# Relationship between Extrusion Condition and Mechanical Properties of FRPP

WEN-YEN CHIU, HSIANG-CHUNG LU, and CHIA-LU CHANG

Graduate Institute of Materials Engineering, National Taiwan University, Taipei, Taiwan, Republic of China

**SYNOPSIS**

In this work, the relationship between extrusion condition and mechanical properties of glass-fiber-reinforced polypropylene (FRPP) was investigated. It was found that the extrusion flow rate was higher but the extrusion pressure was lower as the fiber content decreased. The flow rate and pressure were more temperature-sensitive at high screw speed. As for the mechanical strength of FRPP, the yield strength decreased with increasing the fiber content, but modulus and impact strength significantly increased with increasing the fiber content. The high screw speed did not affect the mechanical strength of PP, but decreased the strength of FRPP. At higher extrusion temperature, the yield strength and modulus of FRPP increased, but the impact strength decreased. The yield strength and modulus of extrudates along the longitudinal direction of extruder were always higher than those along other directions by the effect of fiber orientation. The specimens taken from different positions of extrudate would show different mechanical strength. The way of cooling for the extrudates would affect the mechanical properties of FRPP, too. All the above relations were discussed and well explained from the contribution of fiber distribution, fiber length, crystallinity of PP, and void content.

## INTRODUCTION

In extrusion process, the fluctuation of temperature, pressure, or flow rate would affect the mechanical properties of extrudates. Chan et al.[1] found that an increase of fiber content would result in a decrease of die swelling and an increase of pressure drop. Crowson and Folkes[2] examined the effects of fiber length and fiber cone. On the viscosity of composite melt. They found that the influence was more significant at low shear rate. Turkovich and Erwin[3] reported that fibers with higher length would be found in the cases of high processing temperature and low screw speed. Bright et al.[4] studied the fiber orientation in core region of composite melt, and found fibers perpendicular to the flow direction at high flow rate, but parallel at low flow rate.

For the investigation of mechanical properties, the strength and modulus of composite were found to be increased with increasing the fiber content and fiber length if the interfacial adhesion between fiber and polymer was strong.[5] The mechanical strength was higher in the machine direction than the transverse direction.[6] The existence of bubble and void would decrease the mechanical strength of composite material.[7,8] Marrucci et al.[9] studied the factors forming voids in extrudates under quick cooling.

Additionally, the way of cooling would vary the properties of extrudates such as crystallinity, residual stress, craze, and so on. Coxon and White[10] indicated that no residual stress was found in PP upon cooling at room temperature. The internal stress could even decrease to zero if additives with good heat transfer property was blended in PP.[11]

Journal of Applied Polymer Science, Vol. 43, 1335–1341 (1991)
 CCC 0021-8995/91/071335-07$04.00

# EXPERIMENTAL

## Materials

1. PP: MI = 3.0 g/10 min.
2. GF: 6 mm chopped strand, $d_f$ = 15–22 $\mu$m.

## Preparation of FRPP Specimens

PP was heated under 80–90°C for 2–3 h and GF at 80°C for 1 hour. Both were then mixed at different ratios. The fiber content could be 5, 15, or 25 wt % with symbols of FRPP5, FRPP15, or FRPP25. The mixture was first blended through a single screw extruder ($L/D$ = 24, $D$ = 35 mm), with barrel temperatures of 200, 210, and 230°C, and screw speed of 25 rpm. The temperature of round die was set at 230°C. The extrudate after the first extrusion was cut into small pellets, and then went through the extruder with slit die again for the study of the extrusion condition–mechanical properties relationship. The extrusion condition was varied at different screw speeds, barrel temperatures, and die temperatures. The specimens for tensile test were designed to have thickness of 2 mm, and those for impact strength were 4 mm. The extrudates were cooled in different ways: (1) slowly in air at room temperature and (2) quickly in water.

## Measurement of Mechanical Properties

### *Tensile Test*

All specimens were made in a dumbell shape. The yield strength, modulus, and elongation at break were measured and recorded by an Instron Machine at room temperature with strain rate of 5.0 mm/min.

### *Impact Strength Test*

Specimens were made according to JISK 7110. The impact strength was measured by an Izod impact tester at room temperature.

