and the contact arc.



#### 24.3.2 CASTELLATED DIE SYSTEM

In this system the usual flat die is replaced with three flat dies each having 35 profiled, castellated slots through which a total of 105 tapes are extruded. The profiles of each slot produce 25 ribs in each tape. Stretching of these ribbed tapes shears them into 25 single strand fibres.

#### 24.3.3 EMBOSSED ROLLER SYSTEM

Film, either above or below its crystalline melting point, is brought into contact with profiled rolls. The pattern is then embossed under slight pressure onto the film. Subsequent stretching of the film produces separated, continuous filaments corresponding to the particular profile used. The method is said to offer to the end user close control over properties.

## 24.4 SACK MANUFACTURE

Polypropylene tapes can be woven more readily on most looms than natural fibres, such as jute, because the polypropylene tapes are smooth and so do not snag. Circular weaving, flat weaving, or knitting techniques can all be used with polypropylene tapes. On flat looms speeds of around 20 sacks/h are possible, which is equivalent to the rate achieved for jute sacks. If circular looms are used, however, the rate for polypropylene film tape sacks is claimed to be well over 60 sacks/h. One criticism of circularly woven polypropylene sacks, however, is that they are difficult to stack. This arises from the 'pillow' shape which such a sack tends to assume when it is well filled and it is thus advisable not to overfill.

Closing of woven sacks can be achieved by heat sealing although there are difficulties. It is more usual to close the sacks by conventional techniques such as stitching. This has the advantage that the user does not have to invest in new equipment.

#### 24.4.1 ADVANTAGES OF POLYPROPYLENE SACKS

Woven polypropylene sacks can compete in price with jute sacks but, more important still, is the question of price stability. Because of annual fluctuations in the jute crop there are corresponding fluctuations in price and these can be appreciable. The price of polypropylene

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is, by comparison, extremely stable and it is possible to plan ahead with more certainty.

Woven polypropylene sacks are appreciably lighter than jute sacks. A jute sack weighing 1 kg (2.2 lb), for instance could be replaced by a polypropylene one weighing only about 0.2 kg (0.44 lb). The greatest benefit here lies in reduced freight charges for empty sacks. The light weight is not an unmixed blessing, however, for some products, such as animal feeding stuffs, are sold on gross weight (i.e. including sack weight). Because the polypropylene sack is lighter the gross weight has to be made up by an increase in weight of the product.

An important advantage of the polypropylene sack is its resistance to rotting in damp conditions. This is particularly important in tropical areas where rotting of jute sacks can occur in a matter of weeks. Polypropylene sacks are also resistant to insects and although jute sacks can be treated to improve their water repellency and insect resistance, this adds to their cost. Polypropylene sacks can be made to withstand prolonged exposure to sunlight by the incorporation of ultra-violet stabilisers in polypropylene during the extrusion process. Some idea of the outdoor performance of the two types of sacks can be gained from the fact that a natural fibre yarn exposed to high ultra-violet light conditions loses 80% of its tenacity in two to three months, whereas an ultra-violet stabilised polypropylene stretched tape (either pigmented or unpigmented) loses only 50% of its tenacity in a period of three to four months. Polypropylene sacks are also superior to jute sacks in their resistance to chemical attack.

Polypropylene sacks are better able to retain dusty products, possibly because jute yarns are round or oval in section and this allows fine particles to escape between the yarn interstices. In the case of flat tapes, such as polypropylene film tapes, the load of the sack contents locks the intersecting tapes and appreciably reduces the escape of fine particles.

Polypropylene sacks are tougher and more resistant to breakage by impact. Jute sacks containing 91 kg (200 lb) of product have been tested to withstand about 7 drops before bursting occurred. Polypropylene sacks, containing the same weight of product, withstood 15–16 exactly similar drops before bursting.

The coefficient of friction of jute is higher than that of polypropylene but the incorporation of anti-slip compounds and variations in the sack weave can largely overcome this problem and the stacking characteristics for polypropylene sacks can be entirely satisfactory.

Polypropylene does not impart any odour or flavour to food products while another advantage in the field of food packaging is



the absence of contamination via loose fibres. Another product where contamination by jute fibres is a serious problem is wool. The packaging of bales of wool in Australia is already largely in polypropylene and high density polyethylene and results have been very satisfactory.

The general appearance of polypropylene sacks is very attractive. Four colour printing is already in commercial use and, in addition, the tapes themselves can be manufactured in almost any colour.

## 24.5 APPLICATIONS

The use of polypropylene fabrics for the packaging of bales of wool has already been mentioned. Uses for sacks include the packaging of potatoes and other horticultural produce, grain and animal feeding stuffs. In the case of grain, the ventilation is important since condensation inside the sack would lead to fermentation of the grain. In addition, a woven sack is necessary because of the practice of sampling through the sack without opening it. This obviously has to be done without damage to the sack. Additional applications in tropical countries include the packaging of coffee and sugar, while possibilities exist in the packaging of fish, cotton and groundnuts. In general, woven polypropylene sacks will find applications where the advantages of plastics are required but where a normal film sack is unacceptable for reasons of ventilation, sampling, etc. Much of the impetus for the growth of polypropylene sack manufacture in the U.S.A. was supplied by the use of polypropylene for military sandbags in the jungles of Vietnam. The main factor here, of course, was the resistance of such sacks to the hot and humid conditions so damaging to jute sacks. Insufficient ultra-violet stability in the original polypropylene sacks was later overcome with more efficient ultra-violet stabilisers.

The potential markets for sacks are already vast and are growing rapidly. Both the U.S.A. and the U.S.S.R., for instance, use about 400 million sacks/year. South and East Africa require about 145 million/year; the U.K. 65 million; Germany 45 million; and Italy 20 million.

Because of the trends towards bulk delivery, the demand for sacks may be static or even decreasing slightly in countries such as the U.K. but in the developing countries the demand is increasing due to new and expensive agricultural products needing efficient protection and the long-term prospects for plastic woven sacks looks very bright indeed.

If an impermeable sack is required it is possible to laminate woven polypropylene fabric to low density polyethylene film. By varying the thickness of the film and the type of weave used in the polypropylene

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fabric, a wide range of sacks can be produced. At one end of the scale one can produce a closely woven sack with just enough low density polyethylene for waterproofness, while at the other end we can get what is essentially a film sack supported by an open weave polypropylene fabric.

Woven stretched products also include decorative fabrics, carpet backing and industrial fabrics such as filtercloths, belts and tarpaulins.

For example, woven polypropylene tape fabrics are successfully established for the primary backings of tufted carpets since they overcome the technical and economic disadvantages of natural fibre backings. The latter are not rotproof, have a low dimensional stability and tend to break or deflect the tufting needles, particularly during high speed, fine-gauge tufting. Woven polypropylene fabrics are much lighter, are rotproof and moisture proof and give a higher pile than can be obtained with jute backings.

