Effects of Roller Speed, Temperature, Extrusion Rate and Multiple Extrusions on Mechanical Strength of Molten and Solidified LDPE under Tensile Deformation

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Abstract: An experimental rig was specially designed and constructed for real-time measurements of drawdown forces as a function of volumetric flow rate, die temperature and roller speed for neat low-density polyethylene (LDPE) and reprocessed LDPE during filament stretching process. The mechanical strength of the LDPE samples under both molten and solidified states were discussed. In the molten state, the drawdown force for LDPE melts was dependent on volumetric flow rate, die temperature, roller speed and the number of reprocessing time. In the solidified state, the tensile properties of the solidified LDPE increased with roller speed, but decreased with die temperature and volumetric flow rates. The effect of number of extrusion pass for solidified LDPE was similar to that for molten LDPE. In the case of volumetric flow rates, the mechanical properties of the solidified LDPE reduced with increasing volumetric flow rate, whereas those of the molten LDPE enhanced. The mechanical strength of the molten LDPE could not always be used to assess the mechanical properties of the solidified LDPE.

Keywords: Mechanical strength, Reprocessing, Rheological properties, Low-density polyethylene.

1. Introduction

Elongational flow is an important flow in polymer processes and is significantly affected by molecular weight, draw ratio and various processing parameters [1-3]. According to recent literatures, there have been a large number of investigations on the effects of reprocessing on mechanical, thermal and flow properties under shear deformation for a wide range of polymers, but very rare have been given to studies on the effect of reprocessing on the elongational flow properties of polymer melts, and their mechanical properties of the polymer in the solidified form, under multiple extrusion processes where the molten polymers are under tension deformation.

In this work, the extruded melts (filaments) were solidified and collected for studying the mechanical properties. The mechanical strength of neat LDPE and reprocessed LDPE were investigated under both molten and solidified states and the results were discussed in terms of magnitude changes under a various of processing conditions (volumetric flow rate, die temperature and roller speed). The effect of number of extrusion pass for the reprocessed LDPE was our main interest.

2. Experimental

2.1 Raw Material

Low-density polyethylene (LD1905FA), with a melt flow index of 5 g/10 min was used and supplied by Thai Polyethylene Co., Ltd. (Bangkok, Thailand).

2.2 *Extrusion process and filament winding equipment*

The mechanical strength of LDPE melt was evaluated under tension deformation. **Fig. 1** shows an experimental arrangement for melt strength measurement under the filament winding process. The experimental rig was connected to the end of a single screw extruder used for production of molten LDPE which was then extruded through a circular die before being pulled down to form a continuous filament which was then solidified by ambient air, and collected for studying the tensile properties. To produce re-processed LDPE, the extruded LDPE were pelletized using a pelletizing and cooling unit, collected and re-fed into the extruder and the LDPE were re-processed for four times.

The extrusion speed of the single screw extruder (L/D = 600/25) was varied from 10 to 30 rpm. This would produce volumetric flow rates of LDPE melt of 2.9 – 8.3 x 10^{-7} m^3/s and die temperatures used were 160, 170 and 180°C. For solidified LDPE filament, the tensile test was conducted following the ASTM (D638-08).