# RESULTS AND DISCUSSION

## Extrusion Process

The flow rate and pressure drop in extrusion process for FRPP varied with the fiber content, extrusion temperature, screw speed, etc. Figure 1 showed the effects of fiber content and screw speed on the flow rate. At constant extrusion temperature, the flow rate increased with increasing the screw speed, but decreased with increasing the fiber content. The relationships among fiber content, temperature, and pressure were shown in Figure 2. The pressure decreased at lower fiber content, but increased at higher screw speed. Figure 3 showed the dependence of flow rate on extrusion temperature at different screw speeds and different fiber contents. At high screw speed, the flow rate was more temperature-sensitive.

## Mechanical Properties

### *Tensile Test*

Figure 4 showed the yield strength of PP versus screw speed under different cooling ways. The case of slow cooling always showed higher strength which was not sensitive to the screw speed. However, for the case of FRPP, the strength slightly decreased

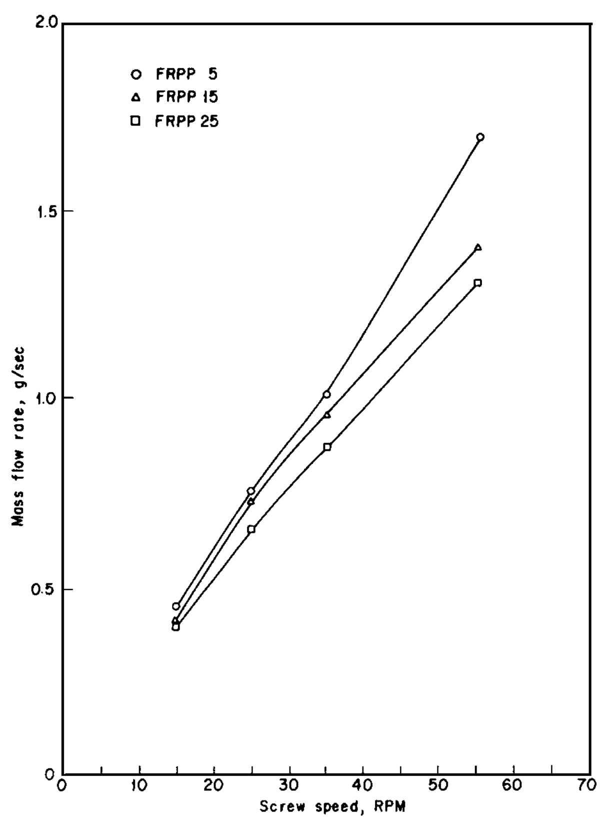


**Figure 1** Flow rate versus screw speed for FRPP5, FRPP15, and FRPP25.

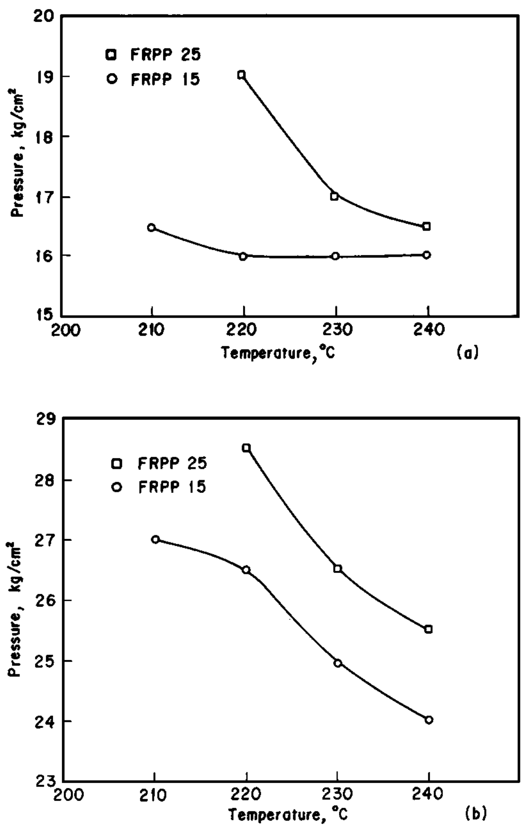


**Figure 2** The dependence of pressure on extrusion temperature at fixed screw speed for FRPP15 and FRPP25: (a) rpm = 15; (b) rpm = 55.

