NOTES

Effect of Some Molecular Parameters on the Flexural Properties of Injection-Molded Polypropylene

INTRODUCTION

The effect of molding conditions on the flexural properties of injection-molded polypropylene (PP) has been studied minutely in previous papers.[1,2] The effect of some molecular parameters on the shrinkages of injection-molded PP has been studied in another paper.[3] In the present study, we aimed to clarify the effect of some molecular parameters such as melt flow index (MFI), random- and block-copolymerization with ethylene, and glass fiber filling on the flexural properties of injection-molded PP.

EXPERIMENTAL

Samples used are shown in Table I. These samples are the same as those used in the previous work[3] for studying shrinkages. A to M are homo-PPs, O and P are random copolymers with ethylene, Q and R are block copolymers with ethylene, and S is a glass fiber-reinforced PP (FRPP).

To obtain specimens of uniform anisotropy, square plates were injection molded by use of a mold with a film gate which was the same as that used in the previous papers.[2,3] Injection-molding was carried out with a Toshiba IS 200A-Type 20-ounce reciprocating-screw injection molding machine.

TABLE I
Properties of Samples and Injection Pressures

Sample	MFI, dg/min	Ethylene content, wt %	Remarks	Injection pressure, kg/cm^2
A	0.55	—	homo-PP	400
B	0.66	—	homo-PP	370
D	1.2	—	homo-PP	350
E	1.3	—	homo-PP	350
F	1.5	—	homo-PP	350
G	1.6	—	homo-PP	350
H	3.9	—	homo-PP	350
I	4.5	—	homo-PP	350
J	5.9	—	homo-PP	350
K	8.2	—	homo-PP	300
L	8.4	—	homo-PP	300
M	14.4	—	homo-PP	300
O	4.2	1.8	random copolymer with ethylene	350
P	9.6	0.5	random copolymer with ethylene	300
Q	1.9	12.0	block copolymer with ethylene	350
R	2.3	14.6	block copolymer with ethylene	350
S	2.1	—	FRPP, glass fiber content = 20 wt-%	350

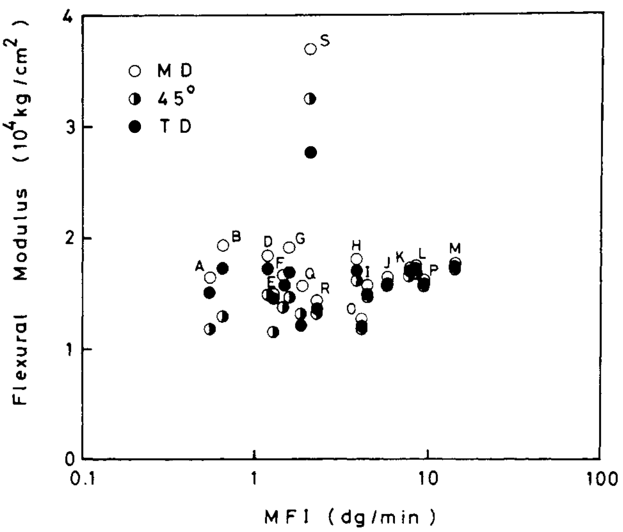

Fig. 1. Variations of flexural moduli in various directions with MFI.

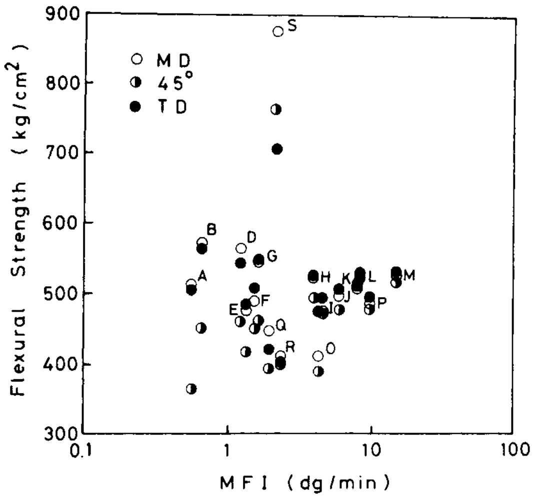

Fig. 2. Variations of flexural strengths in various directions with MFI.

Injection molding conditions were as follows: injection time, 8 sec; adjusting time, 10 sec; cooling time, 30 sec; mold temperature, 40°C; revolution speed of screw, 34 rpm; stroke measuring, 40 mm; injection speed, E-0 (max); cylinder temperature, feed zone 180°C, compression zone 260°C, metering zone 280°C, adaptor 260°C; injection pressure, cf. Table I.

Although it was preferable to maintain the injection pressure constant when the resin was changed, it had to be changed in order to shut out the short-shot and/or flash. However, since this change in injection pressure was small and the injection pressure does not much influence flexural properties,[1] we considered that no problem was created in changing the injection pressure.