Tufted carpet backing is a large market for woven film tapes. A high degree of penetration has already been achieved in the American and European tufted carpet industries and a similar backing is being used for needle punched 'indoor–outdoor' carpeting where the carpet pile is itself made from polypropylene. The polypropylene tapes are fibrillated and chopped into staple lengths for this application. Fibrillated stretched tape is also being used as face yarn for tufted carpets. The potential market for polypropylene carpet backing in the U.K. can be judged from the fact that during the three years 1964–1966, an average of over 100 000 tonnes/annum of jute yarn and jute fabric went into floor covering of one sort or another. Although polypropylene woven fabrics are lighter in weight than jute, the total is still appreciable.

Film fibres (fibrillated film) can be considered as a replacement for sisal. The main areas for takeover are agricultural baler twine, packaging twine and ropes. Baler twine is a large potential outlet for film fibres and has already been penetrated to some extent. The use of polypropylene baler twine has the advantage of giving a rotproof twine as well as being waterproof and not harmful to the digestive systems of farm animals. Polypropylene has a breaking load that is slightly lower than that of sisal but has a much greater strength to weight ratio. The addition of ultra-violet stabilisers to the polypropylene gives a twine with a longer life than sisal twine. Polypropylene twine has a knot strength comparable to that of sisal and can be used on normal twine dispensing equipment with a minimum of modification. The polypropylene twine can, of course, be self-coloured and this opens up several possibilities for the use of twine for identification purposes. The arguments concerning price



stability and continuity of supply also apply in the case of twine.

Agricultural baler twine is a price sensitive commodity and is not so much sold on technical reasons as is packaging twine. In the latter case, superior performance can usually command a price premium and it is for this reason that film fibres have penetrated the packaging twine market to a greater extent than the baler twine one.

The other large market for film fibres is rope. The natural fibres normally used for ropes are sisal and manilla hemp. Manilla hemp is the strongest of all vegetable fibres and thus is used for the manufacture of heavy rope and cordage for marine, industrial and farm use. It is still not as strong as polypropylene, however, as can be seen from *Table 24.1*. Polypropylene film fibre ropes are lighter in weight than manilla hemp or sisal ones and will float on water because the specific gravity of polypropylene is less than one. In addition, they are not subject to moisture pick-up with consequent increase in weight. These points are particularly important in the case of marine ropes.

The newest developments lie mainly in the field of fine fibres or super fibrillated film. Polypropylene fine fibres are very soft, very light in weight and very strong, with excellent abrasion resistance. Outlets include knitting or sewing threads, while in staple form they can be used as reinforcement in non-woven disposables.

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to friction between the stems causing blackening and scarring. The low frictional properties of the polyethylene film reduce the damage to a minimum.

An interesting method of seed conservation also depends on the use of a plastics film. A special fitment to the tractor during harvesting, lays the film on the ground alongside the tractor and the cut crop is turned over on to the film. Advantages are that the crop dries out quickly and moisture from the soil is prevented from rising to the crop. When drying is complete the crop is picked up with the film so that no seed is lost.

## 21.4 WATER CONSERVATION

Plastics films provide a cheap method of conserving water supplies. One widespread use is the making of temporary reservoirs, using black plastics film of about 250 $\mu$m thickness as a lining on the soil surface of suitable excavations. After bulldozing the soil to a suitable depth the film is laid, preferably on a sand layer in case the soil contains stones liable to puncture the film. Enough film is laid to extend over the sides of the reservoir so that weeds are prevented from growing at the water's edge. The cost of such a reservoir is very much less than that of a cement lined one, the cost ratio is roughly in a ratio of one cement to ten film, based on a capacity of around 65 000 l (14 300 gallons). Large capacities are possible and in Canada two lagoons have been constructed with capacities of 27 million litres (6 million gallons) each. The question of seepage has been investigated and in the U.S.A. it has been shown that even film of only 150 $\mu$m thickness gives complete protection against seepage for over five years.

An even more striking use of polyethylene film in water conservation has been developed in the Sahara where the land is first excavated, then lined with film. Before the earth is replaced, perforated plastic pipes are placed near the base of the excavation. When the soil is replaced and plants have been placed in position, water is pumped through the perforated pipes at low pressure. The roots of the plants are attracted downward to the water and it has been shown that less water is required for plant growth using this method than if conventional irrigation methods were used.

## 21.5 REARING OF LIVESTOCK

A sheep house has been constructed from 250 $\mu$m polyethylene film



sandwiched between two layers of nylon netting, spread over tubular steel arches. The sheep house is in Wales and is situated on an exposed hillside. The structure houses 150 sheep and cost only one eighth of the cost of a permanent sheep house.

A minor but interesting use of plastics film is in an automatic battery chicken system where the conveyor belts for transporting food and removing eggs and hen droppings are made from polyethylene terephthalate film. Another aid to animal husbandry is the use in Australia of polyethylene film coats which are fitted to newly sheared sheep to cut down deaths from cold.

## 21.6 BUILDINGS

Some uses for buildings have already been mentioned under the headings of 'Rearing of Livestock' and 'Growing' but there are also some other, more general, ones. Polyethylene film, for instance, with polypropylene or nylon netting support has been used in temporary roofing and walling for a number of farm buildings. Temporary shelters have also been constructed with the same material.

## 21.7 FUTURE GROWTH

In the U.K., penetration by plastics films of the agricultural and horticultural market is still fairly low and a fair amount of future growth can be expected. The area of forced growing may not expand as quickly as some other areas because the climatic conditions of moderate temperatures, low light and high wind are more conducive to the use of permanent greenhouses. On the other hand, film for silage protection is likely to grow reasonably steadily because of the necessity for protection from our high rainfall. Water conservation uses, too, are more likely to grow in other parts of the world with a lower and more irregular rainfall.

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The amount of energy needed to produce a kilogram of food varies widely from the 15.8 MJ necessary for bread to over 200 MJ for prepared meals such as canned and heated meals or freeze dried or reconstituted ones. In many cases, therefore, it is possible to justify the use of packaging on an energy saving basis alone, that is, those cases where the energy equivalent of the expected loss of product during the normal chain of distribution is above the energy expended in making the pack. In the case of sugar, a 5% loss of product would mean a loss of expended energy of about 1 MJ or a total energy loss of 1·75 MJ. Losses of this magnitude would not be unusual in the absence of packaging and would more than repay the packaging energy outlay of 0.9 MJ. Similar considerations applied to beef show a total energy loss of 5% of 68.8 MJ which equals 3.5 MJ against a packaging energy outlay of only 1.4 MJ. Prepared meals would be likely to suffer even greater product losses, if indeed they could be delivered without packaging. In any case the energy losses would be very high.

These arguments show that the energy equation, as far as packaging is concerned, is not a simple one, but it would seem that in most instances packaging can be justified. Of course, savings in the usage of energy must be made and the packaging industry has already made a great deal of progress in the savings of materials by 'light-weighting' and other means. Other energy savings are still possible in terms of the more efficient use of energy in the manufacturing and conversion processes. However, bearing in mind the fact that the total energy bill ascribable to all packaging is of the order of 4–5% of the national total, it would seem that the biggest possibilities for energy saving lie in other fields.