with increasing the screw speed as shown in Figure 5. It might be attributed to the fiber breakage under high shear force.[12] The high yield strength and modulus found in the case of slow cooling in Figures 6 and 4 were due to the effects of crystallinity and crystal morphology of PP.[12–14]

Figures 7 and 8 showed the effects of fiber content on the yield strength and modulus. The yield strength decreased but the modulus increased significantly with an increase of fiber content. Figure 9 showed that the void content increased at high screw speed and high fiber content. The way of cooling also affects the void content slightly. Additionally, the extrudate showed different void contents at different positions. The specimens near the center of the extrudate was found to have a high void content. The mechanical strength of specimens at different positions in extrudate was compared in Figure 10. The specimens near the side of extrudate showed higher yield strength and high modulus by the facts of being higher in fiber content, longer in fiber length, and lower in void content at side position.[12]

The variation of yield strength of FRPP with extrusion temperature was shown in Figure 11. The

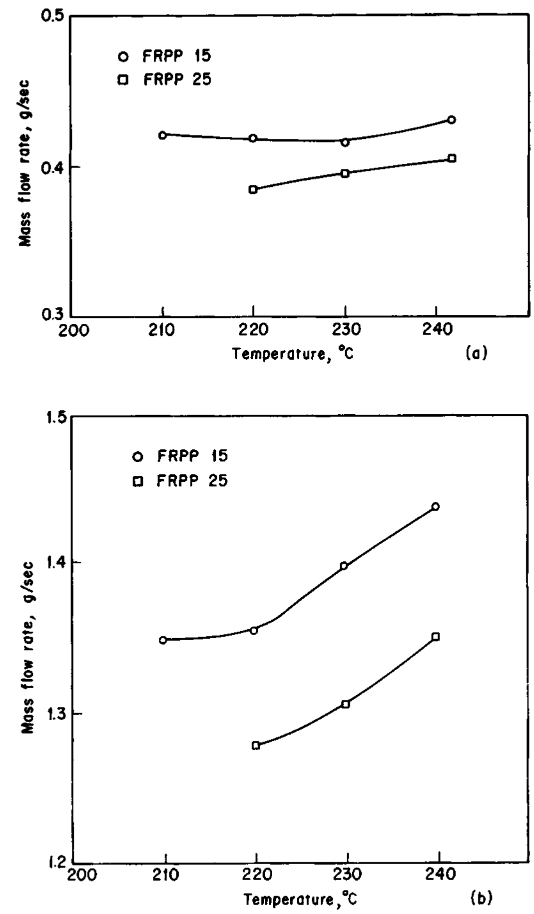


**Figure 3** The dependence of mass flow rate on extrusion temperature at fixed screw speed for FRPP15 and FRPP25: (a) rpm = 15; (b) rpm = 55.

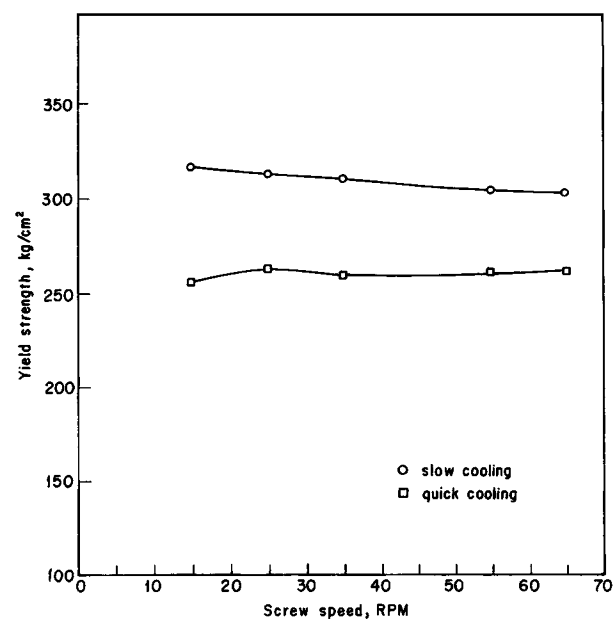


**Figure 4** Yield strength versus screw speed for PP under different cooling ways. Barrel temperature: 190, 210, 230, and 230°C in four zones.

