

POLYMERS

A PROPERTY DATABASE

SECOND EDITION

EDITED BY
BRYAN ELLIS
RAY SMITH



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common are PP blends with LDPE, LLDPE and HDPE. Less common are blends with ULDPE ($\rho = 890 \text{ kg m}^{-3}$) and ultrahigh MW PE. Blend performance and props. are greatly affected by MW and MW distribution, component ratio, nucleating agents, compatibilisation and thermal or radiative history

Morphology: The blends are immiscible. Compatibilisation may be achieved by addition of a copolymer, reactive blending (using peroxides) or post blending treatment by chemical cross-linking, electron beam radiation or γ -radiation. Reactive compatibilisation or radiation lead to lower blend crystallinity. Micromorphology is controlled by composition, nucleating agents, compatibilisers, and thermal or radiative treatment. As little as 10% HDPE in PP gives a large reduction in the PP spherulite size. Finer spherulite size and better mech. props. are obtained if crystallisation is carried out at temps. less than or equal to 127° (T_c for PE). Blends have the most ordered struct. at 40–70% PP. PP-PE copolymers are more ordered than blends and are most ordered at about 95.5% PP. At up to approx. 50% PE, struct. is spherulitic within a PP matrix. At higher PE levels interpenetrating networks are observed [18,19]. There is no evidence of adhesion between the matrix and the dispersed phase at any composition. Morphology (and fracture props.) are greatly modified by the addition of small amounts of EPR [18,19]. Morphological props. of UHMWPE/LMWPP gel films which are fibrilous without apparent separate domains have been reported [17]. Considerable work has been done to relate mech. props. and rheological props. to morphology [19,31,32,33,34,35,36,37]

Volumetric & Calorimetric Properties:

Density:

No.	Value	Note
1	d 0.91–0.96 g/cm ³	PP/HDPE [8,16]
2	d 0.89–0.91 g/cm ³	approx. follows simple additive rule PP/ULDPE [24]

Latent Heat Crystallization: ΔH_f (PP) 85–102 J g⁻¹ (max. at 30–40% ULDPE); ΔH_f (ULDPE) 51–54 J g⁻¹ (monotonic increase with PP content); ΔH_f (total) 52–94 J g⁻¹ (slight deviation-negative near pure components, positive for mid-range compositions from simple additive rule [24])

Melting Temperature:

No.	Value	Note
1	156–160°C	PP
2	130–136°C	HDPE, as PP content increases [8]
3	152.5°C	PP
4	105.5°C	LDPE, initial melting point, all compositions [20]

Transition Temperature General: For polypropylene blends with virtually all types of PE, two distinct melting, crystallisation (or other transition) temps. are observed. Slight changes may occur with composition (sometimes observed to be test method dependent [20]) but are so small as to not contradict the immiscibility of the components. T_m 161° (PP) increases to max. of 161.8° at 50% ULDPE then decreases to 161.4°; actual values depend on grade of ULDPE; similarly T_m (ULDPE) increases with ULDPE content to value depending on grade. T_c (PP) 112° increases to max. 119° then decreases (according to ULDPE grade); T_c (ULDPE) decreases with increasing ULDPE content to 59° [24]

Vicat Softening Point:

No.	Value	Note
1	60–150°C	PP-ULDPE, significant negative deviation from simple additive rule [24]

Surface Properties & Solubility:

Plasticisers: EPM [7,11,12,15]

Transport Properties:

Polymer Melts: Zero shear viscosity η_0 , 9.05 poise (180°, 25% HPPE/75% PP), 6.02 poise (200°, 25% HDPE/75% PP); 2.88 poise (180°, 50% HDPE, 50% PP); 2.12 poise (200°, 50% HDPE, 50% PP); 2.27 poise (180°, 75% HDPE, 25% PP); 1.77 poise (200°, 75% HDPE, 25% PP) [9,16]. Zero shear viscosity decreases with increasing temp. and increase in HDPE composition. Complex viscosity η^* 2.1–3.2 Pa s (PP/ULDPE) [24]. Values vary with composition. Other viscosity measurements have been reported [25]

Permeability of Gases: Water vapour transmission $0.128 \text{ g d}^{-1} \text{ m}^{-2}$ (60% PP, 40% PE, ASTM E96-66B); $0.054 \text{ g d}^{-1} \text{ m}^{-2}$ (33% PP, 60% PE, ASTM E96-66B); $0.63\text{--}0.8 \text{ g d}^{-1} \text{ m}^{-2}$ (10% PP, 90% PE, ASTM E96-66B) [16]

Mechanical Properties:

Mechanical Properties General: The nature and proportions of the components are not sufficient to determine the mech. props. Depending on the time, temp. and rate of mixing the 'same blend' can show different behaviour. The mixing procedure should be optimised [21,22,23]. Mech. props. can be greatly altered by the incorporation of a compatibilising agent. The extent of such effects is dependent on the chemical struct. and/or on the molecular mass of the added copolymer as well as on the blend composition [11,12,15]

