

CHAPTER V

RESULTS & DISCUSSIONS

From literature surveys in Chapter II, there were many researches observed that liquid crystalline polymer can reduce the viscosity of polymer melt. Few researches were done to study about effects of blending with low molar mass liquid crystal.

For example, the research about blend of low molar mass liquid crystal was studied by Buckley, A., et al. They improved the melt processable blend of a low molar mass liquid crystal and a polyolefin or polyester. They claimed the polyolefin as polyethylene and liquid crystal as compound that is capable of forming anisotropic melts phase at a temperature below approximately 370 °C.

In this case, the blends of low molar mass liquid crystal with other polymers were studied. Poly(bisphenol A carbonates) or shortly called polycarbonates were chosen in this study because they have high melt viscosity and high strength. They also have high strength and very widely used. Nobody has investigated blends of this polymer and low molar mass liquid crystal before. Therefore, the studies of polycarbonate with low molar mass liquid crystals are very interesting.

Processing of polycarbonates is very difficult because of their high melt viscosity. In general, the plasticizers will be added during processing to decrease the melt viscosity. General polycarbonates have melting temperature of 250 °C and the commonly processing temperature of polycarbonate is 290 °C (depend upon the molecular weight). So the testing temperature in this experiment was 290 °C. Low molar mass liquid crystal was suggested as a polycarbonate plasticizer in this study.

As we have already known that there are two types of liquid crystals: thermotropic, which has mesophase when increasing temperature and lyotropic, which has mesophase in a suitable solvent. The thermotropic liquid crystals were used in these blends because they were assumed that thermotropic liquid crystals would decrease the melt viscosity of polycarbonates due to their anisotropic nature.

The effects of blending a thermotropic liquid crystal on the properties of polycarbonate were studied on this experiment. Two low molar mass liquid crystals in cyclohexyl-biphenylcyclohexanes (CBC) group: CBC33 and CBC53 were chosen in this study. The chemical structure of CBC33 and CBC53 are shown below:

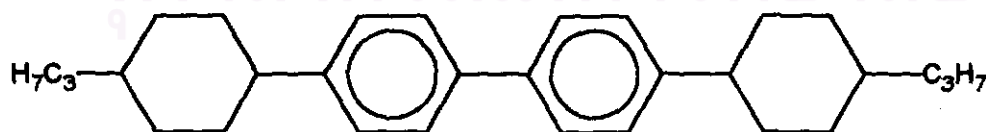


Figure 5-1 Chemical structure of CBC33

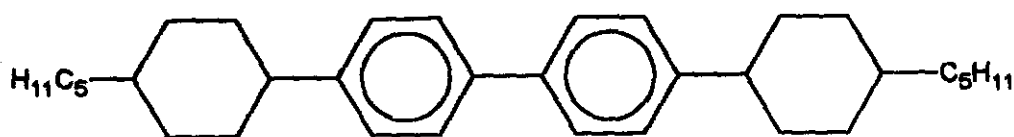


Figure 5-2 Chemical structure of CBC53

The reason for choosing these two liquid crystals is that they have nematic or mesophasic temperature in the range of processable of polycarbonates. CBC33 has nematic temperature to clearing temperature at 223-327 °C. CBC53 has nematic temperature to clearing temperature at 260-317 °C. Blend of polycarbonate and liquid crystals were tested at processing temperature of polycarbonate (290 °C) with also in the nematic region of liquid crystalline compound.

In this study, the viscosity and tensile properties of pure polymers and their blends with low molar mass liquid crystals were investigated. The results of each properties were discussed in this chapter. Blends of polymers with low molar mass liquid crystals can be divided into 2 systems as follows:

System 1. Poly(bisphenol A carbonate) & CBC33

System 2. Poly(bisphenol A carbonate) & CBC53

The two systems were compared in three main properties: viscosity, tensile, and thermal property. The viscosity of pure polycarbonate and the blends were determined by capillary rheometer to check the assumption that low molar mass liquid crystal causes the viscosity reduction of polycarbonate.

The tensile testing was done to determine how liquid crystals affect the mechanical properties of polymer blends. Thermal analysis was also done.

5.1 Viscosity

Pure polycarbonates and the PC blends with low molar mass liquid crystals, CBC33 and CBC53, were determined by using a capillary rheometer. In this study, the capillary of Rosand Precision Ltd. model RH-74 was used.

Blends were first prepared by mixing on hot plate. From the pre-experimental investigation, it was found that if the blends were not melt mixed, the viscosity would not change. This would be because there was not enough time for the diffusion of liquid crystal in bulk polycarbonate when they were in the capillary rheometer (12 minutes). The significant change occurs only with completely mixed blends. The nematic orientation may partially occur between melt mixing. So the viscosity of the blends reported in this study was value of melt mixed blends.

5.1.1 Pure Poly(bisphenol A carbonate)

There are three poly(bisphenol A carbonates) with different melt flow index (MFI) were compared. Polymers that have low MFI will have high viscosity. The notation for PC polymers is PCM7, PCM10, PCM12 and Bayer.

PCM7 referred to polycarbonate with MFI =7.

PCM10 referred to polycarbonate with MFI =10.

PCM12 referred to polycarbonate with MFI =12.

Bayer referred to commercial polycarbonate from Bayer.

It was expected that PCM7 would have a highest viscosity because it has the lowest MFI. Comparison of shear viscosities of 4 pure polycarbonates was shown in Table 5-1.

Table 5.1 Comparison of shear viscosity of pure polymer

| Shear rate (s ⁻¹) | Shear viscosity of polycarbonate (Pa.s) | | | |
|----------------------------------|---|-------|-------|-------|
| | PCM7 | PCM10 | PCM12 | Bayer |
| 1800 | 322.9 | 162.4 | 248.9 | 172.2 |
| 2400 | 270.7 | 145 | 219.8 | 142.5 |
| 3000 | 236.4 | 133.4 | 193.7 | 135.8 |
| 3600 | 203.4 | 121.8 | 162.3 | 116.9 |
| 4800 | 174.3 | 102.1 | 147.2 | 109.8 |
| 6000 | 146.8 | 93.21 | 125.8 | 106.5 |
| 8400 | 104 | 83.5 | 100.3 | 103.6 |

The melt viscosity of pure PC is presented as a function of shear rate in Fig 5-3. The measuring temperature was 290 °C which is the processing temperature of polycarbonates. Shear rate was varied in the range of 1000 - 10000 1/s which was the range used in extrusion and injection molding.

It can be seen that the viscosity of all polycarbonates decreases as the shear rate increases. The viscosity of PCM7 is the highest comparing with other polycarbonates at the same rate of shear, as expected. Bayer is found to have lowest viscosity among other PC.

PCM10 was the lowest viscosity. Its viscosity is almost the same as that of Bayer, which has the same physical apparent pellets and has low viscosity value. It is assumed that this event occurs because of their methods of preparation or processing.

5.1.2 Effects of CBC33 on Poly(bisphenol A carbonate)

The viscosity measurements were made with the blends of polycarbonates and low molar mass liquid crystal in low compositions of liquid crystal: 0.25, 0.5 and 1 percent by weight.

To study the effects of liquid crystals on the shear viscosity, CBC33 was added to the basic polymer. The shear rate versus shear viscosity of the blends at 290 °C with 0.25, 0.5, and 1% wt CBC33 are shown in Fig 5-4 - Fig 5-7. It can be seen that there is a marked reduction in the viscosity with increasing shear rate and CBC33 concentration.

The influences of the CBC33 content on the viscosity of the PCM7 is clearly shown in the Figure 5-4. A significance drop occurs continuously when adding the liquid crystals in the PC. The more contents of CBC33, are the less of the blend viscosity is. Especially, addition of 1 %by weight CBC33 reduces the viscosity of the PCM7 by about 10 times. Thus, one would expect the flow properties of the PCM7 blends were affected significantly. Comparing with the pure polymer, the CBC33 has a significantly low viscosity and CBC33 could plasticize and lubricate the polymer melt and lower the melt viscosity of the blends.