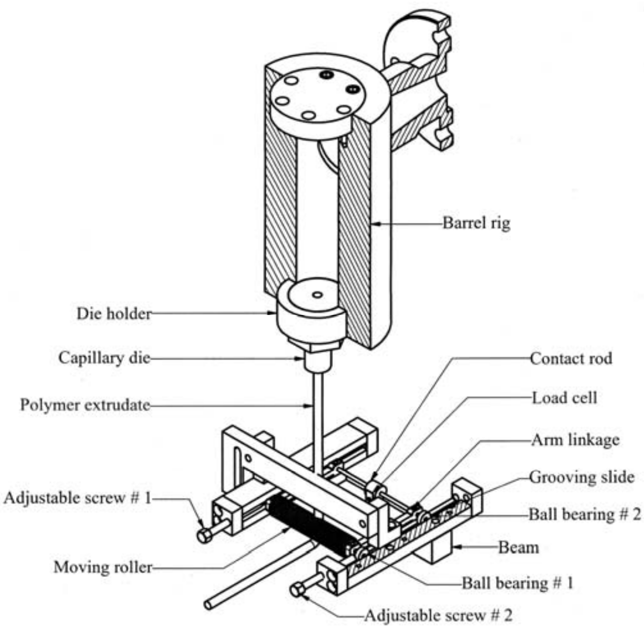

Fig. 1 An experimental arrangement for melt strength measurement

3. Results and Discussion

3.1 Mechanical properties of molten LDPE

Fig. 2 shows curves of drawdown force against drawdown time for three different volumetric flow rates with increasing step-ladder roller speed at 160°C. The results suggested the drawdown forces sharply increased in the initial stages of increasing roller speeds of less than 50 sec drawdown, and then increased with a lesser extent at the final stage of increasing roller speeds. The significant increases in the drawdown force at the initial roller speeds were associated with relatively high molecular entanglement resulting in the elastic resistances to the applied deformation. The force required to deform the melt during higher roller speeds was smaller due to the fact that the molten LDPE molecules at this stage became disentangled and flowed past one another. At higher the volumetric flow rate the greater that drawdown force with longer drawdown time due to higher energy inputs given from the extruder with higher extrusion rate, and such energy could be stored within the LDPE melt during the flow in the die and thus detected by the load cell apparatus. This could be substantiated by Baldi *et al*, [2] and Muke *et al* [4].

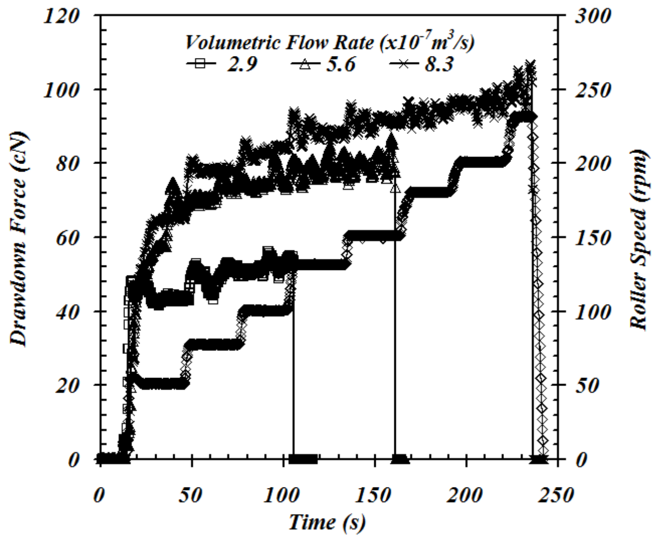

Fig. 2 Plot of drawdown force as a function of roller speed and drawdown time for three different volumetric flow rates

3.2 Effects of reprocessing for molten LDPE

Fig. 3 shows plots of drawdown force against time and step-ladder increasing roller speed at a die temperature of 160°C using three different volumetric flow rates (**Figs. 3a-3c**). The effect of reprocessing on the drawdown force and time at the volumetric flow rate of 2.9x10^{-7} m^3/s (**Fig. 3a**) was not significant as compared to that at higher volumetric flow rates (**Figs. 3b and 3c**). This was due to relatively low shear heating effect for the LDPE melt with at the volumetric flow rate of 2.9x10^{-7} m^3/s. In this work, it was stated that the shear heating effect could probably be caused by molecular chain scission and/or crosslinking. This could be substantiated by the gel-content experiment which was carried out by immersion of the LDPE experienced from different numbers of extrusion pass and different volumetric flow rates in xylene solvent and the gel content determination was calculated according to ASTM D 2765-01 (2001).