## FURTHER READING


BOUSTEAD, I., and HANCOCK, G. F., *Energy and Packaging*, Halstead Press (a division of John Wiley and Sons Inc.), New York (1981)

CADMAN, M. H., Energy—A World Perspective, 'Full Circle', Institute of Packaging Seminar held on 7–9 October 1980 in Norwich, England, Paper no. 1

SMITH, D. J., Energy—Policy, Politics and Packaging Development, Idem, Paper no. 2


# Appendix A

## Properties of Plastics Films

| Material / Property | Low density polyethylene | High density polyethylene | Cast polypropylene | Oriented polypropylene | Rigid PVC | Plasticised PVC | PVDC | Oriented polystyrene | Regenerated cellulose (MS Grade) | Cellulose acetate | Nylon 11 | EVA | Ionomer | Polycarbonate | Polyester |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Yield ($m^2$/kg) (for 25 μm film) | 42.6 | 41.2 | 44.0 | 44.0 | 28.4 | 27.0 –30.5 | 23.4 | 36.9 | 27.4 | 29.8 | 38.3 | 41.9 | 41.7 –42.1 | 32.3 | 28.4 |
| Tensile strength (MN/$m^2$) | 8.6–17.3 | 17.3 –34.6 | 41.5 | 165 –170 | 45.0 –55.3 | 27.6 –34.5 | 48.4 –138 | 62.2 –82.7 | 48.4 –110 | 48.5 –82.7 | 69.0 –96.8 | 13.8 | 17.3 –24.2 | 58.8 | 175 |
| Elongation at break (%) | 500 | 300 | 300 | 50–75 | 120 | 14–200 | 20–40 | 20 | 15–25 | 15–45 | 250 –400 | 650 –800 | 300 –400 | 75 | 70–100 |
| Tear strength (Elmendorf) (g/25 μm) | 200–300 | 20–60 | 50 | 5–10 | — | — | 10–30 | 4–20 | 2–10 | 2–15 | 400 –500 | 50 –100 | 20–80 | 10–16 | 30 |
| Burst strength (Mullen) (kN/$m^2$) (for 25 μm film) | 330 | — | — | — | 205 –275 | — | 205 –485 | — | 138 –155 | 205 –615 | 415 | — | — | 170 –240 | 310 –415 |
| Water vapour transmission (g/$m^2$/day) (for 25 μm film at 90% R.H. and 38°C) | 15–20 | 5 | 10–12 | 7 | 30–40 | 15–40 | 1.5 –5.0 | 70 –150 | 5–15 | 100 –320 | 40 –80 | 50–60 | 25–35 | 77–93 | 25–30 |
| Oxygen permeability ($cm^3$/$m^2$/day/atm) (for 25 μm film) | 6500 – 8500 | 1600 – 2000 | 3700 | 2000 – 2500 | 150 –350 | — | 8–25 | 4500 6000 | 670 (when dry) | 2000 – 3000 | 500 | 11 000 –14 000 | 6000 – 7000 | 4500 | 40–50 |
| Carbon dioxide permeability ($cm^3$/$m^2$/day/atm) (for 25 μm film) | 30 000 –40 000 | 8000 – 10 000 | 10 000 | 7500 – 8500 | 450 – 1000 | — | 50 | 13 000 | 985 (when dry) | 15 500 | 1900 | 40 000 –50 000 | 6000 – 7000 | 27 000 | 300–350 |
| Resistance to oils and greases | Some oils cause swelling | Good | Ex | Ex | Ex | Depends on exact formulation | Ex | V Good | Ex | Ex | Ex | Ex | VGood | Good | Ex |

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# Appendix B

# Identification of Film Materials

The most reliable method of identifying a plastics film is by infra-red spectroscopy but the equipment is expensive and requires skilled operation. There are many simple tests, however, and if they are applied in combination surprisingly good results can be obtained, with experience. If the material to be identified is a laminate then it is necessary to separate it into its component parts before applying any tests.

## B.1 SEPARATION OF LAMINATE PLIES

This is best carried out by refluxing the sample with a suitable solvent. The choice of solvent is dictated by the adhesive used for laminating but if this information is not available the best solvent must be found by experiment.

*Table B.1* shows some of the commonest laminating adhesives together with possible solvents.

## B.2 PHYSICAL PROPERTY TESTS

Films can be separated into two classes on the basis of their extensibility. A sample strip should be taken in the hands and





**Table B.1**

| *Adhesive* | *Solvent(s)* |
|---|---|
| Wax | Acetone, carbon tetrachloride, toluene |
| Starch | Water |
| Casein latex | An emulsion of Duponol (obtainable from DuPont Chem. Company), toluene, ammonia and water |
| Vinyl (PVA, PVAc, etc.) | Acetone, carbon tetrachloride, toluene |
| Low density polyethylene | Toluene (at >60°C) |

stretched gently, but firmly, noting the approximate amount of stretch. Extensible films (classified as those stretching more than 100%) include low density polyethylene, high density polyethylene, polypropylene, stretch PVC, polyvinyl alcohol and rubber hydrochloride. Non-extensible films include cellulose acetate, polyester, regenerated cellulose, nylon, oriented polystyrene and polyvinylidene chloride.

Stiffness is another property which can often give some information as to the material used. Low density polyethylene, polyvinylidene chloride some vinyls and some grades of rubber hydrochloride are limp and soft to the touch and make very little noise when crumpled. Regenerated cellulose, cellulose acetate, nylon, polypropylene, polyester, rigid PVC and some grades of rubber hydrochloride are stiffer, harder to the touch and make more noise when crumpled. Oriented polystyrene is even stiffer and when rattled it has a metallic ring.

Tear strength, or rather, tear propagation resistance, can also yield useful information. The film should be nicked with a knife or razor blade and then torn. Materials with a low tear strength include regenerated cellulose and cellulose acetate while nylon and polyester are slightly higher. Materials with a high resistance to tear propagation include PVC, polyvinylidene chloride, low density polyethylene, and rubber hydrochloride.

## B.3 BURNING TESTS

Two observations may be made with the aid of a flame, namely, whether the film burns after removal of the flame and what kind of odour is given off. *Table B.2* gives the behaviour of some common films when held in a flame for about ten seconds and then withdrawn.

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**Table B.2**

| *Film* | *Continue burning* | *Odour* |
|---|---|---|
| Cellulose acetate | Yes | Acetic acid |
| Cellulose acetate/butyrate | Yes | Acetic acid and rancid butter |
| Nylon | No | Burning hair or feathers |
| Polyethylene | Yes | Burning wax |
| Polypropylene | Yes | Burning wax |
| Polyester | Yes | Sweet, esterlike |
| Polystyrene | Yes (gives sooty specks) | Styrene |
| Polyvinyl chloride | No | Acrid |
| Polyvinylidene chloride | No | Acrid |
| Regenerated cellulose | Yes (does not melt) | Burning paper |
| Rubber hydrochloride | No | Acrid |
| Polycarbonate | No | |

## B.4 DENSITY

Although films do vary in density, there is a good deal of overlap so that this property is of limited use for identification purposes. The only real distinction which can readily be made is between the polyolefin films (polyethylene, polypropylene and poly 4-methyl pentene-1) and the rest. This is because the polyolefins all have densities less than unity and so float on water. Even this test can be misleading if the film sample is creased and so retains small air bubbles. The addition of a small amount of a wetting agent to the water is also essential.

