

Development of High Strength Polyethylene Fiber from Local Materials for Ballistic Applications

Taweechai Amornsakchai¹, Narong Nakornpoom¹, Nuntikant Chaiwong¹ and Kuljira Sujjrote²

¹Department of Chemistry, Faculty of Science, Mahidol University,

Rama 6 Rd, Phayathai, Bangkok 10400

Phone 0-2441-9816 ext 1161, Fax. 0-2441-9322, E-Mail: sctam@mahidol.ac.th

²National Metal and Materials Technology Center, 114 Thailand Science Park,

Paholyothin Rd., Klong 1, Klong Luang, Pathumthani 12120

Phone 0-2564-6500 ext. 4225, Fax.0-2564-6447, E-Mail: kuljiras@mtec.or.th

Abstract

Polymeric fibers have now played a very important role in ballistic applications. In this presentation, high strength polyethylene fiber with tensile modulus in excess of 30 GPa and tensile strength about 1000 MPa has been developed from local materials as a less expensive alternative. Effect of some processing parameters on properties of as-spun and drawn fiber was presented.

1. Introduction

Polymeric fibers have a very strong position in ballistic applications. These include polyethylene fibers such as Spectra[®] and Dyneema[®], Aramid fibers such as Kevlar[®] and Twaron[®] and PBO fiber such as Zylon[®]. Current situation in Thailand has raised an awareness for the development of material for ballistic applications. Various types of fibers, both synthetic and natural, have been tested for the applications. Polyethylene has very high potential for producing high modulus and high strength fibers [1]. There are two main routes to produce polyethylene fibers, i.e. melt spinning [2-4] and solution or gel spinning [5]. The latter involves ultra high molecular weight polyethylene (UHMWPE) and a large amount of solvent in the production. Because of the very high molecular weight

of the material, fiber with very high modulus and strength in excess of 70 GPa and 2.7 GPa, respectively, has been produced and marketed. However, the fiber produced from this method is very expensive due to the nature of the method. Melt spinning, although appropriate to material with lower molecular weight, is an attractive alternative. No solvent is required in the fiber production. The process is therefore much less expensive and also more environmental friendly. Although, polyethylene fiber produced by melt spinning is commercially available and has been around for quite a long time. This fiber has rather low modulus and strength in the region of 4-6 GPa and 400-500 MPa, respectively. To produce stronger fibers, polyethylene needs to be drawn to very high draw ratio exceeding that used in conventional fiber production. It is the objective of the project to develop high strength from local materials. Targeted fiber should have modulus in excess of 30 GPa and tensile strength of about 1000 MPa. In this presentation, preliminary results on the development of this high strength fiber were reported. This includes effect of some processing parameters on the properties of as-spun fibers and also properties of some drawn fibers.

2. Experimental

High density polyethylenes (HDPE) employed in the present study were blends of Thai-zex[®] 6200B and 1600J at a ratio of 50:50 (Blend A) and 5000S and 1600J at 70:30 (Blend B). Fiber was prepared on a Randcastle monofilament line as schematically shown in Figure 1. Fiber was prepared by 2-step method. Extruder temperatures were set at 140, 180, 190 and 215°C for zone 1, 2, 3 and die, respectively. As-spun fiber was spun at a

screw speed of 5 rpm, or otherwise stated. The fiber was allowed to cool in air. The as-spun fiber had a diameter of about 500 μm . The as-spun fiber was drawn to different draw ratios with two sets of rollers through a glycerol bath set at 110°C. Draw ratio was calculated from the ratio of the speed of the follower to leader roller. Tensile testing was carried out at room temperature with sample gauge length of 50 mm and a crosshead speed of 25 mm/min.

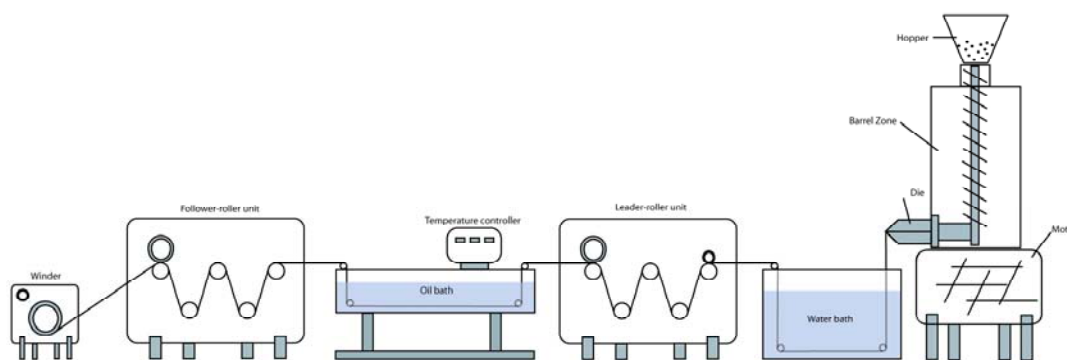


Figure 1. Schematic diagram of a Randcastle monofilament line employed in the study.