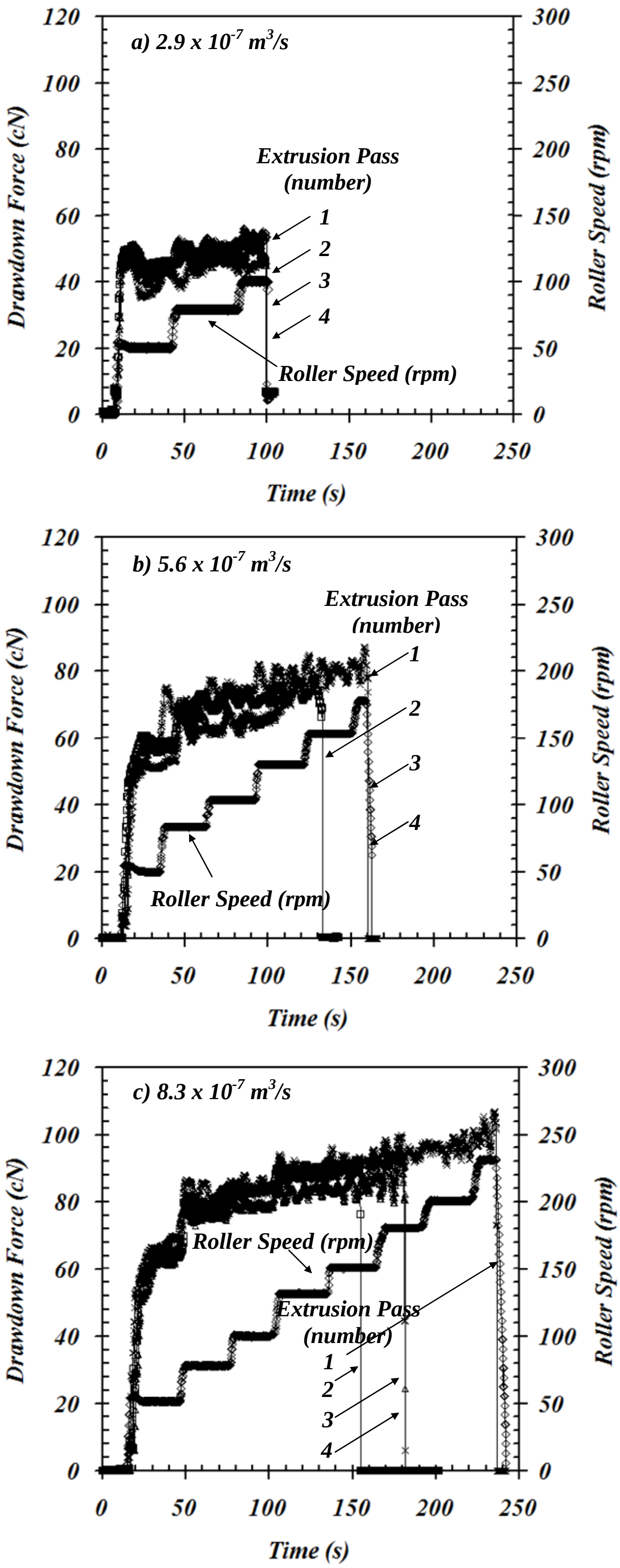

Fig. 3 Drawdown force as a function of drawdown time at 160 ^{o}C of die temperature for a various volumetric flow rates : (a) 2.9x10^{-7} m^3/s, (b) 5.6x10^{-7} m^3/s, (c) 8.3x10^{-7} m^3/s

The gel content results are given in **Table 1**. It can be seen that the changes in gel content were not significant for the sample with low volumetric flow rate suggesting that there was no apparent cross-linking occurring in the LDPE. That was why there were no differences in drawdown force stated in **Fig 3a**. The cross-linking had occurred in the extrusion pass number 4 for LDPE with volumetric flow rate of 5.6x10^{-7} m^3/s and in the extrusion pass numbers 3 and 4 for LDPE with volumetric flow rate of 8.3x10^{-7} m^3/s. The gel content results in **Table 1** corresponding to the drawdown force results in **Fig. 3**, which suggested that the cross-linking structure resulted in increases in the drawdown force and draw time.

Table1. Gel content of reprocess LDPE

The Number of Extrusion Pass	Gel Content (%)		
	Volumetric flow rate (m^3/s)		
	2.9 x 10^{-7}	5.6 x 10^{-7}	8.3 x 10^{-7}
1	0.51	0.95	0.57
2	0.67	1.04	1.86
3	1.11	1.24	9.64*
4	0.85	4.87*	18.23*

* Gel content was clearly observed

3.3 Mechanical properties of solidified LDPE

Fig. 4 shows tensile strength for neat LDPE and reprocessed LDPE samples using a die temperature of 160 ^{o}C collected from different roller speeds and three different volumetric flow rates. In all volumetric flow rates, as the roller speed was increased the tensile strength appeared to increase. This was because higher roller speed, which led to higher molecular orientations of LDPE during solidification. This view could also be supported by the work of Zhang *et al* [5] who stated that LDPE could produce long and twisted lamellar orientation morphology at high draw ratio from the melt spinning process.

In low volumetric flow rate (**Fig. 4a**), the tensile properties appeared to decrease with increasing number of extrusion pass. This was probably due to a decrease in molar mass of the LDPE. In the higher volumetric flow rates (**Figs. 4b and 4c**) the tensile strength decreased at the extrusion pass #2, but started to regain or increase at the extrusion passes #3 and #4. The increase in the tensile strength was associated with the gel-content results given in **Table 1**.