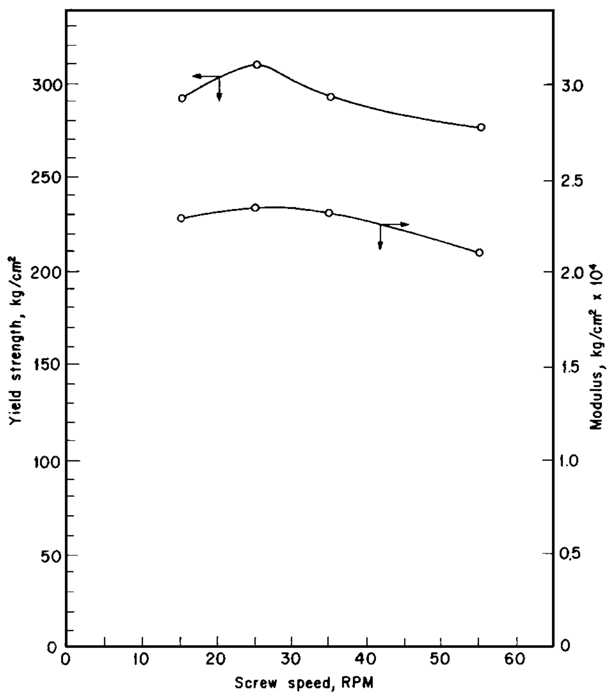


**Figure 5** Yield strength and modulus of FRPP15 versus screw speed. Barrel temperature: 190, 210, 230, and 230°C in four zones, slow cooling.

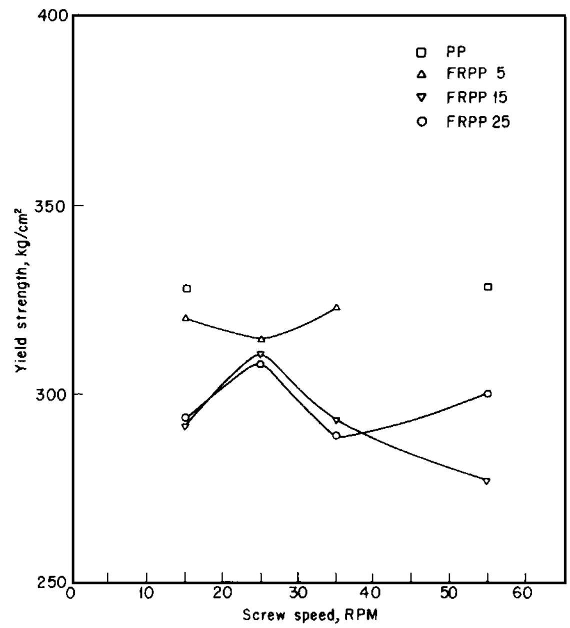


**Figure 7** Yield strength of PP and FRPP versus screw speed. Barrel temperature: all 230°C in four zones, slow cooling.

yield strength increased with increasing the temperature by the reason of being with longer fibers in FRPP under low viscosity, hence low shear force at high temperature. The lower void content found

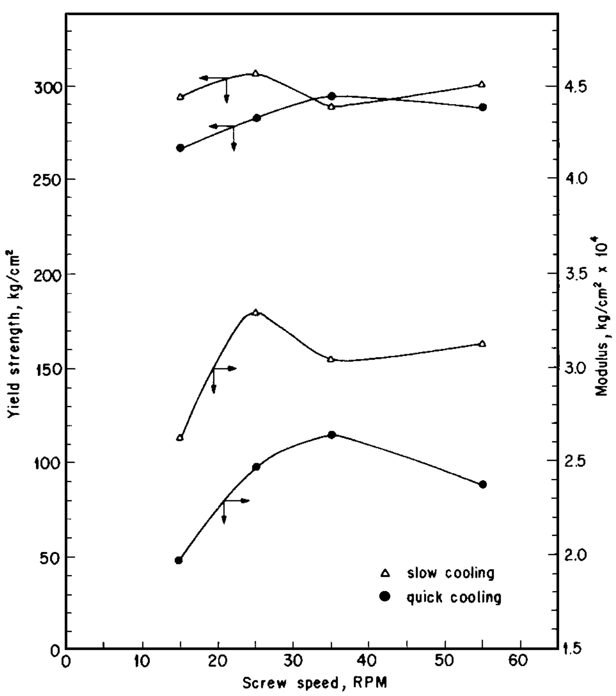


**Figure 6** Yield strength and modulus versus screw speed for FRPP25 under different cooling ways. Barrel temperature: 190, 210, 230, and 230°C in four zones.