Comparison of viscosity of pure poly(bisphenol A carbonates)

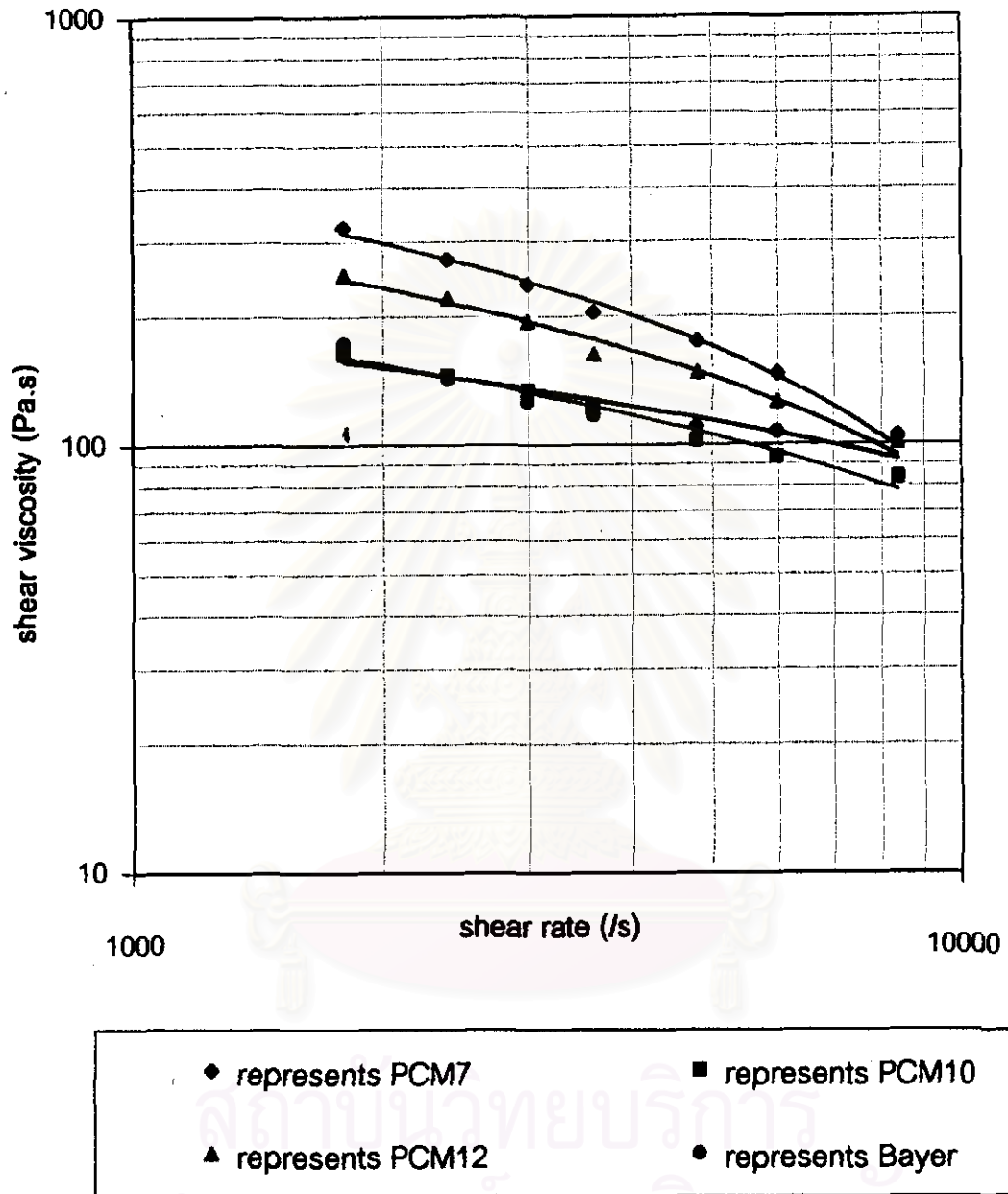


Figure 5-3 comparison of viscosity of pure poly(bisphenol A carbonates)

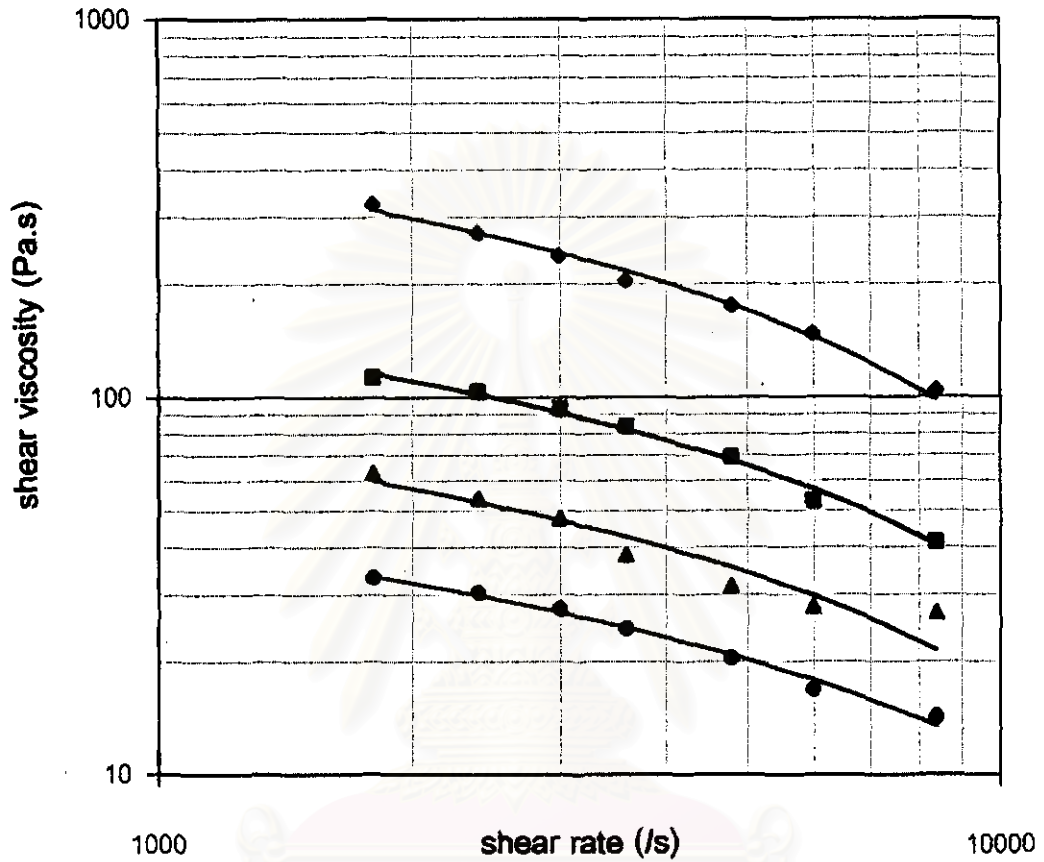
The influences of CBC33 on the viscosity of PCM10 can be shown in the Figure 5-5. The viscosity of PCM10 can be reduced by 70 percent when adding only 0.25 percent of CBC33. However, at higher concentration of CBC33, the effects of CBC33 on the viscosity were less significant. For example, adding 0.5 percent of CBC33, the viscosity still decreased only 78 percent from that of pure component.

The effects of CBC33 on the viscosity of PCM12 can be shown in Figure 5-6. It can be seen that the melt viscosity of the blends at the composition of 0.25, 0.5 and 1% by weight of CBC33 was lower than that of the pure PCM12. A significant drop occurs continuous when adding more concentration of CBC33. At 1 percent CBC33, the viscosity decreased by about 85 percent.

In Figure 5-7, the viscosity of Bayer when adding CBC33 does not reduce much because Bayer already has low viscosity. So if we compare by percent decrease from pure component, the percent decrease of the viscosity of Bayer is less than PCM7, PCM10 and PCM12. However, the 1 percent by weight of Bayer can reduce the viscosity of Bayer by about almost 46 percent.

สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

Blend of PCM7 and CBC33



- ◆ represents pure PCM7
- ▲ represents blend at 0.5 %wt
- represents blend at 0.25 %wt
- represents blend at 1 %wt

Figure 5-4 Shear viscosity of PCM7 and blends of CBC33 at 0.25, 0.5, 1 %wt

Blend of PCM10 and CBC33

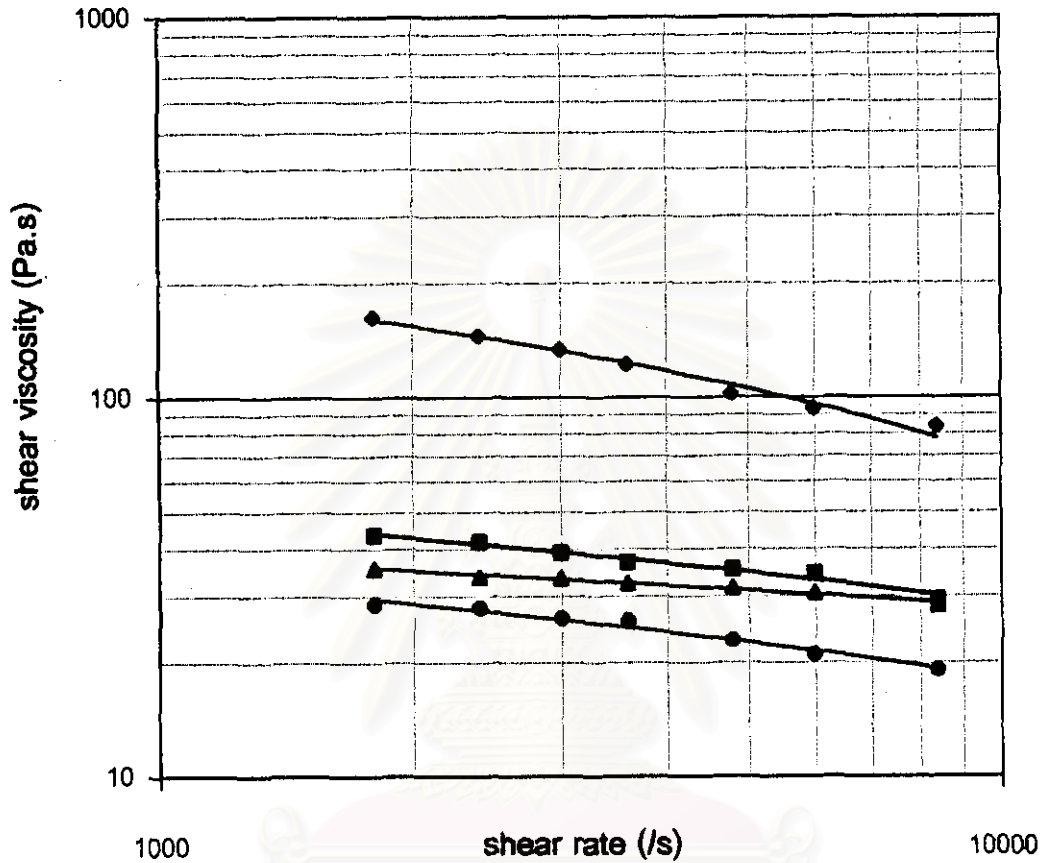


Figure 5-5 Shear viscosity of PCM10 and blends of CBC33 at 0.25, 0.5, 1 %wt

Blend of PCM12 and CBC33

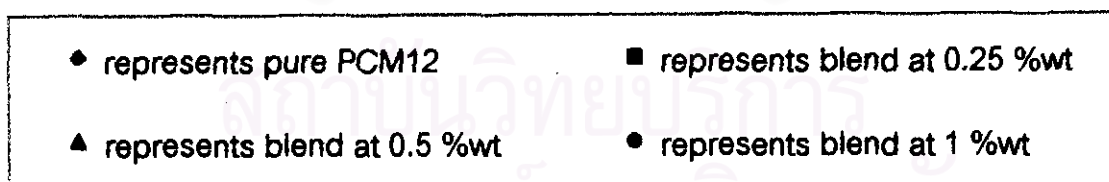
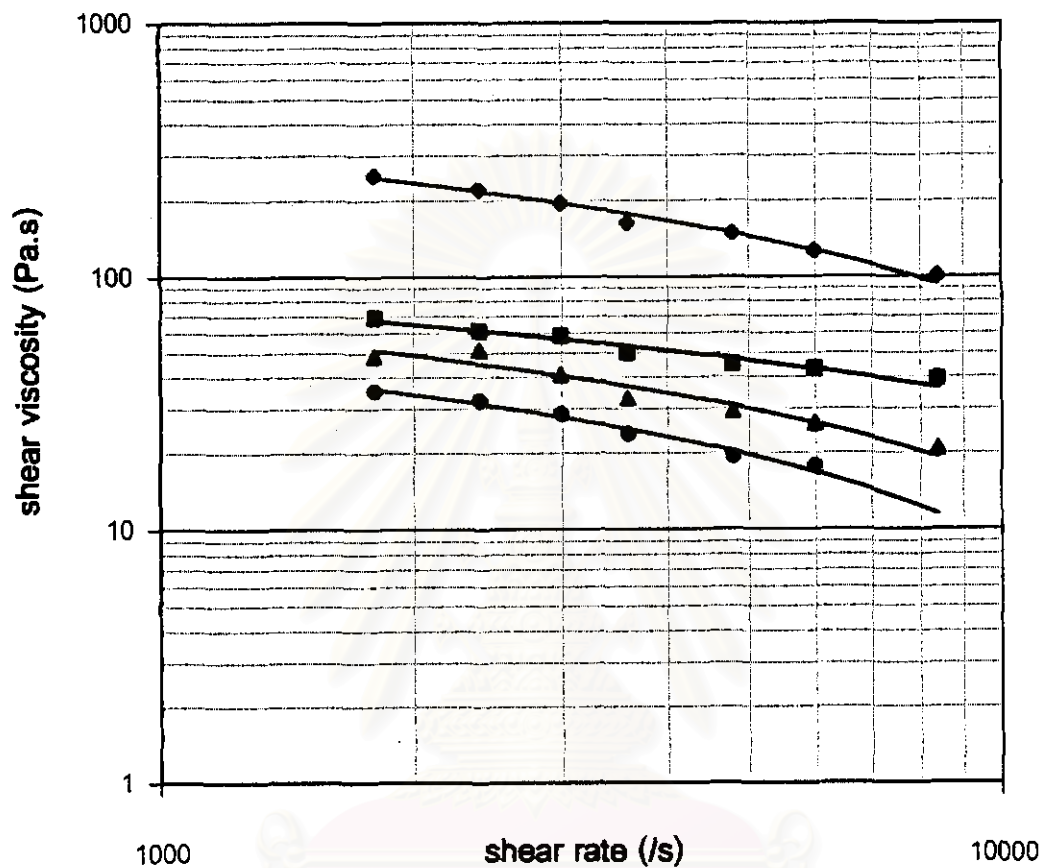
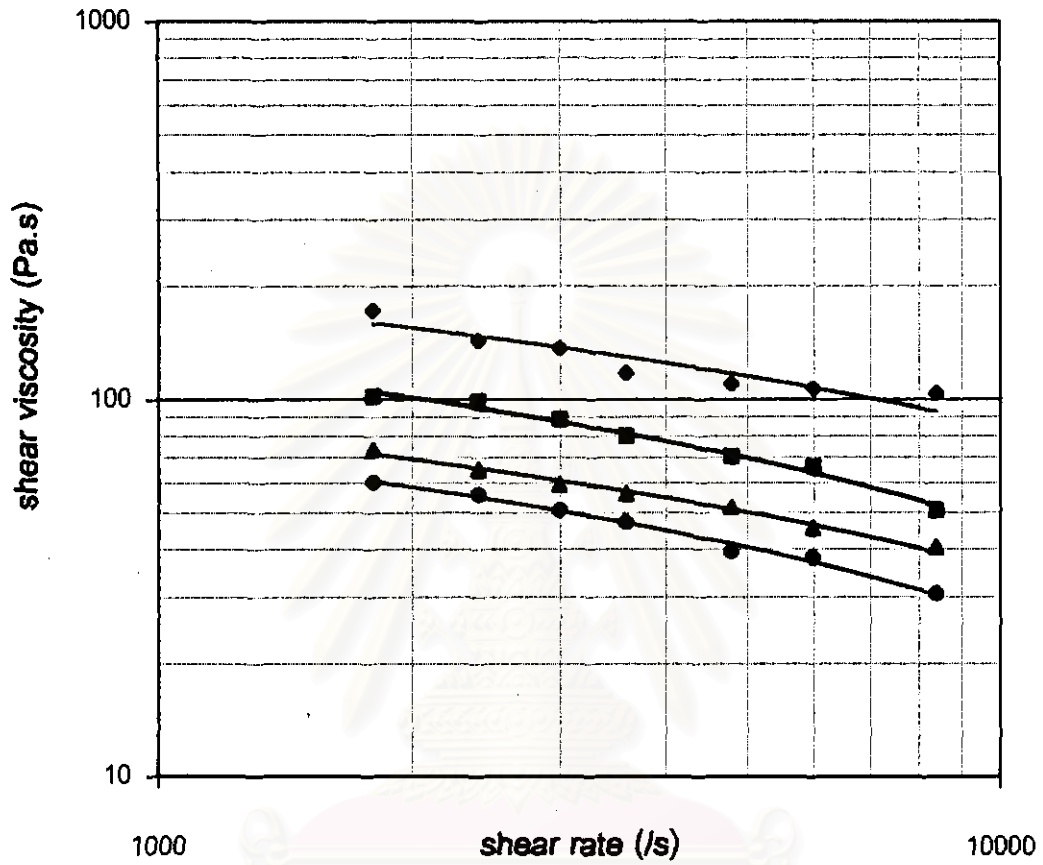