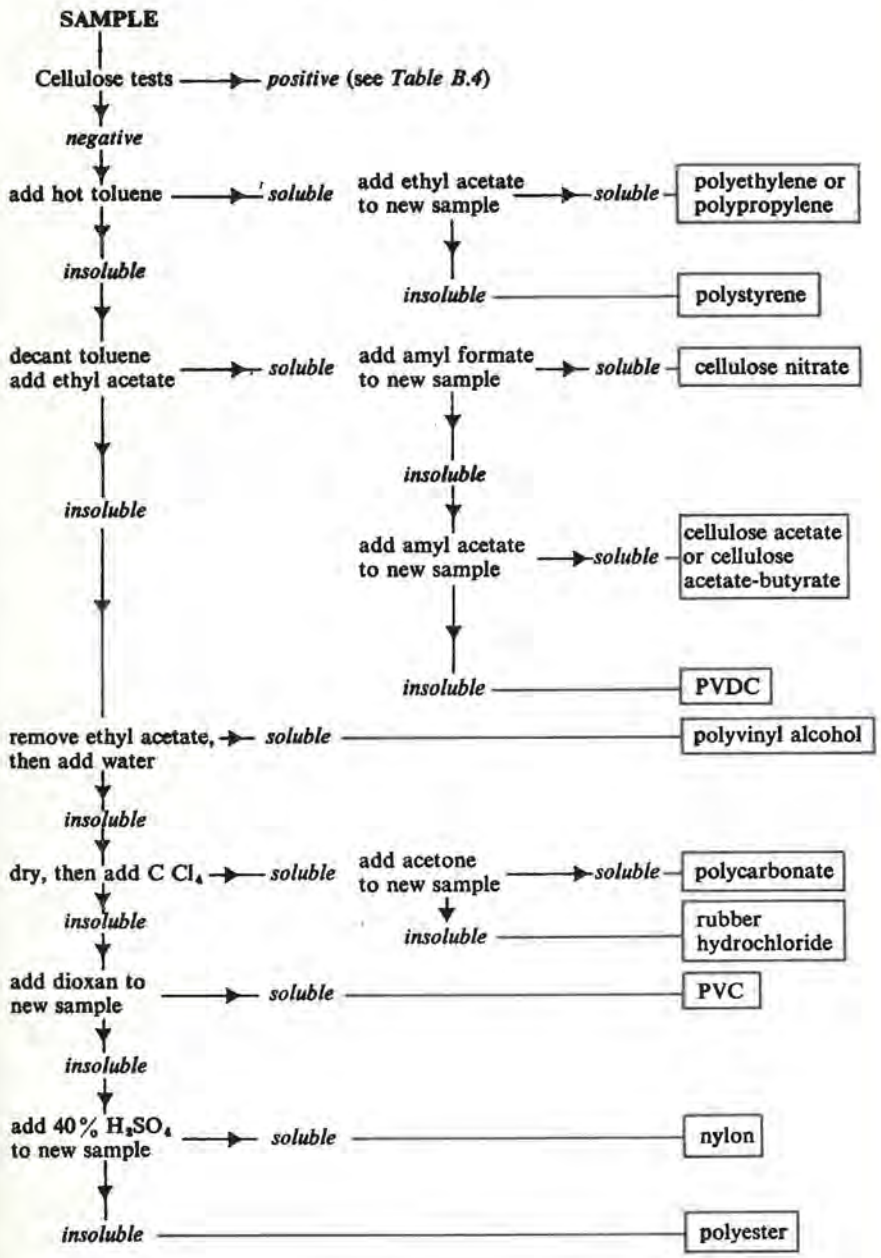
## B.5 CHEMICAL TESTS

### B.5.1 SOLUBILITY

A systematic scheme which makes use of the different solubilities of the common film materials is given in a PIRA Technical Reference Note and is reproduced in *Table B.3* by kind permission of PIRA (The Research Association for the Paper and Board, Printing and Packaging Industries). Before using the table, tests must be made for regenerated cellulose films (coated or plain) and these are then identified by means of *Table B.4*. The tests for regenerated cellulose film are as follows:



**Table B.3**

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(1) Stretch test—not extensible.

(2) Burning test—odour of burning paper.

(3) Tear test—tear strength very low.

(4) Apply hot match head to the film—no hole melted in the material; denotes cellulose.

Other simple chemical tests which may be used are as follows.

### B.5.2 BEILSTEIN TEST FOR HALOGENS

Heat a length of clean copper wire in a non-luminous bunsen flame until the green colour vanishes. Touch the test film with the hot wire and reheat in the bunsen flame. A green colour denotes the presence of halogens. Thus, PVC, polyvinylidene chloride and rubber hydrochloride (containing chlorine) and PTFE or PTCFE (containing fluorine) will all give a positive reaction to the Beilstein test. Some coated cellulose films and coated, oriented polypropylene films may also give a positive reaction because of the presence of polyvinylidene chloride in the coating.

### B.5.3 GRIESS TEST FOR NITROGEN

Heat a sample of the film with manganese dioxide in a combustion tube for three minutes then hold over the tube mouth a piece of filter paper moistened with Griess reagent. A pink or red coloration denotes the presence of nitrogen. Griess reagent is made up as follows: Solution A: 1 g sulphanilic acid is dissolved in 100 $cm^3$ of 30% acetic acid.

Solution B: 0.03 g naphthylamine is boiled in 70 $cm^3$ of water. The colourness supernatant liquor is decanted and mixed with 30 $cm^3$ of glacial acetic acid.

Equal quantities of solutions A and B are mixed as required.

A positive test for nitrogen is given by the polyamides (nylons) and by the nitrocellulose coatings on moisture-proof grades of regenerated cellulose film.

### B.5.4 WECHSLER TEST

This test differentiates between PVC and polyvinylidene chloride which both give positive reactions to the Beilstein test. A mixture



of pyridine and a methanol solution of potassium hydroxide is applied to the film. PVC and vinyl chloride/vinyl acetate copolymers give a pale brown colour while polyvinylidene chloride gives a dark brown to black colour. Rubber hydrochloride does not react at all.

### B.5.5 LIEBERMANN–STORCH–MORAWSKI TEST

This test is a good one for distinguishing between the four films containing chlorine, namely, PVC, vinyl chloride/vinyl acetate, rubber hydrochloride and polyvinylidene chloride (including PVDC coated cellulose films).