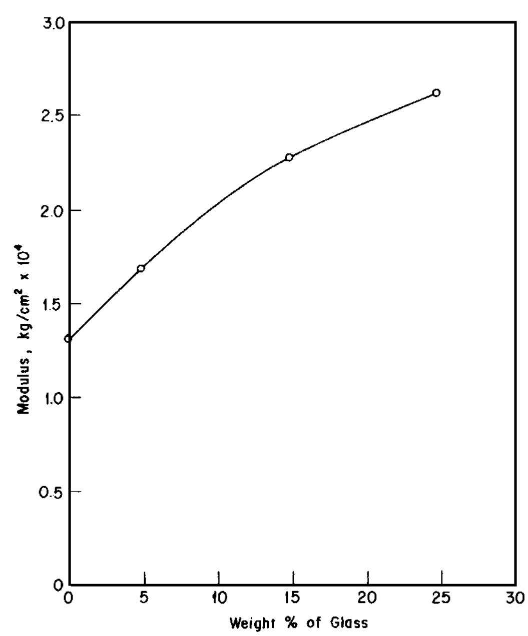


**Figure 8** Modulus of PP reinforced by different weight percent of glass fiber. Barrel temperature: 190, 210, 230, and 230°C in four zones, 15 rpm, slow cooling.

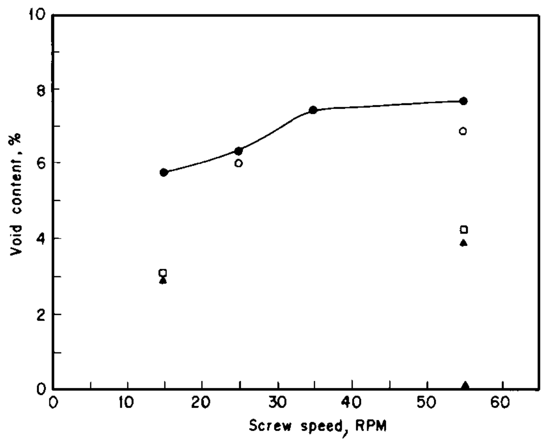


**Figure 9** Void content of FRPP treated with different condition versus screw speed. Barrel temperature: 230°C. (●) FRPP25, center, slow cooling; (○) FRPP25, side, slow cooling; (□) FRPP15, slow cooling; (▲) FRPP15, quick cooling; (△) FRPP5, slow cooling.

at high temperature in Figure 12 might be the other reason for the experimental results of Figure 11.

Figures 13 and 14 showed the variation of yield strength and modulus of FRPP25 with angle between extrusion direction and tensile direction respectively. Both decreased with increasing the angle

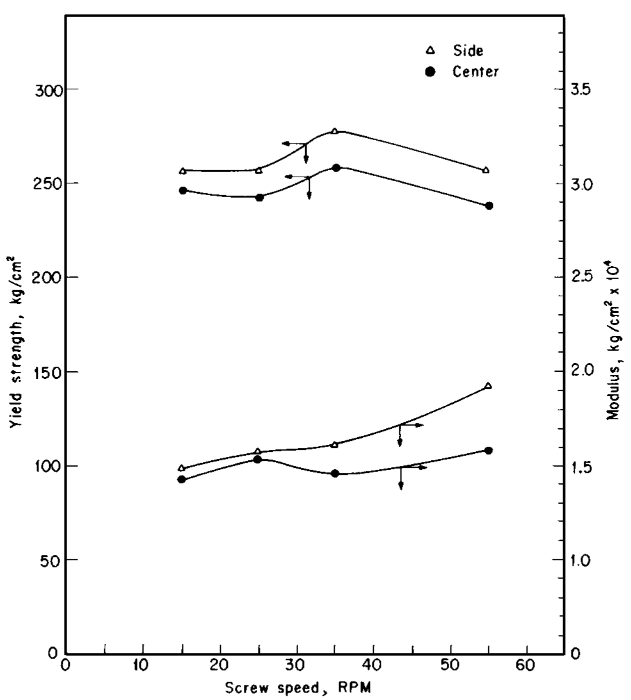


**Figure 10** Yield strength and modulus of FRPP25 at different position of extrudate versus screw speed. Barrel temperature: 190, 210, 230, and 230°C in four zones.

