Effect of Low-Molar-Mass Liquid Crystal on the Melt Processing Conditions of Polycarbonate Using Single Screw Extruder

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ABSTRACT: This research concerned about the effects of low-molar-mass liquid crystal (LMLC) blend with polycarbonates (PCs) that influence the processing conditions (torques) without detrimental to the benign properties of PC. The two PCs, having different weight-average molar mass (PC2600 and PC2405), were blended with LMLC (CBC-33) at concentration about 0.2 wt % using a single screw extruder. As confirmed by the previous observation of Motong et al. (J Appl Polym Sci 2008, 107, 1108), the LMLC could act as a melt viscosity reduction additive for PCs. Because of the reduction in melt viscosity of PC, the operating torque of a single screw extruder used when extruding PC blended with LMLC was reduced up to 83% depended on the mixing condition of LMLC. The mechanical properties were determined by tensile testing specimens from injection molding machine, and the difference of tensile strengths and modulus of elasticity between pure PCs and their blends was less than 10%, which indicated the very low detrimental effects to mechanical properties of the LMLC blend. © 2009 Wiley Periodicals, Inc. J Appl Polym Sci 113: 752–756, 2009

Key words: blending; extrusion; mixing; polycarbonates; processing

INTRODUCTION

Novel properties have been found when blending conventional thermoplastics with liquid crystal polymers. Liquid crystal polymers were known as a new class of engineering polymers, which have the anisotropic properties at certain conditions. The main purpose of blending liquid crystal polymers into isotropic polymer is to decrease the viscosity and increased the mechanical properties.[1] Oriented low-molar-mass liquid crystal (LMLC) polymers can increase the diffusion of the melted polymer molecules[2,3] and reduce the melt viscosity.[4] The reductions of the viscosity of the blends allow the reduction of the processing temperatures that will result in lower the detrimental degradation and saving of the processing energy. Moreover, the sophisticate or delicate mold can be possible to use with the blends. In other word, the processing condition of the lower viscosity blends will be enhanced and accessible. There have been a considerable number of papers in the literatures dealing with phase transitions, characterization of mesophase (the phase that molecules of liquid crystal have an alignment), flow behavior, and mechanical properties of these materials. For instance, Nobile et al.[5] have added about 10 wt % of high-molar-mass liquid crystal (HMLC) polymers in polycarbonate (PC); the viscosity of the blends reduces when compared with the pure PC. In this research, the blends of LMLC were studied instead of HMLC polymer, and the amount of LMLC added was in the range of only 0.2 wt % incomparable with the large amount of HMLC added. In United State Patent (4,434,262), Buckley et al.[6] have studied and improved melt processing blend comprising of a polymer selected from the group consisting of a polyolefin and polyester and a LMLC compound, which is capable of forming an anisotropic melt phase at the melt processing temperature of the blends. However, the usages in the different kind of polymers have not been reported vividly.

Polymeric blends of melt processable polymers and HMLC compounds have been studied in many researches.[7–13] The main reason of blending HMLC with other polymers is to improve the mechanical properties of matrix polymer. Very few researchers have studied about LMLC blends for improving the melt viscosity of the blends since. Consequently, this

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TABLE I
Properties of CBC-33

Melting point	158°C
S-N transition temperature	223°C
Clearing point	327°C
Melting enthalpy	13 kJ/mol
Molar mass	402.67 g/mol

study deals with polymer processing systems of thermoplastic PC and LMLC blends in the single screw extruder. The LMLC, (CBC-33 or 4, 4′-bis (4-propyl-cyclohexyl)-biphenyl), from Merck Company, was chosen to blend with PC because it has the nematic structures in the same range as the processing temperatures of PC. Normally, the melting viscosity of PC is very high and it is difficult to process those materials. The additions of CBC-33 can reduce the operating torques of the processing machines dramatically even use in the low range of 0.2 wt % because of the decrease of melt viscosity of PC.

EXPERIMENTAL

Materials

PC was provided by Bayer Polymers Co. commercial grade having a trade name of "MAKROLON." Two different molar mass of PC used in this work have the average molar mass of 43,493 and 35,806 g/mol. The melt flow indexes at 300°C with 2.16 kg weight are at 19.88 and 23.14 g/10 min, respectively. The appearances of both PCs studied are transparent pellets, and they are noted as PC2600 and PC2405, respectively. The CBC-33 is represented the class of LMLC and has been purchased from Merck Co. under the trade name of "LICRISTAL." The glass transition temperature of both CBC-33 and PC are both around 150°C. The liquid crystal properties of CBC-33 are shown in Table I and their structure is shown as Figure 1.