A small piece of film is placed on a spot plate and covered with a few drops of acetic anhydride. One drop of concentrated sulphuric acid is added so that it enters the liquid. The colours on the film and in the liquid are observed over a period of half an hour.

PVC gives a blue coloration (slow).
VC/VA copolymers give a slow change from green to blue to brown.
PVDC gives a yellow coloration (slow).
Rubber hydrochloride gives no coloration.

## B.6 INSTRUMENTAL TESTS

Ultra-violet and infra-red spectrophotometry can be used to identify films by comparing the ultra-violet and infra-red absorption spectra of the unknown film with spectra previously obtained on known materials.

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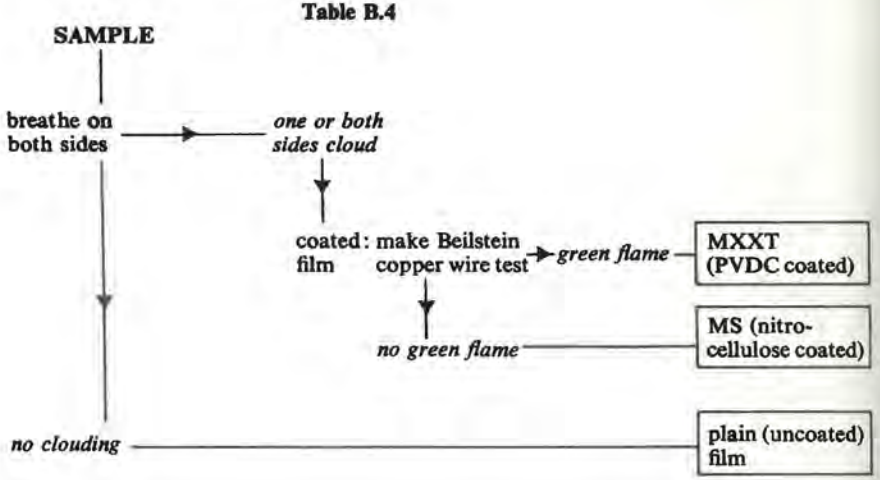
**Table B.4**




# Appendix C
# Trade Names

| *Trade name* | *Type of material* | *Trade name* | *Type of material* |
|---|---|---|---|
| Abselex P | Acrylonitrile butadiene styrene | Britainphane | Cellulose |
| Acelon | Cellulose acetate | Cabulite | Cellulose acetate/ butyrate |
| Acetophane | Cellulose acetate | Capran | Nylon 6 |
| Aerozote | Expanded polyethylene | Cautex | PVC |
| Afubel | Cellulose acetate | Celawrap | Cellulose acetate |
| Alathon | Polyethylene | Cellidor | Cellulose acetate and acetate/ butyrate |
| Alathon/EVA | Ethylene-vinyl acetate co-polymer | Cellit | Cellulose acetate and acetate/ butyrate |
| Alkathene | Polyethylene | | |
| Alloprene | Chlorinated rubber | | |
| Amerplas | Varied thickness polyethylene | Cellolam | Wax laminated cellulose |
| Austrophan | Cellulose | Cellon | Cellulose acetate |
| Azopal | Unplasticised PVC | Cellophane | Cellulose |
| Beneron | Acrylonitrile butadiene styrene | Cellothene | Polyethylene coated cellulose |
| Bepsatene | Polyethylene | Celluloid | Cellulose nitrate |
| Bexfilm | Cellulose acetate and triacetate | Chromalon | Metallised PVC |
| | | Cinabex | Cellulose acetate |
| Bexfoam | Expanded polystyrene | Ciponyl | Polyamide (nylon) |
| | | Cipoviol | Polyvinyl alcohol |
| Bexoid | Cellulose acetate | Clarifoil | Cellulose acetate |
| Bexphane P | Biaxially oriented polypropylene | Clarothene | Ethylene co-polymer |
| Bexphane S | Biaxially oriented polystyrene | Cournova | Polypropylene |
| | | Craylene | Plasticised PVC |
| Bexthene | Polyethylene | Craylon FC | Unplasticised PVC |



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| *Trade name* | *Type of material* |
|---|---|
| Craytherm | Unplasticised PVC |
| Cryovac L | Modified polyethylene |
| Cryovac Y | Biaxially oriented polypropylene |
| Cryovac S | Vinylidene chloride vinyl chloride co-polymer |
| Crystophane | PVC |
| Danathene | Polyethylene |
| Densothene | HD Polyethylene |
| Diolon | Polyamide-poly-olefin laminate |
| Diomex | Polyester-poly-olefin laminate |
| Diophane | Cellulose |
| Dioplex P | Polyethylene-poly-propylene laminate |
| Dioplex PS | PVDC coated polypropylene-polyethylene laminate |
| Diothene | Low density polyethylene |
| Drakatileen | Polyethylene |
| Drakavinyl | PVC |
| Durethan | Nylon 6 |
| Dylan | Polyethylene |
| Embafilm | Cellulose acetate |
| Embafilm B | Cellulose acetate/ butyrate |
| Enkothene | Polyethylene |
| Ethocel | Ethyl cellulose |
| Ethulon | Ethyl cellulose |
| Europhane | Cellulose |
| Fablonex | Polyester-PVC laminate |
| Fablonyl | Polyamide |
| Fablothene | Polyethylene |
| Fertene | LD Polyethylene |
| Filmco | PVC |
| Finoplas | Modified HD Polyethylene |
| Flovic | Vinyl chloride-acetate co-polymer |
| Forticel | Cellulose propionate |
| Fortiflex | HD Polyethylene |
| Franklite | Polyethylene |
| Garmil | Polyethylene |
| Garpac | Polyethylene |
| Genopak | PVC |
| Genotherm | PVC |
| Ger-pak | Polyethylene |
| Guttagena | PVC |
| Hagaten | Polyethylene |
| Hilex | HD Polyethylene |
| Hostaform C | Acetal co-polymer |
| Hostalen G | HD Polyethylene |
| Hostalen PP | Polypropylene |
| Hostaphan | Polyester |
| Hypak R | Polyamide |
| Iolon | Ionomer |
| Kel F | Polytrifluoro-chloroethylene |
| Krehalon | Vinyl chloride-vinylidene chloride co-polymer |
| Lacqtene | Polyethylene |
| Lactophane | Cellulose |
| Laythene | Polyethylene |
| Lexan | Polycarbonate |
| Lumaline | Metallised cellulose acetate |
| Lumarith | Cellulose acetate |
| Luparen | Polypropylene |
| Lupolen | Polyethylene |
| Makrolon | Polycarbonate |
| Meculon | Metallised polyester |
| Melinex | Polyester |
| Metalon | Metallised polyester-PVC laminate |
| Metathene D | Nitrocellulose coated cellulose |
| Metathene X | PVDC coated cellulose |
| Metathene M | Polyester |
| Metathene MX | PVDC coated polyester |
| Metathene P | Oriented polypropylene |
| Metathene PPX | PVDC coated oriented polypropylene |
| Milwrap | Polyethylene |
| Mipolam | Plasticised PVC |
| Mirralon | Metallised cellulose acetate |
| Mirro-brite mylar | Metallised polyester |