Figure 5-6 Shear viscosity of PCM10 and blends of CBC33 at 0.25, 0.5, 1 %wt

Blend of Bayer and CBC33



- ◆ represents pure Bayer
- represents blend at 0.25 %wt
- ▲ represents blend at 0.5 %wt
- represents blend at 1 %wt

Figure 5-7 Shear viscosity of PCM7 and blends of CBC33 at 0.25, 0.5, 1 %wt

The significant reduction in viscosity of the blends leads to an improvement of processability of polymer. This feature should be reflected in the processing parameters, such as extruding temperature, torque, melt viscosity, and injection pressure.

5.1.3 Effects of CBC53 on Poly(bisphenol A carbonate)

The effects of CBC53 on Poly(bisphenol A carbonate) are similar to that of CBC33. It can also reduce the shear viscosity of PC. CBC53 can plasticize all 4 polycarbonates. The flow curves of blends at 0.25, 0.5, and 1 percent by weight of CBC53 are shown in Fig.5-8 – Fig.5-11.

The influences of the CBC53 content on the viscosity of the PCM7 is clearly shown in the Figure 5-8. Shear viscosity decreases as the shear rate increases. A significantly drops occurs continuously when adding the liquid crystals in the PC. The more contents of CBC53 are the less of the blends viscosity is. Especially, addition of 1 %by weight CBC53 reduces the viscosity of the pure PCM7 by about 90 percent similar to that of CBC33. Increasing the percentage of the CBC53 beyond 1% decreases the viscosity continuously to that of the pure component. Comparing with the pure polymer, the CBC53 has a significantly low viscosity and CBC53 could plasticize and lubricate the polymer melt and lower the melt viscosity of the blends.

Figure 5-9 shows the plot of the shear viscosity of PCM10 and their blend versus shear rate. The curve shows that the viscosity can be decreased when blending PC with CBC53. A concentration of 1 percent by weight of CBC53 results in about 80 percent reduction in the viscosity.

The same results can be observed for the blends of CBC53 and PCM12 as shown in Figure 5-10. The viscosity decreases as the CBC53 concentration increases, and all the blends have lower viscosities than that of PC. This may be a result of the high extensional forces present at the entrance of the capillary that deform and orient the liquid crystals in the flow direction. Moreover, the CBC53 has a much lower viscosity than PC, and in the blend the oriented CBC53 phase tends to lubricate the melt.

Similar results were obtained for polycarbonate from Bayer. The flow curves at 290 °C of the Bayer, and of the 0.25, 0.5 and 1 percent of CBC53 blends are shown in Figure 5-11. The viscosity of the blends are lower than the viscosity of Bayer over the whole shear rate range. In other words, small CBC53 contents can reduce the polymer viscosity. But it should be noted that the viscosity does not drop significantly compared with other PC blends.