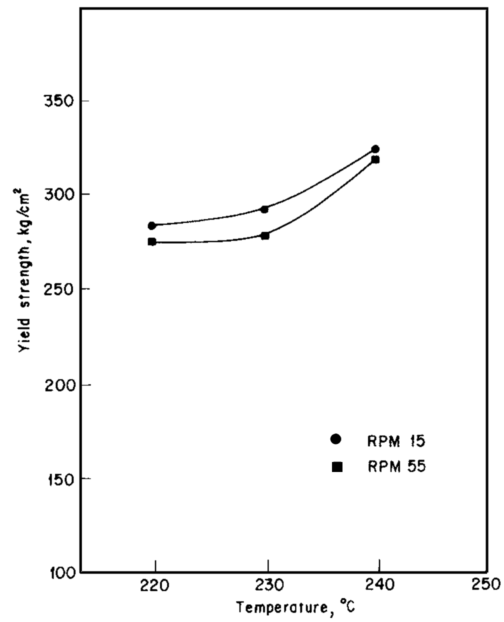


**Figure 11** Variation of yield strength with temperature of extrusion for FRPP15, slow cooling.

except for the modulus at 90°. However, for the specimens with less fiber content, such as FRPP5, the variation of modulus and yield strength with angle was not obvious as shown in Figures 15 and 16.

## *Impact Strength*

The fiber length and interfacial adhesion in FRPP would dominate the impact strength of the composite. Figure 17 showed the impact strengths of PP

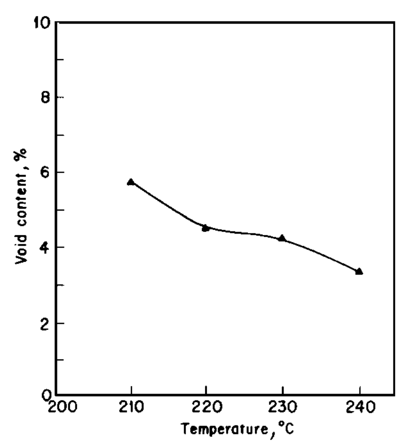


**Figure 12** Variation of void content with extrusion temperature for FRPP15.

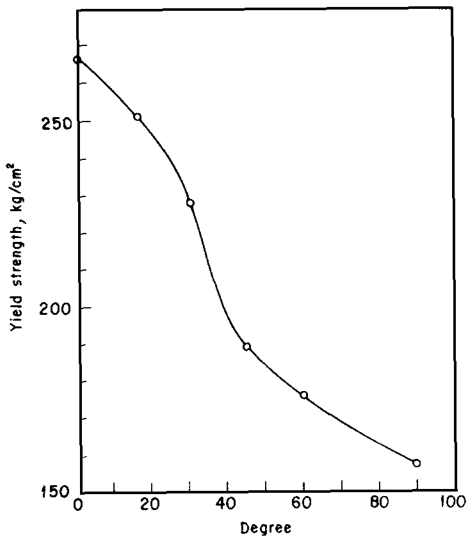


**Figure 13** Variation of yield strength with angle between extrusion direction and tensile direction for FRPP25. Barrel temperature: 180, 200, 220, and 220°C in four zones, 55 rpm, quick cooling.

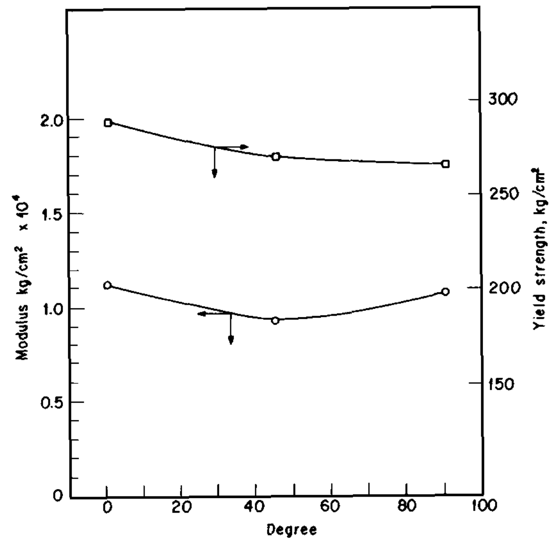


**Figure 15** Variation of modulus and yield strength with angle between extrusion direction and tensile direction for FRPP5. Barrel temperature: 190, 210, 230, and 230°C in four zones, 25 rpm, slow cooling.