Samples preparations

The preparation of master batch contained 8 wt % of CBC-33

To test the method of dispersing the LMLC, the master batch of 8.8 wt % LMLC was prepared and will further mix with the nascent PC in the processing machine. The preliminary master batch blends between PC2600 and CBC-33 were prepared manually using the digital hot plate at 290°C. PC2600 weighed about 15 g was first melted on the teflon-coated plate and added with CBC-33 at about 1.2 g (around 8 wt %). The hot plate was set at 290°C and the blend of PC2600 and CBC-33 was melted mixing manually together for 15 min to have uniform mixtures. After that, the melted blend was put between the heat resistance Kapton films and then compressed for 2 min by the hydraulic hot press at 290°C of 250 kg/cm^3. The resulted blend is in the transparent thin film form and was cooled by air and cut to pieces after removed from the hot press. The master batch of PC2405, the different type of PC, was prepared by the similar procedures but replaced with PC2405 instead of PC2600.

Sample preparation using a single screw extruder

The pure PC2600, PC2405, and the master batch of PC2600 and PC2405 were vacuum dried at 120°C for 24 h before usage in the single screw extruder. Compounding of the materials was done using a Haake single screw extruder model Rheocord R252. Screw diameter is 19.05 mm with L/D of 25 : 1, compression ratio is 3 : 1. Die type is rod die with a die diameter of 3 mm. The operating temperatures of the single screw extruder were set at 260, 270, and 280°C for zone 1, 2, and 3, respectively; die temperature was set at 280°C and cooling temperature was set at 35°C with the screw speed set at 20 rpm. First, pure PC2600 was fed into the hopper of the extruder and the operating torque was noted after 3 min, and the extruded strand was cut into small pellets by a pelletizer with a cutting speed about 300 rpm. The torque detected was noted as pure PC2600 Torque. Second, the pure PC2600 and master batch of CBC-33 (having a concentration about 8 wt %) were mixed as pellets in the plastic bag to obtain the blend with the total concentration of CBC-33 about 0.2 wt %. After that, the well-mixed pellets blend was fed into the extruder. After 3-min pass, the operating torque was noted as PC2600-master-batch Torque, and the strand was cut into the pellet formed. Finally, a part of the pellets from the second processes were fed back into the extruder again. After 3-min pass, the strand was palletized and kept as the PC2600-remix and the operation torque was noted as PC2600-remix Torque. When used up the blend, HDPE was fed to clean the extruder. With the same procedures, the PC2405, which is the different type of PC, was applied instead of PC2600 and the experimental methods were repeated, and the single screw extruder was operated in the same manner as described earlier.

RESULTS AND DISCUSSION

Effect of LMLC on operating torque of the single screw extruder

The operation torque of a single screw extruder when extruding pure PC2600, PC2600 blended with CBC-33

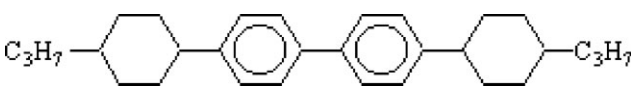

Figure 1 The CBC-33 structure.

(PC2600-master-batch), PC2600-remix, pure PC2405, PC2405 blended with CBC-33 (PC2405-master-batch), and PC2405-remix is shown in Table II. The operation torque of a single screw extruder, when extruding the blends between PC and CBC-33, was lower than pure PC according to the lower melt viscosity of PC with CBC-33. In the case of PC2600, the operation torque of a single screw extruder used when extruding PC2600 and master batch of CBC-33 (PC2600-master-batch) was decreased about 17%, and the torque value of a single screw extruder used when extruding PC2600-remix was reduced about 76%. These reductions in torques represented the well mixed conditions of the blends between PC and CBC-33. The most well mixed condition is the remix blends, which have lowest torque. However, the blend by master-batch mixed condition can also lower down the torques compared with the pure PC according to the addition of the CBC-33. In the case of PC2405, the operation torque of the single screw extruder, when extruding PC2405 and master batch of CBC-33 (PC2405-master-batch), was decreased about 39%, and the operation torque of the single screw extruder used when extruding PC2405-remix was reduced about 83%. Because PC2405 has lower molecular weight than PC2600, the torque of the pure PC of PC2405 and its blends are lower than that of PC2600. Moreover, the similar trend of the mixing condition of CBC-33 can also be found.

The decrease in melt viscosity can be implied from the reduction of the operation torque, which can be vividly showed in Figure 2. The lower molar mass PC (PC2405) that have lower operating torque behaved similarly to the higher molar mass PC (PC2600) but with the greater effects (lower %). The phenomenon can be seen in Figure 3.