Blend of PCM7 and CBC53

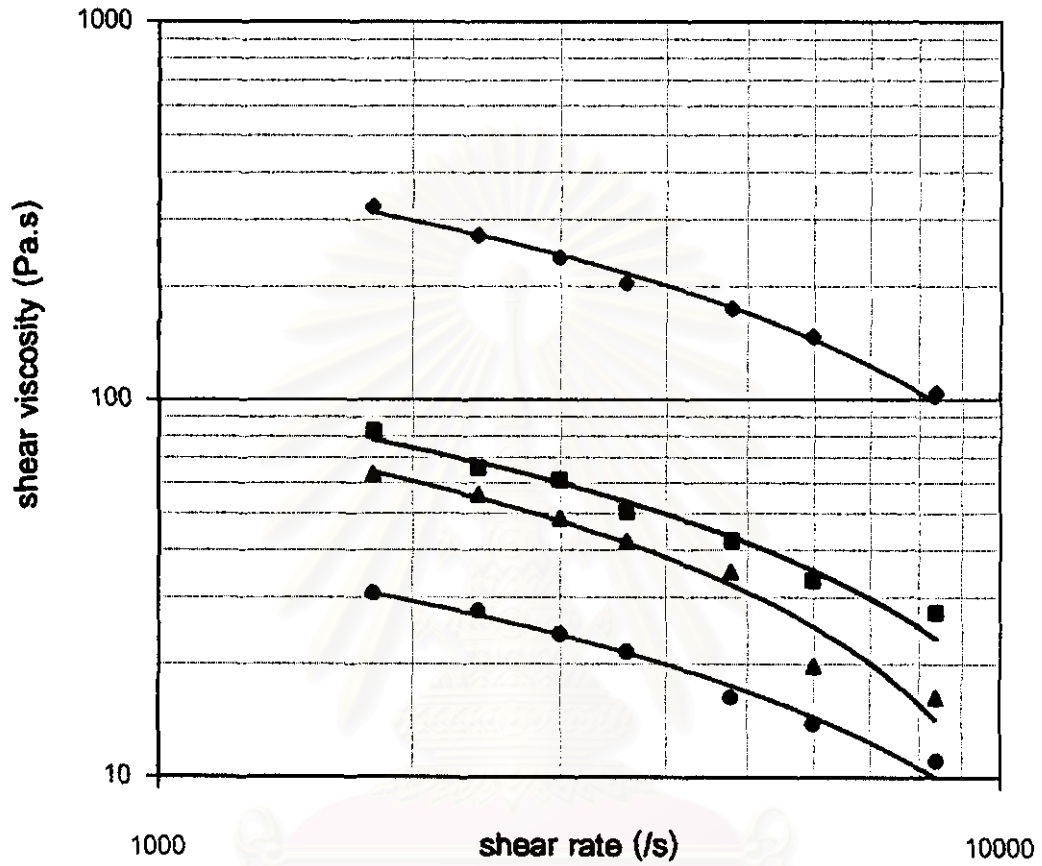


Figure 5-8 Shear viscosity of PCM7 and blends of CBC53 at 0.25, 0.5, 1 %wt

Blend of PCM10 and CBC53

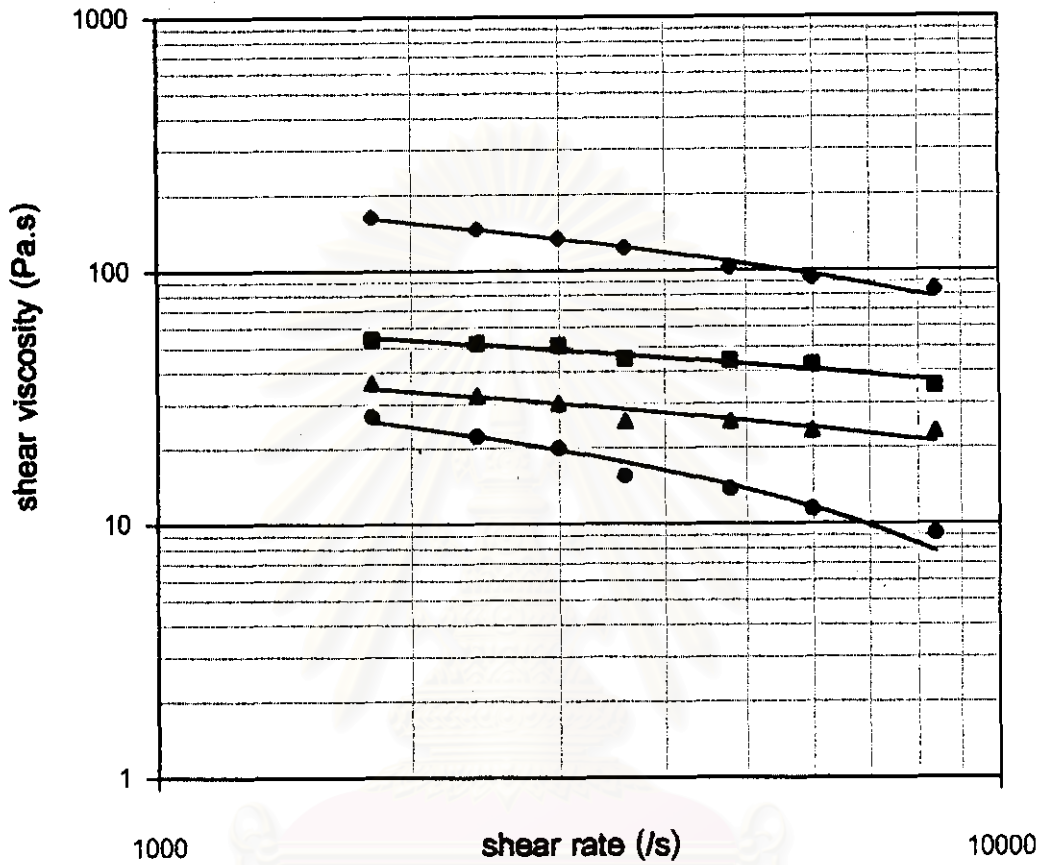


Figure 5-9 Shear viscosity of PCM10 and blends of CBC53 at 0.25, 0.5, 1 %wt

Blend of PCM12 and CBC53

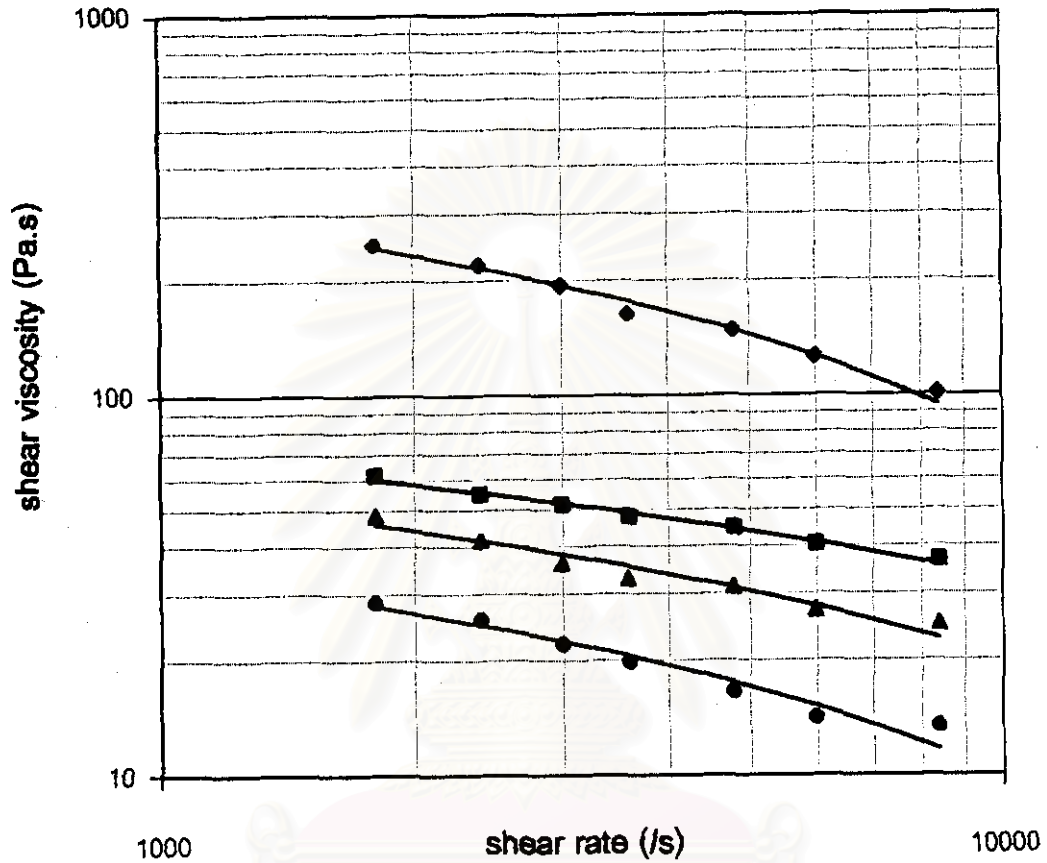


Figure 5-10 Shear viscosity of PCM10 and blends of CBC53 at 0.25, 0.5, 1 %wt

Blend of Bayer and CBC53

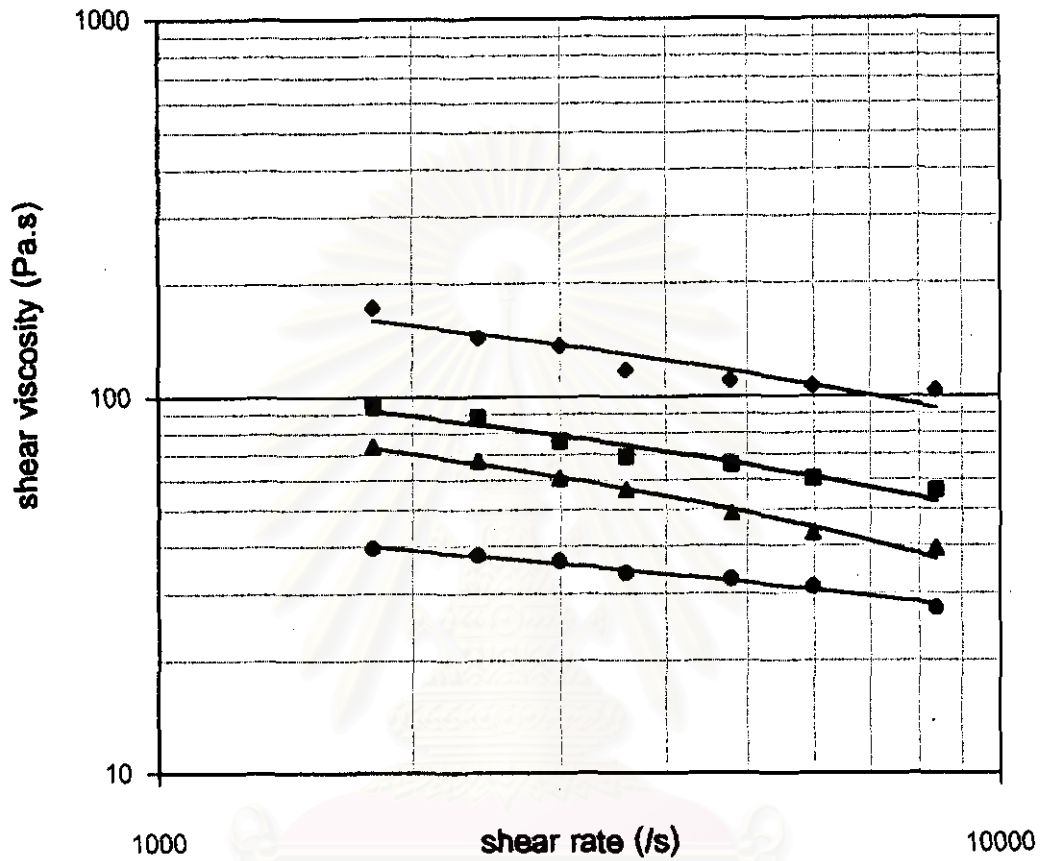


Figure 5-11 Shear viscosity of PCM7 and blends of CBC53 at 0.25, 0.5, 1 %wt

A comparison on the dependence of viscosity on compositions of the blends is clearly presented in Figure 5-12. A significant drop of about 65% in the viscosity of PCM7 occurs at 0.25 percent of CBC33, and it becomes 90% at 1 percent CBC33. The flow properties of the PCM7 are affected by the presence of CBC33 even at the low composition.