By use of a saw, flexural specimens were cut in the machine direction (MD), 45° direction, and transverse direction (TD) from the molded square plates whose centers coincided with the centers of the specimens. Flexural modulus and flexural strength were measured at 23°C according to ASTM D790.

TABLE II
Least-Squares Equations and Correlation Coefficients r_0 Between Flexural Moduli E and Flexural Strengths FS in Various Directions and Logarithmic MFI for Homo-PPs[a]

Property	Direction	Least-squares equation	r_0
	MD	$E_{\mathrm{MD}} = -0.029 \times 10^4 \log(\mathrm{MFI}) + 1.73 \times 10^4$	−0.094
E	45°	$E_{45°} = 0.226 \times 10^4 \log(\mathrm{MFI}) + 1.42 \times 10^4$	0.779**
	TD	$E_{\mathrm{TD}} = 0.061 \times 10^4 \log(\mathrm{MFI}) + 1.60 \times 10^4$	0.278
	MD	$FS_{\mathrm{MD}} = -17.9 \log(\mathrm{MFI}) + 527$	−0.270
FS	45°	$FS_{45°} = 80.5 \log(\mathrm{MFI}) + 432$	0.866**
	TD	$FS_{\mathrm{TD}} = -5.5 \log(\mathrm{MFI}) + 525$	−0.109

[a] $r(10, 0.01) = 0.708$; $r(10, 0.05) = 0.576$.

RESULTS AND DISCUSSION

The variations of the flexural moduli and flexural strengths in various directions with MFI are shown in Figures 1 and 2, respectively. Least-squares equations and correlation coefficients between the flexural moduli and flexural strengths in various directions and logarithmic MFI for homo-PPs are shown in Table II. For the homo-PPs, the flexural moduli and flexural strengths in the MD and TD are practically independent of MFI, and those in the 45° direction increase with increasing MFI. The fact that the flexural modulus and flexural strength in the 45° direction are not much affected by the skin layer and are near those of the unoriented material, as shown in the previous paper,[2] suggests that the flexural modulus and flexural strength of unoriented PP become higher as MFI becomes higher, which has actually been observed.[4] It is assumed that, since the flexural moduli and flexural strengths in the MD and TD become higher as the skin layer becomes thicker in the case of the same resin,[2] the increases in flexural modulus and flexural strength of the resin itself due to the increase of MFI may balance their reduction due to the decrease in thickness of the skin layer (cf. Fig. 5), and hence the flexural moduli and flexural strengths in the MD and TD behave as if they do not depend on MFI. The random and block copolymers with ethylene show lower flexural modulus and flexural strength than the homo-PP, while the FRPP shows higher ones.

The relations between the ratios of the flexural modulus and flexural strength in the MD to those in the 45° direction, $E(\mathrm{MD})/E(45°)$ and $FS(\mathrm{MD})/FS(45°)$, and MFI are shown in Figures 3 and 4, respectively. The reason why the ratios of the flexural properties in the MD to those in the 45°

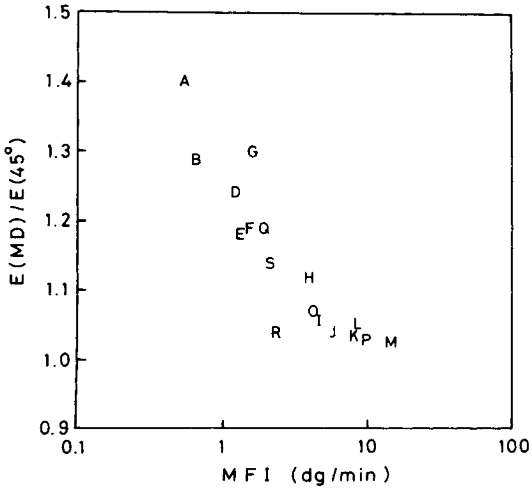

Fig. 3. Variation of ratio of flexural modulus in the MD to that in the 45° direction, $E(\mathrm{MD})/E(45°)$ with MFI.

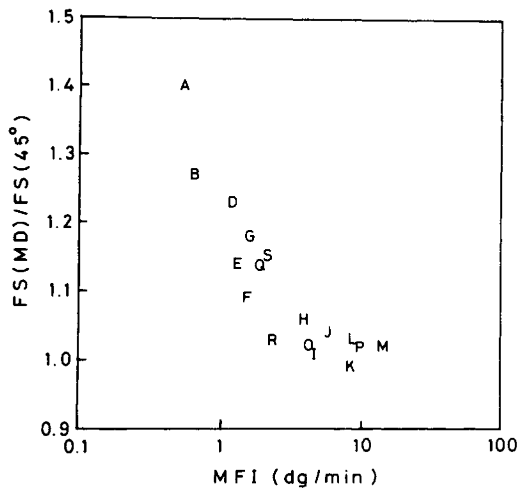

Fig. 4. Variation of ratio of flexural strength in the MD to that in the 45° direction, *FS*(MD)/*FS*(45°) with MFI.