With the same conclusions by Motong et al.[4] in 2008, this phenomenon might assure that LMLC could act as a viscosity modifier for PC in the processing single screw extruder. Therefore, to obtain the same viscosity, the reduction in the processing temperature of PC can be achieved without significantly increase the operation torque more than the normal

TABLE II
The Operating Torques of the Single Screw Extruder

Samples	Torque (Nm)	Color of sample
Pure PC2600	30.3 (100%)	Clear
PC2600 + 0.2 wt % CBC-33 (master batch)	25.1 (83%)	Clear
PC2600 + 0.2 wt % CBC-33 (remix)	7.2 (24%)	Light yellow
Pure PC2405	21.0 (100%)	Clear
PC2405 + 0.2 wt % CBC-33 (master batch)	12.9 (61%)	Clear
PC2405 + 0.2 wt % CBC-33 (remix)	3.6 (17%)	Light yellow

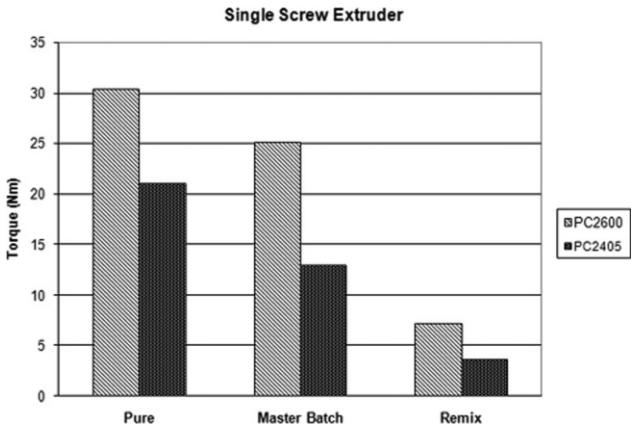

Figure 2 Operation torque of the single screw extruder, when melting pure PC2600, PC2405, and their blends with CBC-33, grouping as three preparation procedures.

operation of pure PC. More over, as can be proven by Motong et al.[3] in 2007, the depression in T_g might be neglect, which is important for polymer processing industries because of very small amount of LMLC added. The reduction in operation torque of PC-master-batch stated the condition to compound the CBC-33 with pure PC. By making the master batch of PC with CBC-33 at 8 wt % and normal mixing of the pellets, the modified melt viscosity PC can be obtained. In the industrial applications, the process of compounding can be achieved by adding CBC-33. For example, before palletizing, or in the first extrude screw of the process, or nascent PC can be compounded with CBC-33 in the normal process of compounding additive. The addition of the master batch will lower down the torque of the screw, so it is safe to operate the process with the machines that are already existed.

The reduction in operation torque of PC-remix stated the better processing condition of the compounded PC. The modified viscosity PC can be

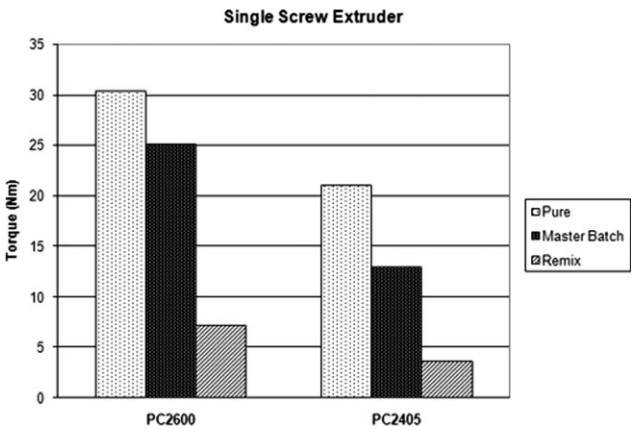

Figure 3 Operation torque of the single screw extruder when melting pure PC2600, PC2405, and their blends with CBC-33, grouping as two molar masses.

extruded with the lower torque, that is, the normal processing machine can be directly applied to the compounded blends of CBC-33 and PC without any modification. The results polymer will have lower melt viscosity that enable the mold to be more complex and enable the PC to use the subtle or multiple molds, which cannot be possible before, because of the high viscosity of PC melt.

In the extrusion, the melting is accomplished by heat transfer for the heated barrel surface and by mechanical shear-heating, the extensional flow could be occurred when a material is longitudinally stretched. The morphology of fractured strands of high-molar-mass thermotropic liquid crystalline polymers blended with polypropylene (PP) at various concentrations of HMLC, showed the well dispersed of HMLC in PP matrix that depended on the concentration of HMLC, which can be as high as 50 wt %.[14] However, the additions of CBC-33 have done in the miscible region,[4] so such morphology cannot be expected. On the other hand, the very low concentration of LMLC will not disturb the morphology of the PC as can be proven by laser light scattering experiments.[4] As seen in this study, the lowest operating torque values were observed when remixed the blending PC with LMLC using a single screw extruder.