A similar flow behavior for blends of thermotropic with liquid crystalline polymer has been observed by several authors [Nobile, M. R., 1989]. The viscosity data of the blends was, in fact, between those of the pure polymers in most cases, while Siegman, et.al, described polymer blends of an amorphous polyamide with a LCP, of which melt viscosity is lower than those of the individual polymers. In our case, the melt viscosity of liquid crystals can not be observed because they have very low melt viscosity. The viscosity data may fall between polymer and liquid crystals.

5.1.4 Comparison of viscosity with various liquid crystals

The blends of polycarbonates with the two molar mass liquid crystals in phenyl-cyclohexylbenzoates group, HP35 and HP5N, were prepared in order to compare the viscosity of the blends. HP35 and HP5N have the clearing point at 176 °C and 226 °C respectively. They do not have the nematic range in the temperature investigated in this work. The PC blends at a low concentration of HP35 and HP5N (0.5%) with the PC were similarly prepared as described in section 4.3.1. The results of this experiment were shown in Table 5-2. The flow curves of the polycarbonates and the blends are shown in Figure 5-13.

Viscosity of PCM7 versus percentage of CBC33

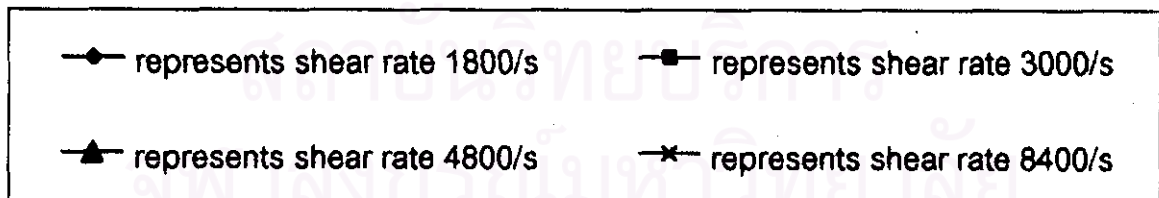
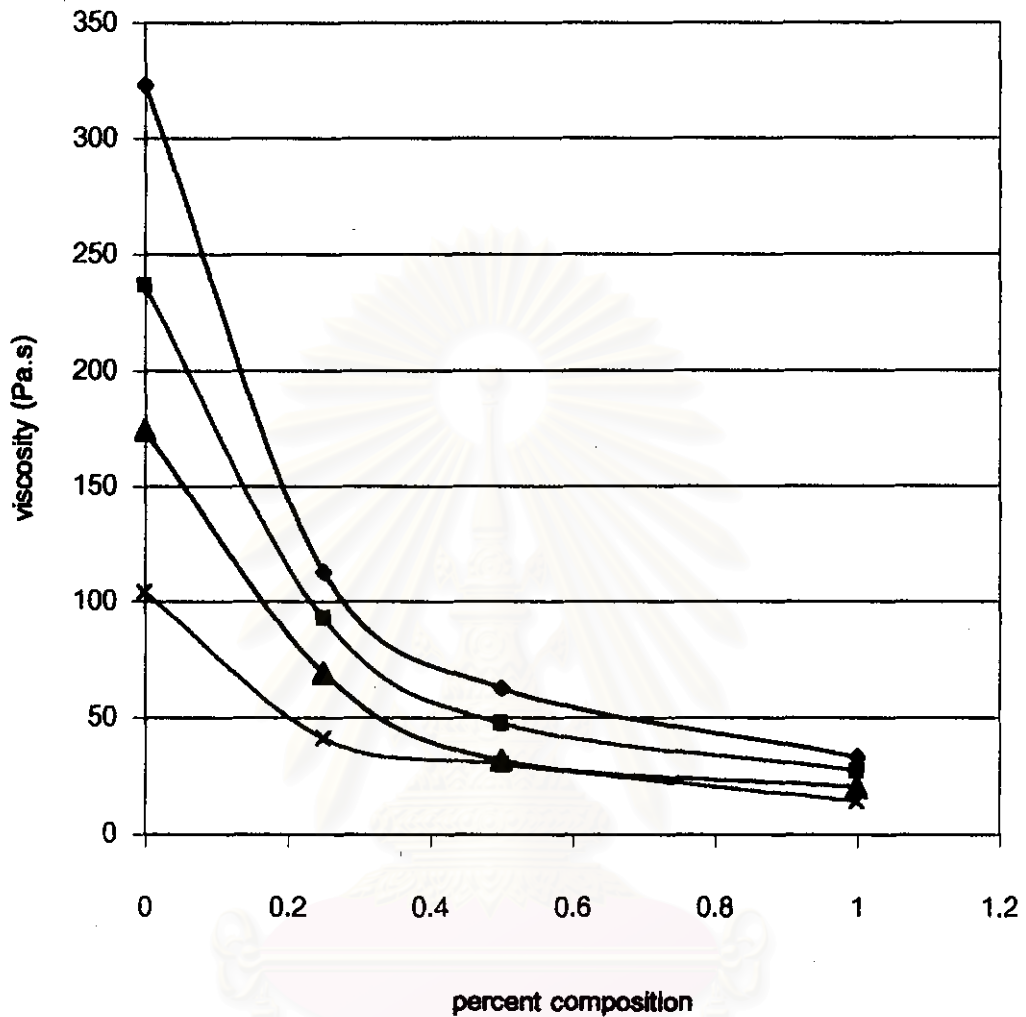


Figure 5-12 Viscosity of PCM7 versus percentage of CBC33

Table 5-2 Comparison of blend of Bayer and LC at 0.5% composition.

| shear rate | Shear viscosity (s^{-1}) | | | | |
|---------------|------------------------------|---------------------|---------------------|--------------------|--------------------|
| | Bayer pure | Bayer/ 0.5%CBC33 | Bayer/ 0.5%CBC53 | Bayer/ 0.5%HP35 | Bayer/ 0.5%HP5N |
| 1800 | 172.2 | 73.14 | 73.22 | 170.5 | 168.6 |
| 2400 | 142.5 | 64.71 | 67.14 | 139.8 | 139.9 |
| 3000 | 135.8 | 58.96 | 60.14 | 124.4 | 123.5 |
| 3600 | 116.9 | 55.96 | 56.17 | 115 | 114.8 |
| 4800 | 109.8 | 51.39 | 48.56 | 109.7 | 105 |
| 6000 | 106.5 | 45.35 | 42.9 | 104.2 | 101 |
| 8400 | 103.6 | 40.37 | 39 | 99.2 | 98.8 |

From Table 5-2 and Figure 5-13, it can be obviously seen that at 0.5 percent liquid crystal, CBC33 and CBC53 can reduce the viscosity of Bayer, while HP35 and HP5N can not. The difference in the viscosity data of the Bayer PC blends with HP35 and HP5N is not significant compared to the viscosity of the pure Bayer PC. On the other hand, the viscosity of the Bayer PC blends with CBC33 and CBC53 is much lower than that of the pure Bayer PC. Hence, these results suggested that nematic structure of the liquid crystal might be the cause of the reduction in viscosity. There is a dramatic drop in viscosity when blending polycarbonates with CBC33 or CBC53. But liquid crystals in HP group can not affect the viscosity of PC.