| *Trade Name* | *Type of Material* |
|---|---|
| Montothene | Ethylene-vinyl acetate co-polymer |
| Moplefan | Polypropylene |
| Mylar | Polyester |
| Mylothene | Polyester-poly-ethylene laminate |
| Nataraj | PVC |
| Natene | Polyethylene |
| Nichiray | Biaxially oriented polyamide |
| Pentathene | Polyethylene |
| Pevalon | Polyvinyl alcohol |
| Phriphan | Cellulose |
| Phrithen | Polyethylene |
| Plastokarbon | Polycarbonate |
| Plastotene | Polyethylene |
| Plastothen | Polyethylene |
| Plastylene | Polyethylene |
| Platilon C | Nylon 6 |
| Pliofilm | Rubber hydrochloride |
| Polyart | Modified polyethylene |
| Polycell | Polyethylene coated cellulose |
| Polyflex | Biaxially oriented polystyrene |
| Polytherm | Unplasticised PVC |
| Pony | PVC |
| Porvic | Microporous PVC |
| Propafilm C | PVDC coated biaxially oriented polypropylene |
| Propafilm O | Biaxially oriented polypropylene |
| Propathene | Polypropylene |
| Propophane | Polypropylene |
| Propophane EPI | Ethylene-propylene co-polymer |
| Propylex | Polypropylene |
| Prylene | Polypropylene |
| Ralsin | Nylon 11 |
| Rayofilm | Cellulose |
| Rayophane | Cellulose |
| Rayoscine | Cellulose |
| Resinite | PVC |
| Reynolon | PVC |
| Rhodialine | Cellulose acetate |
| Rhodopas | PVC/acetate |
| Rhodophane | Cellulose acetate |
| Rholene | HD polyethylene |
| Rilsan | Nylon 11 |
| Santoforme F | Expanded flexible cellular polystyrene |
| Saran | Vinylidene chloride-vinyl chloride co-polymer |
| Saranex | Polyethylene-PVDC-polyethylene laminate |
| Sarolene H | HD polyethylene |
| Sarolene 63P | Polypropylene |
| Sarovyl | PVC |
| Saroy SP61 | Polystyrene |
| Sicofoil A | Cellulose acetate |
| Sicofoil N | Cellulose nitrate |
| Sidaplax | Biaxially oriented polystyrene |
| Sidathene | Polyethylene |
| Silpak | Polyethylene |
| Styrafoil | Biaxially oriented polystyrene |
| Suprathen | LD polyethylene |
| Supronyl | Polyamide |
| Suprotherm C | PVC |
| Surlyn | Ionomer |
| Synthene | Nylon-polyethylene laminate |
| Tectophane | Cellulose |
| Tenasco | Rayon reinforced polyethylene sheeting |
| Tenofol | Polyethylene |
| Termex | Polyester |
| Terphane | Polyester |
| Tissuthene | Ultra thin HD polyethylene |
| Trespaphan | Polypropylene |
| Triacel | Cellulose acetate and acetate/ butyrate |
| Trithene | Polytrifluoro-chloroethylene |
| Trosifol | Polyvinyl butyral |
| Trovilon | PVC |
| Trovitherm | Unplasticised PVC |
| Trycite | Oriented polystyrene |
| Tuftane | Polyurethane |

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| *Trade Name* | *Type of Material* | *Trade Name* | *Type of Material* |
|---|---|---|---|
| Tullon | Polyamide | Vinolyte | Vinyl chloride-vinyl acetate co-polymer |
| Ukayphane | Cellulose | | |
| Ultrathene | EVA co-polymer | Viscacelle | Cellulose |
| Utilex | Cellulose acetate | Viscophane | Cellulose |
| Valeron | Cross laminated biaxially oriented polyethylene | Vistal | Polyethylene |
| | | Vitafilm | PVC |
| | | Vitrone | PVC |
| Velbex | PVC | Vondafol PC | Polycarbonate |
| Ventoplas | Perforated polyethylene | Vondafol PPO | Polyphenylene oxide |
| Viniplas | PVC | Vybak | PVC |
| | | Zendel | Polyethylene |

# Appendix D
# Additives for Plastics Films

Most plastics films contain additives of one sort or another. Some are included to overcome problems encountered during processing. These may arise, for example, because of the sensitivity to oxidation shown by some plastics, particularly at the high temperatures encountered during film extrusion. Sometimes materials are added in order to overcome end-use problems such as blocking or low impact strength. In many instances, more than one problem may be encountered and the selection of the correct blend of additives becomes more difficult because of the possibility of synergistic effects or interference with one additive by another. Some of the additives used are described below, together with an account of their functions.

## D.1 ANTI-BLOCKING AGENTS

As mentioned in Chapter 9, thin films tend to stick together, especially if they have a smooth surface without irregularities. This 'blocking' can cause difficulties in handling and processing the film. It is particularly annoying where packs of film are used for wrapping. Additives to overcome blocking are usually based on very fine powders of low solubility in the plastic. These then migrate to the surface of the film where they produce surface irregularities. The most common antiblock additive of this type is finely divided silica of between 1 and 7 microns in diameter. Concentrations range from 1 to 6 parts per 1000. The tendency to block can also be reduced



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by the addition of organic amides, such as erucamide, and metallic soaps, such as zinc stearate.

## D.2 ANTI-FOGGING AGENTS

Moisture tends to condense as droplets on packaging films, particularly when wrapping fresh produce such as potatoes and tomatoes. This then obstructs the customer's view of the contents. Such droplets can be dispersed by the addition of non-ionic ethoxylates or hydrophilic fatty acid esters, such as glycerol stearate. These act by promoting the deposition of continuous films of moisture, thus improving visibility.

## D.3 ANTIOXIDANTS

Although plastics, as a class, are relatively stable compounds, many are susceptible to attack by oxygen, particularly at high temperatures. This is because high temperatures accelerate the oxidation reactions. Hazards may be long-term ones, as in outdoor use, especially in the tropics, or short-term, as in film extrusion where conditions of high temperature obtain, albeit of relatively short duration.

The way in which oxidation may be slowed or inhibited can be seen by considering the oxidation processes themselves. With most polymers the initial effect of oxidation is either depolymerisation or cross-linking. In the former instance, chain scission occurs, with the formation of lower molecular weight oxygenated compounds. Among these are acids, aldehydes, hydroxy acids, etc. The attack normally starts at double bonds already present in the molecule or at tertiary carbon atoms (hence forming a double bond). This sort of behaviour is typical of polypropylene where oxidation can eventually lead to the formation of very low molecular weight products, such as butyric acid.

In the latter instance (cross-linking), the first products are higher molecular weight, relatively infusible gels. These react further to give, eventually, lower molecular weight compounds. This type of reaction is displayed by polyethylene. As a rule both types of reaction are chain reactions, often involving hydroperoxy radicals. Hence, the reactions can be slowed down or inhibited by compounds that interrupt the chain reaction at some point.

