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The Wiley Encyclopedia of PACKAGING TECHNOLOGY



Edited by Kit L. Yam

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THIRD EDITION

THE WILEY ENCYCLOPEDIA OF PACKAGING

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ENCYCLOPEDIA OF PACKAGING TECHNOLOGY

THIRD EDITION

EDITED BY
KIT L. YAM



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Library of Congress Cataloging-in-Publication Data:

The Wiley encyclopedia of packaging technology/edited by Kit L. Yam. – 3rd ed.
p. cm.

Includes index.

ISBN 978-0-470-08704-6 (cloth)

I. Packaging–Dictionaries. I. Yam, Kit L. II. Title: Encyclopedia of packaging technology. III. Title: Packaging technology.
TS195.A2W55 2009
688.803–dc22

2009021663

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

failure include absence of a true fusion weld of the interfaces of the materials being sealed, among other reasons. Occasionally, unwelded seals perform well under mechanical testing, but fail in the actual applications. When there is not a true fusion weld, portions of the packaged product may find their way out of the package through the seal. For seals that must be reliable, particularly where sterility must be ensured in a package (see Healthcare packaging), sections of the seals should be examined under the microscope. Unless examination shows that the interface between the sealant portions of the laminations has been completely obliterated, the seals should be suspect; with a true fusion weld, there is no visible interface remaining.

The exception to this is peelable seals. The only way to ensure that these are acceptable for the long term is to subject them to rough-handling testing for extended times, exceeding the environmental extremes likely to be encountered. If heat processing is involved, good sense dictates that the tests be carried out for at least twice the period of time that the product is heat processed. Tests should also be conducted to simulate environmental pressure fluctuations at something in excess of the maximum temperature expected to be used in processing. For the packaging of chemicals, or other corrosive products, testing should be carried out with filled packages, subjected to rough handling, elevated temperatures, and any other severe conditions that might be experienced.

When dealing with flexible material constructions, even small wrinkles in the seal area produce a statistically significant percentage of leakers. Aside from visual inspection, no satisfactory automatic system has yet been devised to isolate packages with small seal wrinkles, although a great deal of time and money has been spent in this area. When developing a packaging system where seal integrity is paramount, everything should be done in the design of the system and its equipment to eliminate chances for seal wrinkles. The best way is to keep the packaging materials under tension in two directions while they are being sealed. This can do more to achieve success in eliminating seal wrinkles than any other single effort that might be made. Frequently, design of the packaging can be improved for the sole purpose of reducing the possibility of wrinkles in the seals.

Packaging testing can be also be conducted to evaluate the seal integrity of packages. Typically, this involves vacuum testing or pressurization testing. These tests can be conducted to the point of failure or set to test for pressure decay within the package. Vacuum tests can be conducted dry or under water. Pressure tests can be conducted by compression or inflation. In inflation pressure tests, the packages can be restrained or unrestrained. Additional options include dye leak tests and testing for leaking of gas out of or into the package.

Attempts have also been made to adopt online tests for seal integrity. These include optical comparators, deflection tests, infrared tests to evaluate the heat profile, and ultrasonic imaging techniques. All of these techniques have advantages and disadvantages. None are considered to give complete assurance of well-sealed packages.

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SHEET, PETG

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PETG copolyester is a clear amorphous polymer with a glass-transition temperature (T_g) of approximately 81°C (178°F) as determined by differential scanning calorimetry (DSC). It is manufactured by an addition of a second glycol to polyethylene terephthalate (PET) to eliminate crystallization; therefore, all PETG-finished products are amorphous. PETG has a number-average molecular weight (M_n) of approximately 26,000. As with all thermoplastic polyesters, PETG is subject to hydrolysis (during processing) in the melt state. Although some reduction in molecular weight is a normal consequence of melt extrusion, insufficient drying of PETG can result in an excessive inherent (or intrinsic) viscosity (IV) breakdown that is reflected in lower physical properties—particularly impact strength.

A harmful degree of hydrolytic degradation can be prevented if PETG is dried in a dehumidifying dryer at 65°C (149°F) for 4 h to reduce the moisture level to less than 0.08% before processing.

The molecular weight of either PETG pellets or extruded sheet can be correlated to IV, which is normally determined with a capillary viscometer; however, because this procedure is complex and the required solvents are hazardous, a simpler melt-flow-rate test is preferable. The resulting flow-rate number can later be converted (via the calibration curves) to the more standard polyester IV units.