Comparison of blends viscosity of Bayer and various liquid crystals

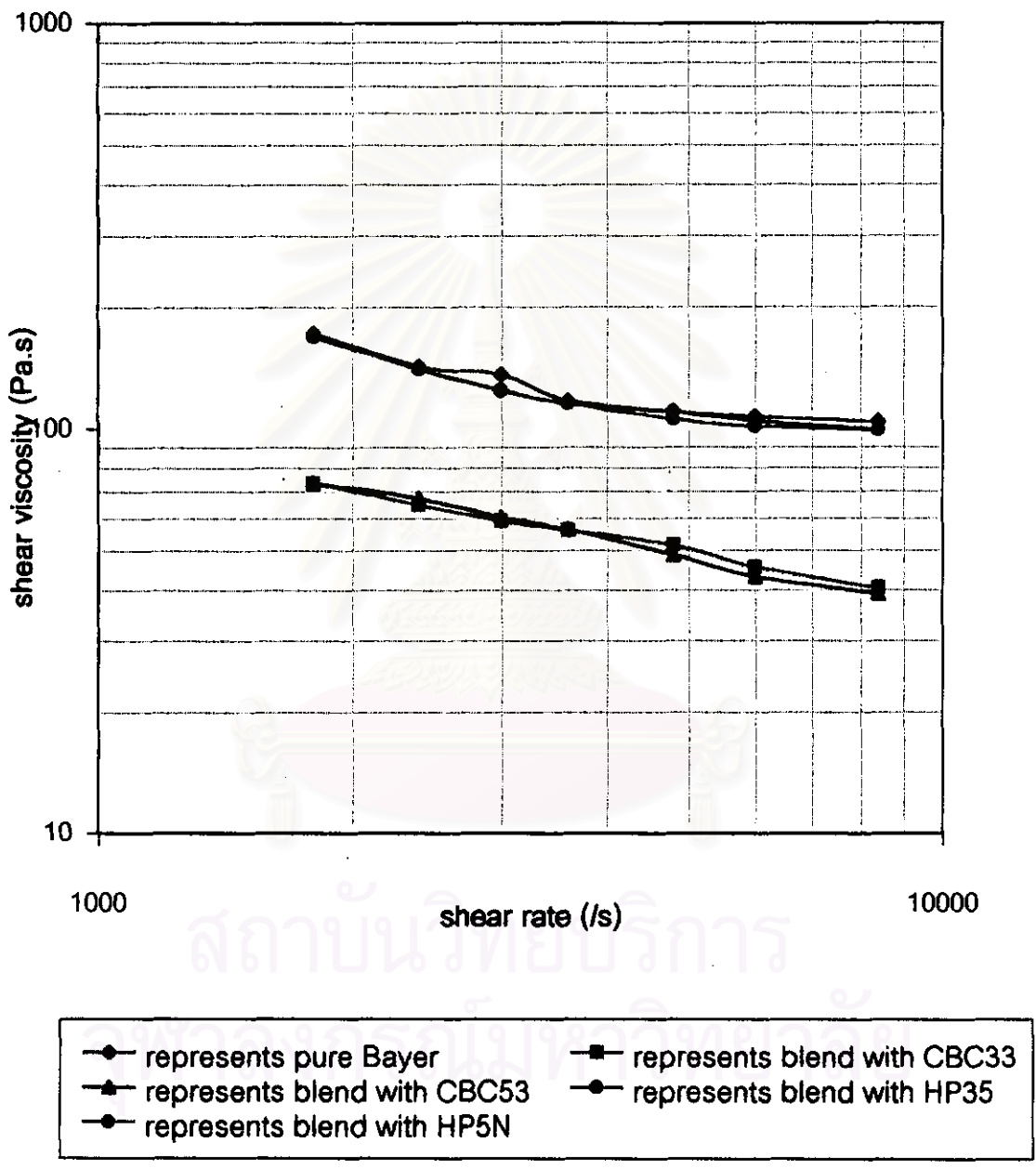


Figure 5-13 Comparison of blends viscosity at 0.5% composition and 290 °C

This result might be explained by the nematic orientation of the liquid crystal. Liquid crystals may act as floc and the nematic structures of the liquid crystal may orient themselves in the flow direction of the polymer. The polymers can then easily flow under shear in the capillary rheometer.

Liquid crystal compounds are compounds which are liquid crystalline (i.e., anisotropic) in the melt phase [Buckley, A. 1984]. The molecular weight of the compound is preferably below about 1000, and may be below about 500. The compound must be capable of forming an anisotropic melt at the melt processing temperature of the blend. The liquid crystals should also not chemically react with the PC in the melt blend. In contrast to the liquid crystals, the polycarbonates are not capable of forming an anisotropic melt phase. The melt blend system seemed to be the suspension of polymer phase and liquid crystal flocs.

Many fluids of commercial and biological importance are dispersed system, such as solids suspended in liquid, (dispersions) and liquid-liquid suspensions. Examples of the former include inks, paints, pigment slurries, and concrete; examples of the latter include mayonnaise and butter. When blending liquid crystal on thermoplastics polymer, the system act as liquid-liquid suspensions in the melt state.

Generally, dispersion of a solid or liquid in a liquid affects the viscosity. In many cases Newtonian flow behavior is transformed into non-Newtonian flow behavior. Shear thinning resulted from the ability of the solid particles or liquid droplets can come together to form network structures when at rest or under low shear. With increasing shear, the interlinked structure or flocs

gradually breaks down, and the resistance to flow decreases. The viscosity of a dispersed system depends on hydrodynamic interactions between particles or droplets and the liquid, particle-particle interactions, and interparticle attractions that promote the formation of aggregates, floc, and networks. In such system, the structure changes are reversible.

The results in this section confirm that only small amount of liquid crystals can reduce the viscosity of the poly(bisphenol-A-carbonates). The reduction of the viscosity of PC blends may allow a reduction in the processing temperature that, hence, could save the energy for processing.



สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

5.2 Tensile Properties

Many researches have been done on the blends of polymers and liquid crystalline polymers in order to increase the engineering performance of thermoplastics. Such composite materials have been applied in the aerospace, automotive and marine industries [Folkes, M. J. 1993]. The principle goal for blending is to achieve improvements in mechanical properties by using the LCP component to reinforce the flexible thermoplastics through the formation of fibers.

Siegmann, et al., [1985] were among the first to report *in situ* composite formation when studying a system containing amorphous polyamide and an experimental Vectra type LCP.

There is no papers studied the blends of low molar mass liquid crystals in mechanical properties. Most paper, which studied liquid crystals, focused on the phase behavior. In this study, the tensile properties were done to examine how liquid crystal effects the mechanical properties.

The average tensile properties of pure polycarbonate (Bayer) and the blends of CBC33, CBC53 are summarized in the table below. The raw data from the measurements can be seen in appendix.

Table 5-3 Tensile properties of Bayer and blends with CBC33

| Properties | 0%CBC33 | 0.25%CBC33 | 0.5%CBC33 |
|-----------------------|---------|------------|-----------|
| tensile strength | 40.03 | 39.99 | 39.35 |
| extension | 4.836 | 4.574 | 4.551 |
| Modulus of elasticity | 342.93 | 356.5 | 387.99 |
| work done | 429.7 | 438.31 | 350.84 |

Table 5-4 Tensile properties of Bayer and blends with CBC53.

| Properties | 0%CBC53 | 0.25%CBC53 | 0.5%CBC53 |
|-----------------------|---------|------------|-----------|
| tensile strength | 40.03 | 39.95 | 39.39 |
| extension | 4.836 | 4.156 | 4.296 |
| Modulus of elasticity | 342.93 | 403.36 | 421.18 |
| work done | 429.7 | 363.59 | 323.69 |

5.2.1 Effects of liquid crystals on tensile strength

Figure 5-14 shows the dependence of tensile strength of Bayer polycarbonate on the percent composition blending of CBC33 and CBC53. Tensile strength corresponds to the actual rupture of the test specimens. It can be seen that tensile strength of the blends of polycarbonate with liquid crystals do not significantly increase or decrease from the pure polycarbonate. Since, the liquid crystal added in a small amount (only 0.25 or 0.5%), it might

not be able to affect the tensile strength. In general, the addition of small molecules should decrease in tensile strength, but in this case liquid crystals do not make a remarkable (or increase) in polymer. The results might indicate that low molar mass liquid crystals do not acted as a mechanical reinforcement like most liquid crystal polymer.

5.2.2 Effects of liquid crystals on extension

The values of the extension of blends are reported as a function of the liquid crystal percent compositions in Figure 5-15. The addition of liquid crystal particle tends to decrease the extension of polymer as increasing the liquid crystals in the range of low concentration. But this is not significant because the extension decrease just less than 10 percent compared with pure polycarbonate. However, CBC53 seems to have stronger effects on the extension than CBC33.

5.2.3 Effects of liquid crystals on modulus of elasticity

Modulus of elasticity of polymer blends with liquid crystals is shown in Figure 5-16. From this figure, it can be seen that blends containing 0.25 and 0.5% CBC33 or CBC53 exhibit a little higher modulus of elasticity than the pure polycarbonate. This shows that the addition of liquid crystals is slightly increases the modulus of elasticity.

5.2.4 Effects of liquid crystals on work done

One of the important tensile properties is the work done. This property represents the area of stress-strain curves, which refer to the mechanical properties of materials. Normally, the work done depends on the characteristics of polymer materials such as strength, toughness, impact strength, etc.

From the plot of the work done versus percent composition of liquid crystal shown in Figure 5-17, it can be seen that there is not a significant change in work done. Work done on blends is similar to that of the pure polymer. It is possible to think that the quantity of liquid crystal added to the polymer is small so it might not be enough to change that property.