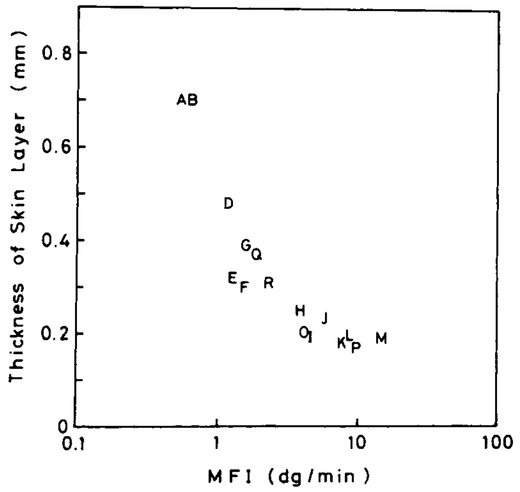

Fig. 5. Variation of thickness of skin layer with MFI.

direction are taken is that the effect of only molecular chain orientation subtracted the characteristics of the resin itself can be evaluated, since the flexural properties in the 45° direction are almost unaffected by the skin layer and are nearly equal to those of unoriented material.[2] These ratios decrease with increasing MFI, independent of the kind of resin.

It has been shown in the previous papers[1,2,5] that an injection-molded PP shows a clear skin/core morphology when it is observed with a polarized microscope. The square plates molded in this study also showed clear skin/core morphologies, except for the S sample. The relation between the thickness of the skin layer at the center area of the square plate and MFI is shown in Figure 5. The thickness of the skin layer decreases with increasing MFI.

From the fact that the variations of E(MD)/E(45°) and FS(MD)/FS(45°) with MFI are very similar to the variation in thickness of the skin layer with MFI, it is expected that there are close relationships between them. These relationships are shown in Figures 6 and 7. There is a upward-curved relationship with a positive slope between E(MD)/E(45°) and the thickness of the skin layer and a linear relationship with a positive slope between FS(MD)/FS(45°) and the thickness of the skin layer. These ratios do not become unity at zero thickness of the skin layer but become unity

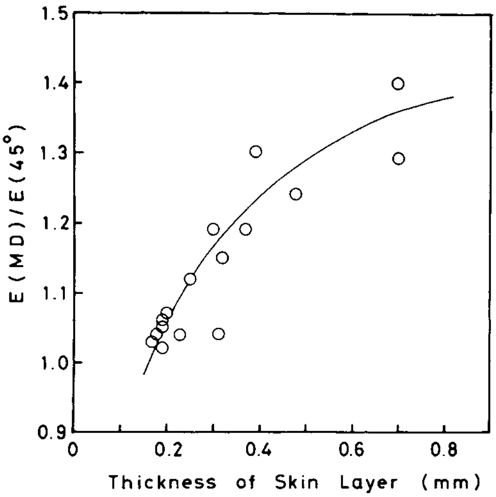

Fig. 6. Relationship between E(MD)/E(45°) and thickness of skin layer.

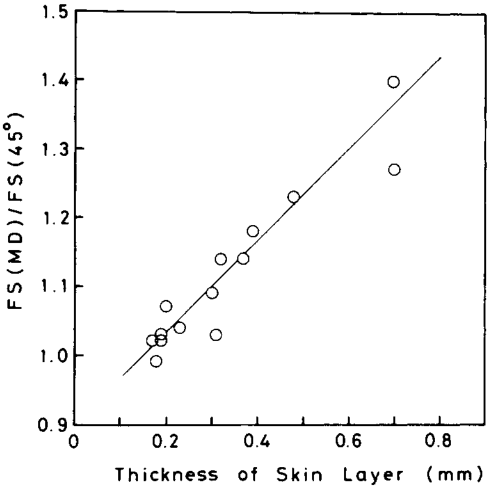

Fig. 7. Relationship between FS(MD)/FS(45°) and thickness of skin layer.

at about 0.15 mm thickness of the skin layer. This is probably so because, since the flexural modulus and flexural strength in the 45° direction are slightly reduced with increase in thickness of the skin layer as shown in the previous paper[2] and hence are slightly affected by the molecular chain orientation in the case of the same resin, they cannot be regarded rigorously as those for unoriented material, and because the most outer oriented amorphous layer ca. 0.05 mm thick was included in the skin layer.

CONCLUSIONS

By use of a mold with a film gate, various PPs were injection molded at fixed molding conditions into square plates of uniform orientational anisotropy. The effect of some molecular parameters on flexural properties was studied on the molded specimen cut in various directions. For homo-PPs, the flexural moduli and flexural strengths in the MD and TD were constant, independent of MFI, while those in the 45° direction increased with increasing MFI. The flexural moduli and flexural strengths of random and block copolymers with ethylene were lower than those of the homo-PPs, while those of a FRPP were higher than those of the homo-PPs.

The ratios of the flexural modulus and flexural strength in the MD to those in the 45° direction decreased with increasing MFI and were in positive correlationships with the thickness of the skin layer, regardless of the kind of resin.

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