Thermal and electrical properties of PETG copolyester are shown in Tables 1 and 2.

Unstressed sheet extruded from PETG copolyester exhibits good resistance to dilute aqueous solutions of mineral acids, bases, salts, soaps, aliphatic hydrocarbons, alcohols, and a variety of oils.

Halogenated hydrocarbons, low-molecular-weight ketones, and aromatic hydrocarbons will swell or dissolve the plastic.

A plastic sheet extruded from PETG copolyester has good transparency, low haze, and high surface gloss. It has high stiffness and good impact strength. The physical properties for a 3-mm (0.12-in.) PETG sheet are shown in Table 1.

PETG COPOLYESTER SHEET EXTRUSION

PETG copolyester can be extruded into a clear, tough, amorphous sheet at melt temperatures that usually range within 230–250°C (446–482°F). The sheet thickness is limited only by the cooling capacity of the processing rollstock and/or the capability of the downstream takeoff equipment, but otherwise it might typically range from 1 mm (0.04 in.) to 13 mm (0.50 in.) or thicker.

The extrusion of PETG copolyester is straightforward, and good results can be expected when suitable equipment and proper procedures are used, which include pellet drying, melt extrusion into sheet, and nip polishing on a chrome-plated three-roll stack to ensure an excellent surface finish and good transverse-direction gauge control. Machine-direction gauge control is dependent on the uniformity of extruder output. Excellent uniformity can be obtained using a gear pump with PETG, but its use is especially suggested when regrind is included in the PETG feedstock.

At a given speed, a gear pump provides a constant volumetric rate of copolymer melt to the sheet die. The pressure between the extruder discharge and the entrance to the gear pump is controlled by varying the extruder screw rpm. The variation in extruder output caused by changes in the percentage of regrind or particle shape and size are isolated from the extrusion, die, and the effect on the plastic sheet gauge is minimized. For example, a gear pump set at a suction pressure of 6.9 MPa (1000 psi) would typically control PETG sheet gauge to approximately $\pm 4\%$.

A barrier screw that is cored for water cooling in the feed zone is typically used to extrude the PETG sheet. Industry practice for all polyesters, including PETG copolyester, usually requires an extruder screw with a minimum length/diameter (L/D) ratio of 24:1. As the L/D ratio increases (e.g., 30:1), output capacity (lb/h) and output stability ($\pm$ lb/h) will improve for PETG copolyester, if a suitably designed extrusion screw is used.

Melt filtration is normally used to trap contaminants and/or other types of particulate matter such as "fines," which can be associated with regrind use. A simple screen pack assembly is often used with PETG copolyester, but several different types of automated filtration systems are commercially available for polyesters.

SECONDARY FABRICATION OF PETG SHEET

The manufacture of plastic articles from PETG copolyester sheet normally involves secondary operations such as sawing, drilling, bending, decorating, and assembling. PETG sheet can be worked with most tools that are suitable for use with wood or metal; however, the tool speed normally must be reduced to prevent friction melting.

PETG copolyester sheet thickness of ≤ 2.5 mm (0.10 in.) can be cut effectively with either a power shear (straight cut) or with a steel rule die (irregular cut). The blade-to-bed clearance and alignment for the shear knife edge is an important consideration when cutting PETG sheet. Additionally, a steel rule die press must have a very accurate stroke to prevent damage to the cutting die. Saw cutting is a preferred technique for sheet thicknesses of > 2.5 mm (0.10 in.).

FORMING

Hot Bending. PETG copolyester sheet can be bent around a small radius by preheating an area on both sides with an electric strip heater and then quickly bending the sheet along the heated line. Sheet thicknesses of > 3.2 mm (0.13 in.) should be turned periodically during the heating cycle.

Cold Bending. Unheated PETG sheet of ≤ 2.5 mm (0.10 in.) thick can be successfully brake formed at bending rates somewhat slower than heated sheet.

Thermoforming. Several different thermoforming techniques can be used to force a PETG sheet, once heated, into the shape of a mold by mechanical force, vacuum force, or by air pressure. Both male (plug) and female (cavity) molds can be used. Low-cost plaster molds, cast aluminum molds, and/or water-cooled steel molds are commonly used. Typical forming processes include vacuum, drape, and matched mold. Thermoformed items include light fixtures, tote trays, housewares, toys, and a variety of different transparent enclosures.