Effect of LMLC on mechanical properties

Table III shows the tensile strengths of pure PC2600 and its blends with CBC-33 by mixing in a single screw extruder. The differences in the tensile strengths between pure PC2600 and its blends with CBC-33 (PC2600-master-batch) are less than 10%. Table IV shows the modulus of elasticity values of pure PC2600, PC2405, and their blends with CBC-33 by mixing in the single screw extruder. The modulus of elasticity values of pure PC2600, PC2405, and their blends with CBC-33 are relatively the same, the differences in the modulus of elasticity values between pure PC2600, PC2405, and their blends with CBC-33 are less than 10% for all mixing processes. This may indicate that there is no effect on mechanical properties of the CBC-33 blend regarding the tensile strength and modulus of elasticity. The reduction in torques of the single screw extruder came from the reduction in melt viscosity according to LMLC regardless of the degradation of the PCs. The pure PC2405 and its blends also laid within the vicinity of the error 10% as same as PC2600 and its blends.

TABLE III
Tensile Strengths of Pure PC2600, Pure PC2405, and the Blend with CBC-33

	Single screw extruder
Pure PC2600	36.2 ± 3.2
PC2600 + 0.2 wt % CBC-33 (master batch)	39.3 ± 2.5
PC2600 + 0.2 wt % CBC-33 (remix)	37.9 ± 4.7
Pure PC2405	37.4 ± 4.3
PC2405 + 0.2 wt % CBC-33 (master batch)	40.0 ± 3.6
PC2405 + 0.2 wt % CBC-33 (remix)	39.0 ± 5.8

TABLE IV
Modulus of Elasticity Values of Pure PC2600, PC2405, and Their Blends with CBC-33

	Single screw extruder
Pure PC2600	768 ± 23
PC2600 + 0.2 wt % CBC-33 (master batch)	781 ± 12
PC2600 + 0.2 wt % CBC-33 (remix)	755 ± 51
Pure PC2405	722 ± 56
PC2405 + 0.2 wt % CBC-33 (master batch)	764 ± 37
PC2405 + 0.2 wt % CBC-33 (remix)	699 ± 61

CONCLUSIONS

The operation torque of a single screw extruder, when extruding the blends of different molar mass PC with 0.2 wt % CBC-33, was reduced dramatically compared with pure PC and depended on the well mixing condition of the blends. This phenomenon also supported the results found by Motong et al.[4] in 2008, that the small amount of LMLC could be a melt viscosity modifier for PC. The lower are the melt viscosities, the lower are the torques of the single screw extruder, which operated at the same temperature. The reduction of operation torque is highly remarkable for PC2405, which has lower molar mass. The additions of small amount of LMLC to PC have slightly affected the mechanical properties of PCs because the differences in the tensile strengths and modulus of elasticity values between pure PC and their blends with LMLC are less than 10%. No special modification of the single screw extruder is needed when apply the CBC-33 to the PC. The compounding of PC can be done easier with lower torque when added the master batch of PC with CBC-33 (8 wt % in master-batch), which implied the possibility of reducing the compounding temperature. The well mix PC with CBC-33 (PC-remix) can be extruded with the lower torque, which implied the possibility of lower the molding temperature or more subtle mold can be possibly applied with PC.

References

1. He, J.; Bu, W. Polymer 1994, 35, 5061.
2. Wacharawichanant, S.; Thongyai, S.; Tanodekaew, S.; Higgins, J. S.; Clarke, N. Polymer 2004, 45, 2201.

3. Motong, N.; Clarke, N.; Thompson, R. L.; Collins, S. A.; Thongyai, S. J Polym Sci Part B: Polym Phys 2007, 45, 2187.
4. Motong, N.; Thongyai, S.; Clarke, N. J Appl Polym Sci 2008, 107, 1108.
5. Nobile, M. R.; Amendola, E.; Nicolias, L. Polym Eng Sci 1989, 29, 244.
6. Buckley, A.; Conciatori, A. B.; Calundamm, G. W. U.S. Pat. 4,434,262 (1984).
7. Siegmann, A.; Dagan, A.; Kenig, S.; Polymer 1985, 26, 1325.
8. Blizard, K. G.; Baird, D. G. Polym Eng Sci 1987, 27, 653.
9. Tariq, M.; Pierre, M.; Carreau, J.; Chapleau, N. Polym Eng Sci 1989, 29, 600.
10. Cottis, S.; Chin, H.; Shiau, W.; Shopland, D. U.S. Pat. 5,262,473 (1993).
11. Beery, D.; Kenig, S.; Siegmanm, A. Polym Eng Sci 1991, 31, 451.
12. Beery, D.; Kenig, S.; Siegmanm, A. Polym Eng Sci 1992, 32, 14.
13. Lin, Y. C.; Lee, H. W.; Winter, H. H. Polymer 1993, 34, 4703.
14. Saengsuwan, S.; Bualek-Limcharoen, S.; Mitchell, G. R.; Olley, R. H. Polymer 2003, 44, 3407.