Tensile (Young's) Modulus:

No.	Value	Note
1	735 MPa	max. at 80% PP [18]
2	686 MPa	7000 kg cm ⁻² , PP
3	1078 MPa	11000 kg cm ⁻² , HDPE
4	1034 MPa	150000 psi [30]
5	1379–1724 MPa	200000–250000 psi, injection moulded
6	620–724 MPa	90000–105000 psi, compression moulded
7	482–620 MPa	70000–90000 psi, max. at 25–50% PP, pressed and quenched [21]
8	90–896 MPa	13000–130000 psi [29]
9	240–1250 MPa	0.24–1.25 GPa [25]
10	2000–15000 MPa	draw ratio 20
11	15000–50000 MPa	min. at 70% PP, draw ratio 40
12	22000–50000 MPa	draw ratio 60
13	30000–100000 MPa	approx., linear, draw ratio 100 [17,30]

Flexural Modulus:

No.	Value	Note
1	130–840 MPa	linear [20]
2	245–1240 MPa	23°
3	1210–3310 MPa	-40° [20]
4	100–1500 MPa	[19]

Tensile Strength Break:

No.	Value	Note
1	22–35 MPa	max. at 75–90% PP
2	15.9–30 MPa	50% PP [8,16,18,28]

3	21 MPa	approx., max., PP/LLDPE [15,20,25]
4	300 MPa	draw ratio 10
5	500 MPa	PP
6	600 MPa	max. at 70% PP
7	400 MPa	PE, draw ratio 20
8	600–900 MPa	PP
9	1300–1500 MPa	PE, draw ratio 40
10	700 MPa	PP
11	1600 MPa	PE, draw ratio 60
12	1000 MPa	PP
13	2200 MPa	PE, draw ratio 100
14	3000 MPa	approx., draw ratio 300 [17,30]

Elastic Modulus:

No.	Value	Note
1	1000 MPa	approx., all compositions [12]

Tensile Strength Yield:

No.	Value	Elongation	Note
1	21–34 MPa		[8,18,28]
2	<25 MPa	20%	max., 50:50 PP/LDPE [31]

Miscellaneous Moduli:

No.	Value	Note	Type
1	827 MPa	PP	Secant modulus
2	896 MPa	max. at 90% PP	Secant modulus
3	669 MPa	PE [16]	Secant modulus
4	110–450 MPa	5% elongation [20,21]	5% modulus
5	50–220 MPa	linear [20]	Shear modulus

Impact Strength: Tensile impact strength 67 kJ m⁻² (32 ft lb in⁻¹, 100% PP), 21 kJ m⁻² (10 ft lb in⁻¹, 45% PP/55% LDPE), 189 kJ m⁻² (90 ft lb in⁻¹, 100% LDPE) [15]

Fracture Mechanical Properties: Extent of stress whitening for impact test specimens, including those modified with, has been reported [11]

Izod Notch:

No.	Value	Notch	Note
1	53.4 J/m	Y	1 ft lb in ⁻¹ , 100% PP [26]
2	107 J/m	N	2 ft lb in ⁻¹ , 50% PP [26]
3	587 J/m	N	11 ft lb in ⁻¹ , 25% PP [26]
4	1070 J/m	N	20 ft lb in ⁻¹ , 100% HDPE [26]
5	60–87 J/m	Y	room temp., 90% PP/10% ULDPE [24]
6	21 J/m	Y	0°, 5–10% ULDPE [24]
7	16 J/m	Y	-20°, 5–10% ULDPE [24]
8	13–16 J/m	Y	-30°, 5–10% ULDPE [24]

Izod Area:

No.	Value	Notch	Note
1	4 kJ/m ²	Unnotched	100% PP [1]

2	2 kJ/m ²	Unnotched	75% PP/25% HDPE [1]
3	1.3 kJ/m ²	Unnotched	50% PP/50% HDPE [1]
4	2.2 kJ/m ²	Unnotched	25% PP/75% HDPE [1]
5	8.4 kJ/m ²	Unnotched	100% HDPE [1]
6	9 kJ/m ²	Unnotched	50% PP/50% LLDPE [29]
7	53 kJ/m ²	Notched	room temp., 95% PP/5% ULDPE [24]

Charpy:

No.	Value	Notch	Note
1	3.5	N	100% PP [20]
2	76	N	100% LDPE [20]

Optical Properties:

Transmission and Spectra: Ir absorption band ratios 720–731 cm⁻¹ (PE), 973–998 cm⁻¹ (PP) may be used to determine blend composition [23]

Total Internal Reflection: Birefringence 0.040–0.042 (25% PE); 0.043–0.048 (40% PE) (20° < T < 170°, sharp fall in value at approx. 170°, UHMWPE/LMWPP Gel film) [17]

Polymer Stability:

Recyclability: Much of the interest in these blends has been generated by the fact that PP, HDPE, LDPE constitute a major proportion of plastic waste which is therefore a potential source [21]

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