PETG Sheet Assembly. Several solvents, cements, and adhesives can be used effectively with PETG copolyester sheet products. Sheet edges, once aligned, are softened by applying cement and clamping until dry.

A PETG copolyester sheet is often fabricated with mechanical fasteners. This technique is preferred if frequent disassembly of a product is required. Common mechanical fasteners include screws, rivets, bolts, clips, hinges, and dowels. This may be a concern, however, if security is a consideration.

PETG Sheet Finishing. PETG copolyester sheet is best sanded wet to avoid frictional heat buildup. An 80-grit silicon carbide could be initially used, followed by progressively finer abrasives (e.g., 280, 400, and 600).

PETG Sheet Decoration. PETG copolyester sheet can be hotdie-stamped through a film carrier that contains either

Table 1. Typical Properties of 3-mm PETG Copolyester Sheet^a

Property ^b	ASTM Method	Units		Typical Value	
		SI	U.S. Customary	SI	U.S. Customary
General					
Density	D1505	kg/m ³	g/cm ³	1270	1.27
Water absorption	D570	%	%	0.2	0.2
Mechanical					
Tensile stress at yield	D638	MPa	psi	53	7700
Tensile stress at break	D638	MPa	psi	26	3800
Elongation at yield	D638	%	%	4.8	4.8
Elongation at break	D638	%	%	50	50
Tensile modulus	D638	MPa	10 ⁵ psi	2200	3.2
Flexural modulus	D790	MPa	10 ⁵ psi	2100	3.1
Flexural strength	D790	MPa	psi	77	11,200
Rockwell hardness	D785	R scale	R scale	115	115
Izod impact strength, notched	D256	J/m	ft. lbf/in.	88	1.7
	D256	J/m	ft. lbf/in.	66	1.2
	D256	J/m	ft. lbf/in.	39	0.7
Impact strength, unnotched	D4812	J/m	ft. lbf/in.	NB ^c	NB ^c
	D4812	J/m	ft. lbf/in.	NB ^c	NB ^c
	D4812	J/m	ft. lbf/in.	NB ^c	NB ^c
Impact resistance—puncture, energy at maximum load	D3763	J	ft. lbf	33	24
	D3763	atJ	ft. lbf	40	30
	D3763	J	ft. lbf	42	31
	D3763	J	ft. lbf	43	32
	D3763	J	ft. lbf	47	34
Thermal					
Deflection temperature	D648	°C	°F	74	164
Vicat softening temperature	D648	°C	°F	70	157
Underwriters Laboratory (UL) flammability classification	D1525 UL94	°C	°F	83	181
				^d	^d
Flammability (France)	NFP 92501	—	—	^e	^e
Flammability (Germany)	DIN 4102, Part 1	—	—	B2	B2
Flammability (Great Britain)	BS 476, Part 7	—	—	2	2
Oxygen index ^f	D2863	%	%	26	26
Coefficient of linear thermal expansion	D696	10 ⁻⁵ /°F	10 ⁻⁵ /°F	6.8	3.8

Optical						
Haze						
Light transmission						
Gloss						
Color ^a						
Yellowness index						
Refractive index, N_d						
Electrical						
Dielectric constant						
Dissipation factor						
Arc resistance						
Volume resistivity						
Surface resistivity						
Dielectric strength short time						

^a Properties reported here are typical of average lots. Eastman makes no representation that the material in any particular shipment will conform exactly to the values given.

^b Unless noted otherwise, all tests are run at 23°C (73°F) and 50% rh, using specimens machined from extruded sheeting with a thickness as indicated.

^c Nonbreak as defined in ASTM D4812 using specimens with thickness as indicated.

^d Not tested by UL but would expect to be the same as Spectar copolyester 14471 (94V-2 for thicknesses of 3.13–12.7 mm (0.123–0.5 in.) and 94HB for thicknesses of <3.13 mm (0.123 in.)).

^e Tests performed on 5-mm sheeting gave a rating of M2.

^f Dripping and warpage of samples during testing can cause erratic test results.