3. Results and discussion

High strength fiber is obtained by drawing the as-spun fiber to very high draw ratios. Therefore, the drawability of the fiber is controlled by both the properties of as-spun fiber and drawing conditions. Generally, as-spun fiber with high crystallinity and low orientation would provide higher draw ratio. Table 1 displays yield stress, which relates to crystallinity, of as-spun fibers produced with different screw and collection (leader) speeds. It is clear that condition with lower screw and leader speeds provides as-spun fiber with higher yield stress. If the leader speeds are increased, yield stress of the as-spun fiber would decrease, as shown in Table 2. Therefore, to obtain as-spun fibers with high yield stress, the spinning speed has to be compromised.

Yield stress of as-spun fiber can also be controlled by lower cooling rate. As-spun fiber was fed through an aluminium tube (25 mm in diameter and 420 mm in length) to retard

cooling before being quench in water and collected. The results are shown in Table 3. It can be seen that by using

Table 1 Yield stress of as-spun fibers obtained with different screw speeds and leader speeds. (Blend A).

Screw speed x Leader speed (rpm)	Yield Stress of as-spun (MPa)
1x1	26.6 \pm 1.0
3x3	24.5 \pm 0.4
5x5	23.9 \pm 0.2
7x7	21.1 \pm 0.6
9x9	19.3 \pm 0.4

Table 2 Yield stress of as-spun fiber obtained with fixed screw speed and collected with different leader speeds. (Blend A).

Screw speed x Leader speed (rpm)	Yield stress of as-spun fiber (MPa)
1x1	25.6 \pm 0.7
1x3	23.6 \pm 0.6
1x5	22.9 \pm 0.3
1x7	22.4 \pm 0.4

an aluminium tube, yield stress of as-spun fiber could be increased.

Table 3 Yield stress of as-spun fibers obtained with and without aluminium tube to retard cooling. (Blend A).

Sample	Cooling Method	
	With Al. Tube	Without Al. Tube
1	23.7	22.6
2	24.3	22.8
3	23.6	21.5
4	24.2	21.2
5	23.4	21.4
Average	23.8 ± 0.4	21.9 ± 0.7

Selected as-spun fibers were drawn to various draw ratios. Tensile modulus and strength of drawn fibers are shown in Figure 2. Fiber with modulus as high as 43 GPa and strength about 1000 MPa can be produced. This high strength fibers have much higher mechanical properties than conventional polyethylene fiber.

Stress-strain curves of this high strength fiber depend very much on strain rate as shown in Figure 3. This suggests that the fiber could be much stronger when subjected to load at the ballistic speed.

4. Conclusion

High strength polyethylene fiber with tensile modulus in excess of 30 GPa and tensile strength about 1000 MPa can be produced from local polyethylenes. The spinning conditions such as screw and collection speeds and cooling can be optimised to provide as-spun fibers with high yield stress. Generally, low screw and collection speeds and slow cooling are preferred. High strength drawn fiber shows very high sensitivity to strain rate and is expected to be much stronger when subjected to load at ballistic speed.

Acknowledgements

Technical assistance from the Ballistic testing unit, Center for defense industry and military energy is kindly acknowledged.

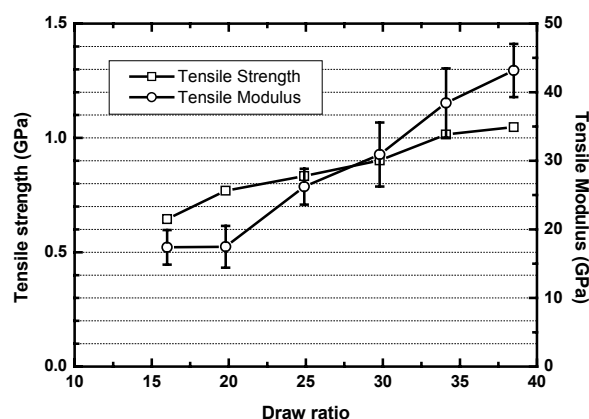


Figure 2 Tensile modulus and strength of fibers drawn to different draw ratios. (Blend B).

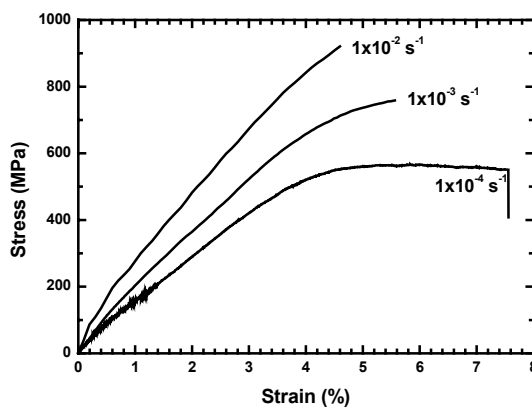


Figure 3 Fiber (draw ratio 30X) behavior under tensile stress at different strain rate and its measured strength. (Blend A).

References

- [1] Treloar, L. R. G., *Polymer*, **1**, 95, (1960).
- [2] Andrews, J. M. and Ward, I. M., *J. Mater. Sci.*, **5**, 411 (1970).
- [3] Capaccio, G. and Ward, I. M., *Polymer*, **15**, 233 (1974).
- [4] Wu, W. and Black, W. B., *Polym. Eng. Sci.*, **19**, 1163 (1979).
- [5] Smith, P. and Lemstra, P.J., *J. Mater. Sci.*, **15**, 505, (1980).