The requirements of ideal antioxidants may be summarised as follows:



(a) They must be permanent.
(b) They must be capable of inhibiting oxidation under all conditions likely to be encountered in storage, processing and service.
(c) They must be non-blooming.
(d) They must not discolour during processing or, later, when the product is exposed to light.
(e) They must not adversely affect the characteristic properties of the base polymer.
(f) They must be non-toxic and odourless.

The oxidation processes are highly temperature sensitive. They may also be greatly affected by other factors such as catalyst residues and UV radiation. Surface area will also affect oxidative processes and this is an important factor with films. It is often impracticable, therefore, to consider antioxidants in isolation. In practice, stabilisation systems are combinations designed to give optimum protection in relation to oxidation, temperature and UV. In addition antioxidants often display marked synergism, so that many antioxidant systems comprise two or more compounds, notably hindered phenols and organic sulphides. Hindered phenols (such as butylated hydroxytoluene—BHT) act as free-radical scavengers or polymer chain terminators. Other types of antioxidants, such as organophosphites, act as hydroperoxide decomposers.

## D.4 ANTI-STATIC ADDITIVES

Plastics films are non-conductors of electricity and tend to accumulate electrical charges. Such charges may be developed by friction between different layers of particles of the plastics itself, between the plastics and processing equipment or by electro-ionisation from dust or radiation. These electrostatic charges can cause problems during processing or during end use.

The two main problems in processing are: (a) adhesion, either between individual particles or layers of the plastic itself, or between the plastics and processing equipment; and (b) discharging to earth by sparking. This can lead to electric shocks to operators, pin holes in film and local overheating. In extreme cases it can cause a fire hazard. End use problems include dust pick-up and adhesion of thin films, coupled with sparking when they are separated.

The two main properties which an effective anti-static agent must have are a degree of electrical conductivity and a marked tendency to migrate to the surface of the film (where lies the main concentration

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of the electrostatic charge). A wide range of materials has been investigated for anti-static effectiveness, but the most common in actual use are either glycol derivatives or quaternary ammonium compounds. The latter are ionised to some extent in the anhydrous state and hence act as conductors in their own right. Glycol derivatives do have some slight conductivity but their main effect is the sorption of moisture (because of their hygroscopic nature) and it is the moisture layer that acts as the main path to earth for the electrostatic charge.

The presence of a layer of anti-static material on the surface of the film could interfere with the receptiveness of the film to printing inks. However, migration to the surface is a slow process, normally several days, so trouble can usually be avoided by printing the film soon after extrusion. In many instances, printing is carried out in-line with film extrusion.

A rather different problem is that of packaging certain electronic devices and components. A feature of an increasing number of these is their sensitivity to electrostatic discharge (ESD) and electrical overstress (OES). Ordinary anti-static additives are not always effective in producing 'static safe' films and carbon black-based films are often used.

## D.5 BLOWING AGENTS

Reducing the density of a plastics film by giving it a cellular structure allows the production of a film having greater stiffness for a given weight of polymer. In the manufacture of cellular PE and PP films, for example, a master-batch containing a blowing agent is added to the granules which are then extruded as usual. The blowing agent is normally a compound that breaks down at the temperature of extrusion to give nitrogen that then expands the extruded molten mass. One nitrogen based blowing agent is azobisformamide (ABFA) while another is azodicarbonamide. Mixtures of sodium carbonate or bicarbonate with acids are also used. With the nitrogen compounds, the residues are largely volatile and disappear although some may remain in solution. If the salt/acid mixtures are used, the pores will contain carbon dioxide and the plastic will contain residues of the appropriate sodium salt.

Expanded PS sheet can be made by two different methods. One starts with PS beads that have been impregnated, under pressure, with a liquefiable gas, usually pentane. A nucleating agent (such as a mixture of citric acid and sodium bicarbonate) is also added in order to produce a fine cell size. The other method uses ordinary



PS beads as the feedstock and gassing is carried out in the extruder. The blowing agent, here, is usually a fluorinated hydrocarbon. A nucleating agent is again necessary.

## D.6 COLOURANTS

Many packaging films are unpigmented but some are coloured by the addition of either pigments or dyestuffs. Pigments are black, white, coloured, metallic or fluorescent, organic or inorganic solids that are insoluble in, and remain essentially unaffected by, the medium into which they are dispersed. They are small in particle size, generally in the range 0.01–1.0 microns in diameter. Pigments produce colour by the selective absorption of light, but, because they are solids, they also scatter light. Light scattering is undesirable in a transparent film but is desirable if opacity is required. There are some organic pigments that are extremely small in particle size and so scatter very little light. They act, therefore, more like dyes. Organic pigments are characterised by high colour strength, brightness, low density, high oil absorption, and sensitivity to heat and light. Inorganic pigments are more opaque, less bright and weaker in tint. However, they are more resistant to heat, light, chemical attack, migration and weathering. They also have higher density, lower cost and less antioxidant effect. One example is molybdate orange for vinyl film.

Dyes are intensely coloured, solubilised organic substances that are retained by the medium they colour, by chemical bonding, absorption or mechanical retention. Dyes produce colour by absorption of light without affecting transparency or optical purity.

Selection of a colourant for plastics is governed not only by the colouring characteristics of the pigment or dye but also by the resin to be coloured—its properties and compatibility—and the method by which it is processed. For example, PVC and its copolymers liberate hydrochloric acid at high temperatures so that acid-sensitive colourants like cadmium red and ultra-marine blue must be used with care. In addition, molten nylon acts as a strong acidic reducing agent and can decolourise certain dyes and pigments. Colourants must be heat stable enough to withstand processing temperatures, which are sometimes very high. Colourants may also react with other additives used in the film, such as heat and light stabilisers. As an example, sulphur-containing cadmium pigments react with the nickel-bearing stabilisers used in some film grade PPs.

An important factor is that of dispersion, to develop colour strength and maximum optical properties. Dyes are not normally a

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problem because of their soluble nature, but pigments need to be properly wetted by the plastic or by suitable vehicles. Poor dispersion can lead to processing difficulties with thin films. Improvements have been made through surface treatment of pigments or through better grinding techniques.

## D.7 FRAGRANCE ENHANCERS

These are added to films which have an undesirable odour and to films that may absorb an undesirable odour from contact. An example of the latter would be films used as garbage bags.

## D.8 HEAT STABILISERS

The high temperatures encountered during film extrusion can cause thermal decomposition of certain plastics. This follows a similar path to the decomposition reactions caused by oxidation. There is a close relationship between the two reactions, thermal decomposition being catalysed by oxygen and oxidation being catalysed by heat. Some polymers such as low density polyethylene and the nylons are stable enough not to require heat stabilisers, but PVC, high density polyethylene and polypropylene may require significant amounts.