and FRPP versus screw speed. It decreased with increasing the screw speed, which resulted from the more serious fiber breakage upon high shear force. From the comparison of impact strength of PP with that of FRPP in Figure 17, the fiber did largely enhance the impact strength of PP. However, FRPP25 showed lower impact strength than FRPP15. The reason might be due to the existence of shorter fibers and the high void content in FRPP25 as shown in Figure 18. Figure 19 showed the variation of impact

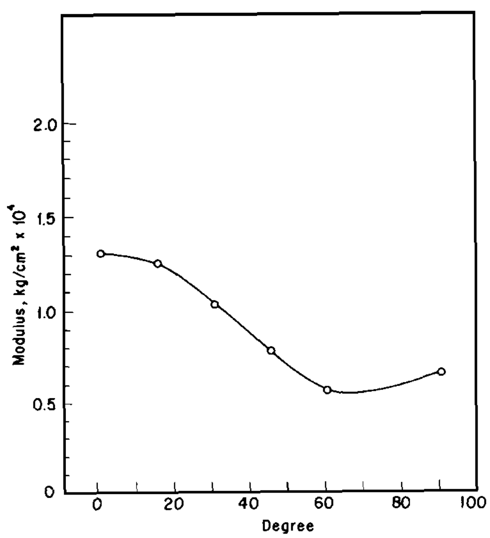


**Figure 14** Variation of modulus with angle between extrusion direction and tensile direction for FRPP25. Barrel temperature: 180, 200, 220, and 220°C in four zones, 55 rpm, quick cooling.

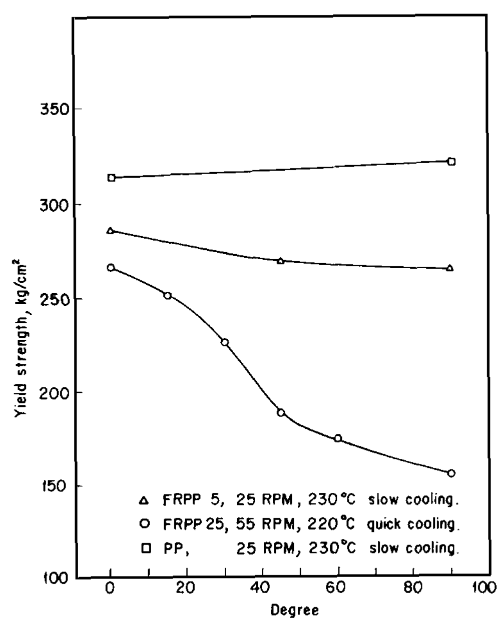


**Figure 16** Variation of yield strength with angle between extrusion direction and tensile direction for PP, FRPP5, and FRPP25.

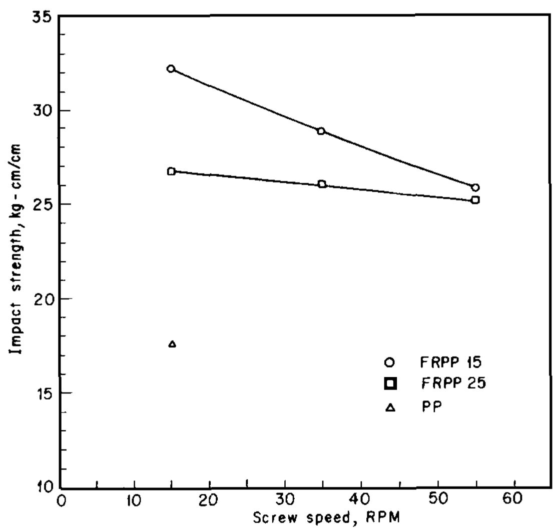


**Figure 17** Impact strength of PP, FRPP15, and FRPP25 versus screw speed. FRPP15: 230°C, slow cooling; FRPP25: 230°C, slow cooling; PP: 230°C, quick cooling.