Table 2. Thermal Properties of 3-mm PETG Copolyester Sheet^a

Property, ^b Units	Typical Value	Test Method	
		ASTM	ISO
Deflection temperature at 1.83-MPa (264-psi) fiber stress			
°C	64		
°F	147	D648	75
at 0.46-MPa (66-psi) fiber stress			
°C	70		
°F	158		
Vicat softening point			
°C	85	D1525	306
°F	185		
Thermal conductivity			
W/m · K	0.19	C177	—
(Btu · in.)/(h · ft ² · °F)	1.3		
Glass-transition temperature			
°C	81	c	c
°F	178		
Specific heat, kJ/(kg · K) [Btu/(lb · °F)]			
at 60°C (140°F)	1.30 (0.31)		
at 100°C (212°F)	1.76 (0.42)		
at 150°C (302°F)	1.88 (0.45)	c	c
at 200°C (392°F)	1.97 (0.47)		
at 250°C (482°F)	2.05 (0.49)		
Coefficient of linear thermal expansion, mm/(mm · °C) [in./(in. · °F)]	5.1 × 10 ⁻⁵ (2.8 × 10 ⁻⁵)	D696	—
Flammability [3.2-mm (1/8-in.)-thick specimen] cm/min	<2.5		
in./min	<1	D635	—
UL flammability classification			
3.2 mm (0.125 in.)	94V-2		
1.6 mm (0.0625 in.)	94HB	UL94	—
Oxygen index %	24	D2863	—
Melt density			
at 200°C, g/cm ³	1.19	—	—
at 250°C, g/cm ³	0.98		

^a Properties reported here are typical of average lots. Eastman makes no representation that the material in any particular shipment will conform exactly to the values given.

^b Unless noted otherwise, all tests were run at 23°C (73°F) and 50% rh.

^c Glass-transition temperature and specific heat were determined by DSC.

^d UL flammability classifications are formula-specific. Spectar copolyester 14471 has the ratings shown.

metal or paint. Letters, designs, and trademarks are examples of hot-stamped processes. PETG sheet can also be printed on conventional processes such as letterpress, offset lithography, rotogravure, silk screen, and stenciling. Application of a protective lacquer is often applied over the hot-stamped and printed areas (see the Decorating articles).

PETG copolyester can be extruded in a variety of thicknesses, coextruded with or without tie layers, and formed or fabricated, to meet the needs of ever-increasing consumer and industrial markets. The price, performance, and availability of PETG copolyester make it a very important material in the plastics market today.

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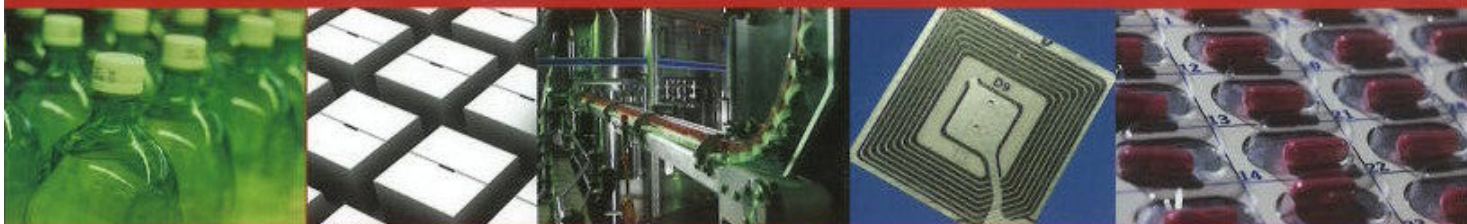
SHELF LIFE

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to Humanity, Seneca, South
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DEFINITION OF SHELF LIFE

Shelf life is the time after production and packaging that a product remains acceptable under defined environmental

The complete and authoritative guide to modern packaging technologies—updated and expanded



From A to Z, *The Wiley Encyclopedia of Packaging Technology, Third Edition* covers all aspects of packaging technologies essential to the food and pharmaceutical industries, among others. This edition has been thoroughly updated and expanded to include important innovations and changes in materials, processes, and technologies that have occurred over the past decade. It is an invaluable resource for packaging technologists, scientists and engineers, students and educators, packaging material suppliers, packaging converters, packaging machinery manufacturers, processors, retailers, and regulatory agencies.

In addition to updating and improving articles from the previous edition, new articles are also added to cover the recent advances and developments in packaging. Content new to this edition includes:

- Advanced packaging materials such as antimicrobial materials, biobased materials, nanocomposite materials, ceramic-coated films, and perforated films
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KIT L. YAM, PhD, is Professor and Graduate Program Director of the Department of Food Science at Rutgers University. In this encyclopedia, he brings many years of teaching, research, and consulting experience in packaging to provide a wealth of information and knowledge useful for readers to tackle real-world packaging problems.

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