A wide range of heat stabilisers is available, the most common being barium/cadmium, organotin and lead compounds. The choice in any particular instance is governed by the temperatures likely to be encountered, the duration of protection required, the amount of oxygen present and the presence or absence of antioxidants.

## D.9 IMPACT MODIFIERS

These are added to inherently brittle polymers such as PVC and polystyrene to improve their impact strength. Acrylic polymers, such as methylmethacrylate/styrene/butadiene, are particularly useful in the production of clear PVC films. Concentrations of around 7.5 g of acrylic modifier per 100 g of PVC give a product with good room temperature impact resistance, but the concentration must be increased to 12.5 g per 100 g to obtain a film with good impact resistance at 0°C. Ethylene/vinyl acetate copolymers (EVA) are also good impact modifiers for PVC film.



## D.10 PLASTICISERS

According to the International Union of Pure and Applied Chemistry, a plasticiser is a substance incorporated into a plastic or an elastomer to increase flexibility, workability and distensibility. A plasticiser may reduce the melt viscosity, lower the glass transition temperature or lower the elastic modulus of the plastic. Some thin films, such as those produced from the polyolefins, are flexible and do not require plasticisation. However, brittle polymers like PVC are usually plasticised in order to obtain flexible films. The proportion of plasticiser is quoted as per hundred resin (phr) rather than per hundred total plastic (%). In other words, 10 phr means 10 parts plasticiser to 100 parts resin ( = 10 parts plasticiser to 110 parts total plastic = 9.1%). For straightforward overwrapping applications a low to medium plasticiser content would be used (10–50 phr). The higher proportions are needed for the cling wrapping of apples, tomatoes, etc., and still higher proportions are used for meat wrapping where a high permeability to oxygen is required.

Plasticisers should have a low volatility, be colourless and be compatible with the resin. If the film is to be used in food contact applications the plasticiser must also be free from toxic hazard and taint. Among the common plasticisers for PVC are phthalates, adipates and maleates. The tendency of plasticisers to migrate can be reduced by using polymeric plasticisers, such as polyesters and epoxidised oils.

Plasticisation by the incorporation of an additive is known as external plasticisation. The mechanism by which such additives work is separation of the polymer chains, with a consequent reduction of the intermolecular forces. This effect can also be achieved by synthesising a polymer structure with suitable side chains, spaced at intervals along the main polymer chain. These side chains keep the main polymer chains apart so that intermolecular forces are again reduced. In practice this is achieved by copolymerising vinyl chloride with vinyl acetate. Such copolymerisation is known as internal plasticisation.

## D.11 SLIP ADDITIVES

Thin films, particularly those with smooth surfaces, tend to 'drag' when being pulled over metal surfaces such as a forming plate. Both static and dynamic friction may be important in film handling. Where 'drag' is likely to be a problem, slip additives are incorporated into

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the resin. Slip additives act as external lubricants and the materials normally used are fatty acid amides. In addition to solving problems in film handling equipment, slip additives are also useful in applications where sheaves of film are to be dispensed.

## D.12 UV SCREENING AGENTS

UV radiation has a harmful effect on many products, particularly on certain foodstuffs. Where these effects are likely to be significant they can be greatly reduced by the addition of UV screening agents to the film wrapper or sachet. These screening agents act by absorbing or reflecting the UV radiation. The reflected radiation is dispersed harmlessly but absorbed UV radiation is converted to radiation of a different wavelength and this might have an effect on the plastic. If the converted wavelength is in the visible or infra-red spectrum then it is relatively harmless but shorter wavelengths, such as different areas of the UV spectrum, could have a deleterious effect on the film itself. In most food packaging applications, however, the time of exposure to UV is likely to be small and the effect on the plastic should be negligible.

UV screening is achieved either by pigments or by colourless organic compounds that absorb the radiation. One example of a bag incorporating a UV screen is the one used for pre-packed potatoes. This is often tinted a light brown colour to prevent 'greening' of the potatoes. The most effective pigment is carbon black which gives optimum protection at concentrations of about 2–3%. Films intended for outdoor use, particularly in the tropics, are often protected in this way.

## D.13 UV STABILISERS

These are added for the purpose of protecting the film itself and operate by intefering with the degradation chain reactions started, or catalysed by, the radiation. It has been established that the breakdown of polymeric materials under exposure to UV radiation involves a light-catalysed free radical mechanism. This results in rupture of the bonds along the polymer chain and degradation of the physical properties of the polymer. In practice one or more of the following effects can result from exposure of unstabilised polymers to UV energy sources.



(1) Discolouration due to the formation of conjugated structures or complex radicals.
(2) A reduction in tensile or impact strength.
(3) Dimensional changes.
(4) Surface crazing or cracking.
(5) Powdering.

The various polymers differ in their sensitivity to UV radiation. Cellulose nitrate, for example, deteriorates quite rapidly whereas poly(methyl methacrylate) is quite resistant.

The requirements for a UV stabiliser are as follows.

(a) The material must absorb UV light in the desired region.
(b) It must be stable under processing conditions.
(c) It must be compatible with the polymer.
(d) It must be chemically inert.
(e) There must be no toxic hazard.

Materials commonly used as UV stabilisers include benztriazole derivatives, benzophenone derivatives and metallic complexes, such as nickel or cobalt salts of substituted phenols, alkylphenones and dithiophosphinates. Most of the UV stabilisers mentioned are highly effective at low concentrations and are used at levels of 0.1% or less.

## D.14 COMPOUNDING

Most of the additives mentioned are best incorporated in the form of master batches, dispersed in a small quantity of polymer. Plasticisers are a different matter, not only because they are liquids but because they are added in larger quantities. Thorough mixing is essential and a combination of heating (to 80–100°C) and intense agitation is usually used.

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# PLASTICS FILMS

## JOHN · H · BRISTON

The many applications for plastics films has grown rapidly over recent years, especially in the field of packaging. This book has long been the established work on this subject because of its unified approach which includes not only film forming materials and their properties but also the important topics of film manufacture, film conversion (printing, lamination, wrapping and bag manufacture) and end-uses such as packaging applications, agriculture, horticulture, building and construction, synthetic papers, film tapes and fibres.

For this third edition the opportunity has been taken to extensively update and revise the text to take account of recent advances in materials conversion processes. In particular, the section on vacuum and gas packaging has been expanded to cover controlled/modified atmosphere packaging, while the chapter on thermoforming has been rewritten to incorporate sections on control of wall thickness, automatic operation and solid phase pressure forming. A new appendix covering additives for plastics films has been included and the chapters on organolepsis and health safety have also been completely re-written by Dr L L Katan, reflecting their continuing importance, especially to the food industry.

All technologists in the fields of packaging and plastics, whether as convertors or users of films and laminates or film manufacturers in the pharmaceutical, food, agricultural printing, cosmetics or toiletries industries, will welcome this new edition of a valuable handbook. Students of polymer science and those studying for the membership examinations of the Plastics and Rubber Institute or the Institute of Packaging will find it a useful reference text.

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