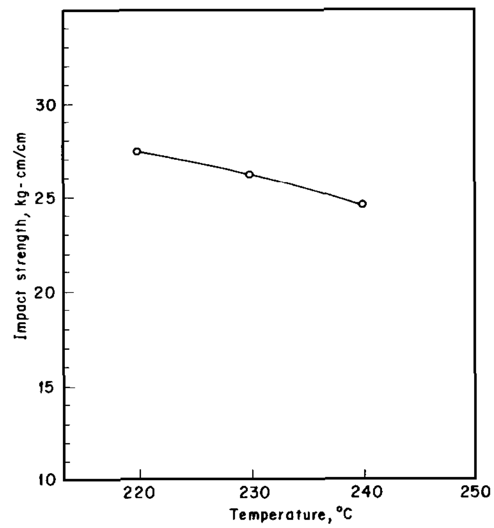


**Figure 19** Variation of impact strength with temperature of extrusion for FRPP15. 35 rpm, quick cooling.

strength of FRPP15 with extrusion temperature. The higher the temperature was, the lower the impact strength would be.

It was concluded that the extrusion conditions, such as screw speed, temperature, and fiber content, would influence the mechanical properties of FRPP significantly. The specimens at different positions of extrudate showed different mechanical strength. All experimental observation would be well explained from the combination of the factors of fiber length, fiber orientation, void content, and morphology of crystallization of PP.

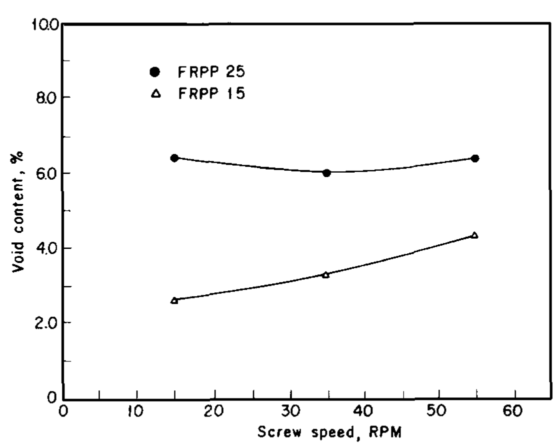


**Figure 18** Void content of FRPP15 and FRPP25 versus screw speed. FRPP25: 230°C, slow cooling; FRPP15: 220°C, slow cooling.

## REFERENCES

1. Y. Chan, J. L. White, and Y. Oyanagi, *Polym. Eng. Sci.*, **18,** 268 (1978).
2. R. J. Crowson and M. J. Folkes, *Polym. Eng. Sci.*, **20,** 934 (1980).
3. R. V. Turkovich and L. Erwin, *Polym. Eng. Sci.*, **23,** 743 (1983).
4. P. F. Bright, R. J. Crowson, and M. J. Folkes, *J. Mater. Sci.*, **13,** 2497 (1978).
5. N. Laws and R. McLaughlin, *J. Mech. Phys. Solids*, **27,** 1 (1979).
6. L. Kacir, O. Ishai, and M. Narkis, *Polym. Eng. Sci.*, **18,** 45 (1978).
7. E. J. Kohn, A. G. Sands, and R. C. Clark, *Ind. Eng. Chem. Prod. Res. Dev.*, **7,** 197 (1968).
8. M. W. Darlington and G. R. Smith, *Polymer*, **16,** 459 (1975).
9. G. Titomanlio, S. Piccarolo, and G. Marrucci, *Polym. Eng. Sci.*, **25,** 91 (1985).
10. L. D. Coxon and J. R. White, *Polym. Eng. Sci.*, **20,** 230 (1980).
11. J. Kubat and M. Rigdahl, *Polym. Eng. Sci.*, **16,** 792 (1976).
12. W. Y. Chiu and G. D. Shyu, *J. Appl. Polym. Sci.*, **34,** 1493 (1987).
13. Cheng Chen Fan-Chiang, Master thesis, National Taiwan University, Taiwan, R.O.C., 1987.
14. H. J. Tai, Master thesis, National Taiwan University, Taiwan, R.O.C., 1988.

*Received March 26, 1990*
*Accepted January 9, 1991*