Melt Strength and Extrudate Swell of High-Melt-Strength Polypropylene

Masataka SUGIMOTO, Yuichi MASUBUCHI, Jun-ichi TAKIMOTO, and Kiyohito KOYAMA*

*Department of Materials Science and Engineering, Yamagata University,
Jonan 4-3-16, Yonezawa, 992 Japan
(Received: January 20, 1999)*

Key Words : High-melt-strength polypropylene / Melt strength / Extrudate swell /

1. INTRODUCTION

The linear polypropylene (PP) of commerce has many desirable and beneficial physical properties. PP is also one of superior materials having reusability. Therefore polypropylene has been expected in various applications. Polypropylene is, however, linear polymer which exhibits low melt strength and weak strain hardening behavior in elongational flow. One of effective approaches to achieve the high melt strength is adding long chain branches or grafting on to backbone species. It is possible to crosslink PP by irradiation of an electron beam and by addition of a peroxide.^{1~4)} The PP branching or grafting shows the high melt strength and the strain hardening. The modifications cause the broadened molecular weight distribution (MWD) owing to the simultaneous two chemical reactions: β -scission and recombination of radicals formed in polymer materials. The PPs used here were not treated with an electron beam and a peroxide, their MWD were similar to that of general commercial PP. Nevertheless, some samples showed the marked high melt strength. This is a basic study to demonstrate how the melt strength and extrudate swell of the high-melt-strength PP are influenced by the temperature and the melt flow rate.

2. EXPERIMENTAL

2.1 MATERIALS

We used conventional PPs (e.g., PP-A) and high-melt strength PP grades "NEWTREN" (e.g., PP-B) supplied by Chisso Petrochemical Co. Melt flow rate (MFR), average molecular weight and molecular weight

distribution for representative samples (PP-A, and PP-B) are summarized in Table I. The presence of long chain branching was, however, evident neither for PP-A nor for PP-B by GPC-LALLS. The molecular weight distribution estimated by GPC of the PP-B was similar with that of conventional PP, i.e., PP-A.

2.2 METHODS

The examined rheological properties were melt strength and swell ratio which were measured by Capilograph (Toyoseiki Co. Ltd.) having orifice of 2.095 mm. The melt strength (cN: centi-Newton) was measured after keeping the samples at constant temperatures of 180 to 250 °C for 5 min. The extrusion rate and the take up velocity were 20 mm/min. The swell ratio was obtained from the ratio of the extrudate diameter to the orifice, the extruding condition was the same with that of the melt strength measurement. MFR was obtained by weighing the flowed PP for 10 min under 0.212 N at 230 °C using a melt flow indexer (Toyoseiki Co. Ltd.).

3. RESULTS AND DISCUSSION

A dependence of the melt strength on temperature is shown in Fig. 1. The melt strength of PP-B was much higher than that of PP-A in the temperature range considered. As might be expected, the melt strength of conventional PP-A decreased with increasing temperature owing to a decrease of the relaxation time. The dependence of the melt strength for PP-B on temperature was rather weaker than that of PP-A. Fig. 2

Table I Average molecular weights of samples

Sample	MFR	Mw/10 ⁵	Mw/Mn	Mz/Mw
A	2.7	2.7	4.1	3.0
B	3.2	2.4	4.0	2.9

*To whom correspondence should be addressed.
Phon: +81-238-26-3058, Fax +81-238-26-3411
e-mail: kkoyama@eie.yz.yamagata-u.ac.jp

shows the effect of the MFR which may correlate with the weight-average molecular weight on the melt strength. The superiority of the high-melt-strength PP tended to become higher as increasing the MFR. In Fig. 3, with increasing the MFR, the swell ratio of the high-melt-strength PP increased. This is contrary tendency to that of conventional PP.

As mentioned above the high-melt-strength PP showed the marked high melt strength, and the high extrudate swell ratio which may originate mainly from elastic strain recovery. Nevertheless, the relationship between molecular weight and radius of gyration obtained by GPC-LALLS in far dilute solutions of the high melt-strength PP was almost similar to that of the conventional PP. One explanation may be due to a presence of a few linear or branching UHMW components which could not be dissolved in a solvent, or could not pass through the columns owing to the huge molecular size. Besides this, the level of branching might be less than the lower limits of measurement by LALLS. Furthermore there is one other thing that is important in the estimation of

Fig. 1 Variation of melt strength with temperature for polypropylene. Sample: (×), conventional PP (PP-A); (●), high-melt-strength PP (PP-B).

Fig. 2 Variation of melt strength with melt flow rate for polypropylene at 210°C. Sample: (×), conventional PP; (●), high-melt-strength PP.

Fig. 3 Variation of swell ratio with melt flow rate for polypropylene at 210°C. Sample: (×), conventional PP; (●), high-melt-strength PP.

branches. In the LALLS measurement if the gyration radius of branching chain is similar to that of its linear analog, we cannot distinguish whether the chain is linear or branching one. Therefore we cannot, at this moment, say for certain what gave raise to the rather unusual melt strength and extrudate swell behaviors. As regarding the homogeneous blends with its linear ultra-high molecular weight analog, there are some studies on the elongational behavior mainly for the amorphous polymer systems.⁵⁻⁸⁾

To discuss the mechanism of the enhanced melt strength of the high-melt-strength PP, further details on the melt behaviors regarding the chain structure will be reported in the near future.

REFERENCES

- 1) U. S. Patent, 4,916,198, (1980) Himont Inc., Scheve BJ, Mayfield JW, Denicola AJ, C. A. 105: 19185e.
- 2) Yoshii F, Makuuchi K, Kikukawa S, Tanaka T, Saitoh J, Koyama K, *J Appli Polym Sci*, **60**, 617 (1996).
- 3) Wong B, Baker WE, *Polymer*, **38**, 2781 (1997).
- 4) Sugimoto M, Masubuchi Y, Takimoto J, Koyama K, to be published.
- 5) Koyama K, Ishizuka O, *Nihon Reoroji Gakkaishi*, **13**, 93 (1985).
- 6) Koyama K, *Nihon Reoroji Gakkaishi*, **19**, 174 (1991).
- 7) Deguchi T, Takahashi M, Masuda T, *Nihon Reoroji Gakkai Preprints*, **24**, 68 (1997).
- 8) Minegishi A, Naka Y, Takahashi T, Masubuchi Y, Takimoto J, Koyama K, *Nihon Reoroji Gakkaishi*, **25**, 215 (1997).