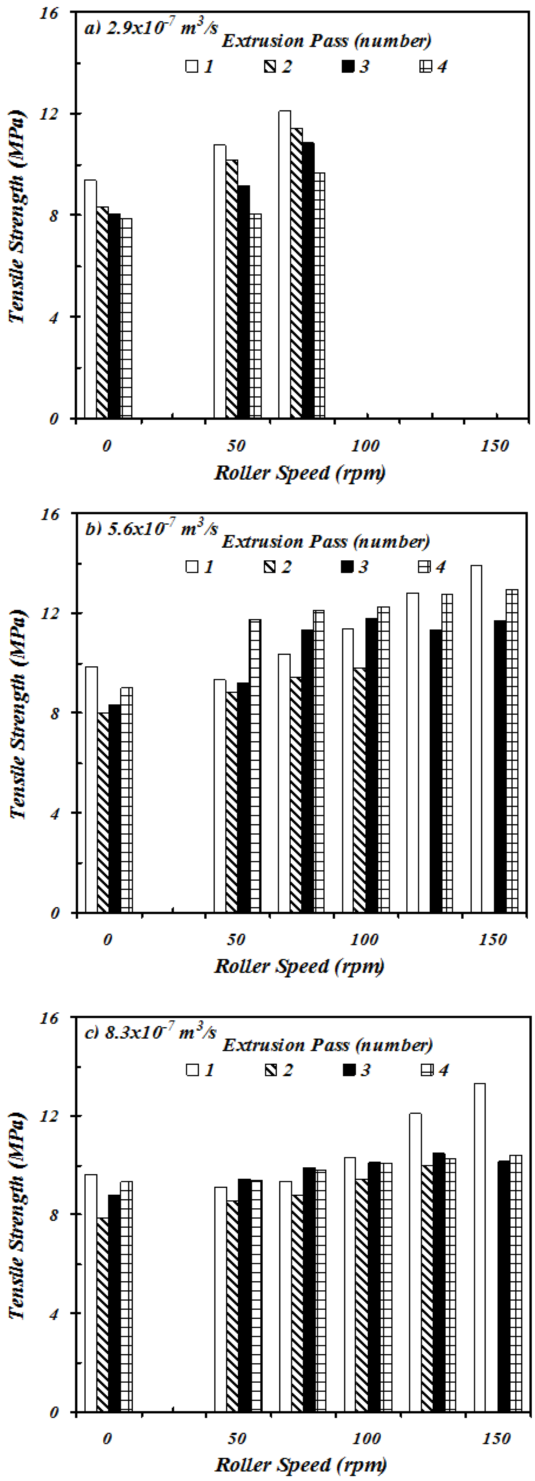

Fig. 4 Tensile strength as a function of roller speed for a various volumetric flow rate: (a) 2.9×10^{-7} m^3/s, (b) 5.6×10^{-7} m^3/s, (c) 8.3×10^{-7} m^3/s

The results in **Fig. 4** interestingly suggest that, for any given roller speeds, increasing the volumetric flow rate resulted in decreases in tensile properties. This was due to that higher extrusion rate or volumetric flow rate produced higher shearing stresses to the melt during the flow and this would cause molecular degradation of the melt and thus weakening the mechanical strength of the solidified LDPE. Besides, the cross-linked structure of molten LDPE may cause more difficulty in crystallization of the LDPE during cooling.

4. Conclusions

In the molten state, the drawdown force was dependent on volumetric flow rate, die temperature, roller speed and the number of reprocessing time. The drawdown force for molten LDPE was not affected by number of extrusion pass at low volumetric flow rate, but influenced at high volumetric flow rates. The tensile properties of the solidified LDPE appeared to increase with roller speed, but decreased with die temperature. The effect of number of extrusion on tensile properties for solidified LDPE was similar to that for molten LDPE. In the case of volumetric flow rates, the tensile properties for the solidified LDPE worsened when the volumetric flow rate was increased, but the opposite was observed for the molten LDPE. The mechanical strength of the molten LDPE could not always be used to assess the mechanical properties of the solidified LDPE.

Acknowledgments

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References

1. M. H. Wagner, B. Collignon, and J. Verbeke, *Rheol. Acta*, **35**, 117 (1996)
2. F. Baldi, A. Franceschini, and T. Riccò, *Rheol. Acta.*, **46**, 965 (2007)
3. M. H. Wagner, H. Bastian, A. Bernnat, S. Kurzbeck, and C. K. Chai, *Rheol. Acta*, **41**, 316 (2002)
4. S. Muke, I. Ivanov, N. Kao, and S. N. Bhattacharya, J. *Non-Newt. Fluid Mech.*, **101**, 77 (2001)
5. X.M. Zhang, S. Elkoun, A. Ajji, M.A. Huneault, *Polymer*, **45**, 217 (2004)