It is concluded that the addition of a small amount of low molar mass liquid crystal does not effect the mechanical properties of polycarbonate. The tensile strength, extension, modulus of elasticity and work done do not change much as blended with the low molar mass liquid crystal. The liquid crystals are observed to affect the viscosity rather than the tensile properties of the PC. The viscosity of PC blends significantly decreases while the mechanical properties of the PC relatively unchanged.

Tensile strength of blends with CBC33 and CBC53

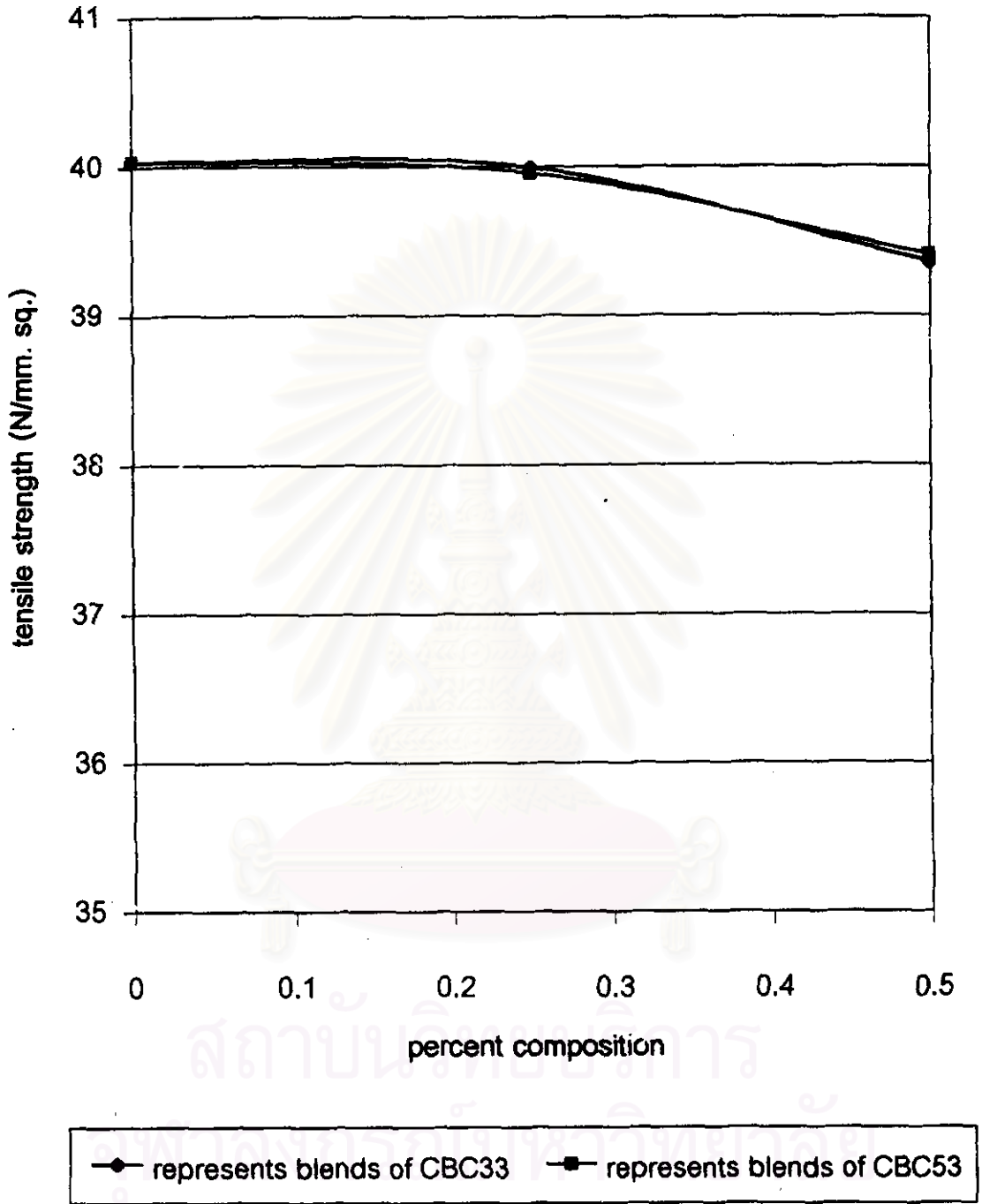


Figure 5-14 Tensile strength of blends with CBC33 and CBC53

Extension of blends with CBC33 and CBC53

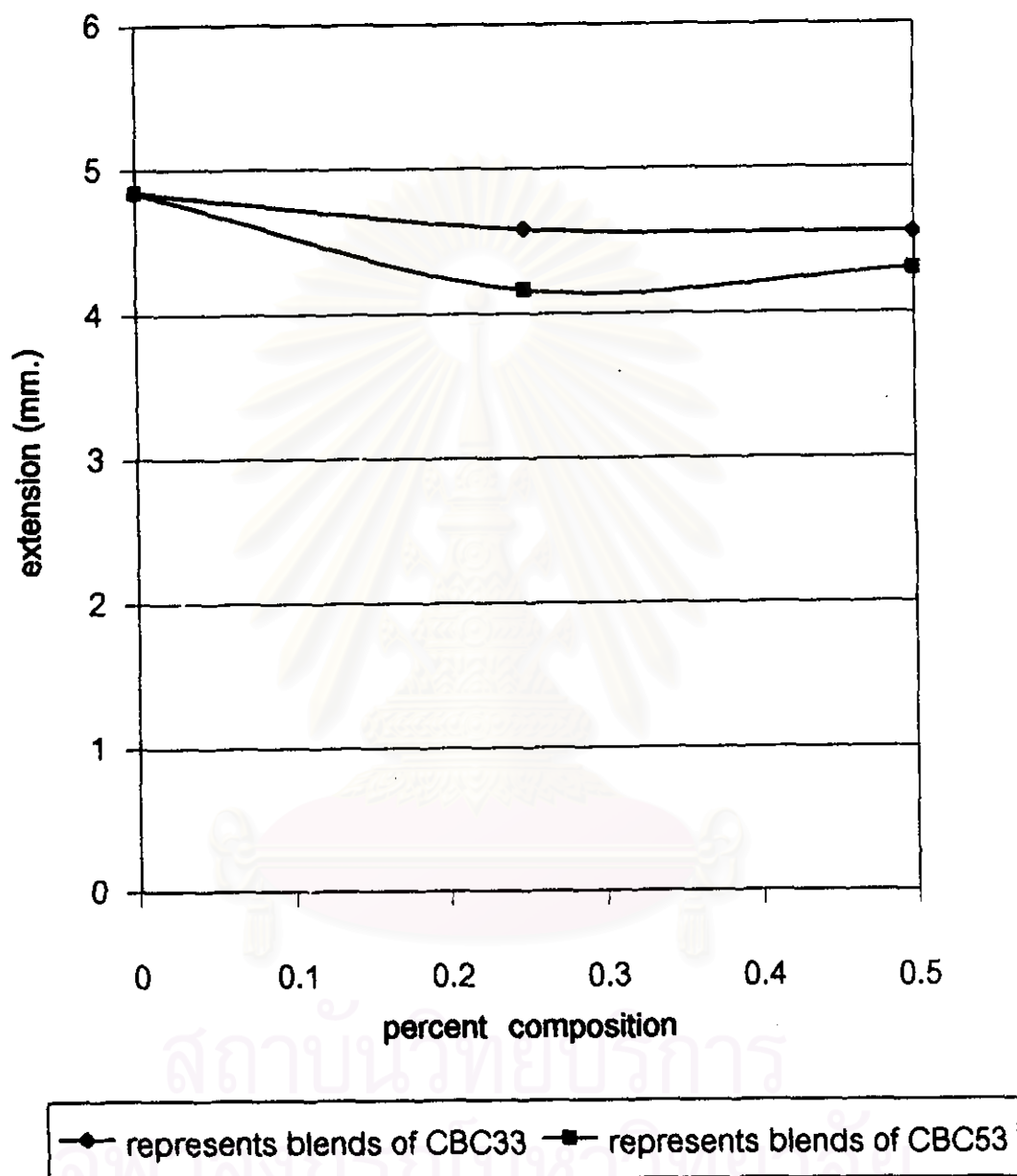
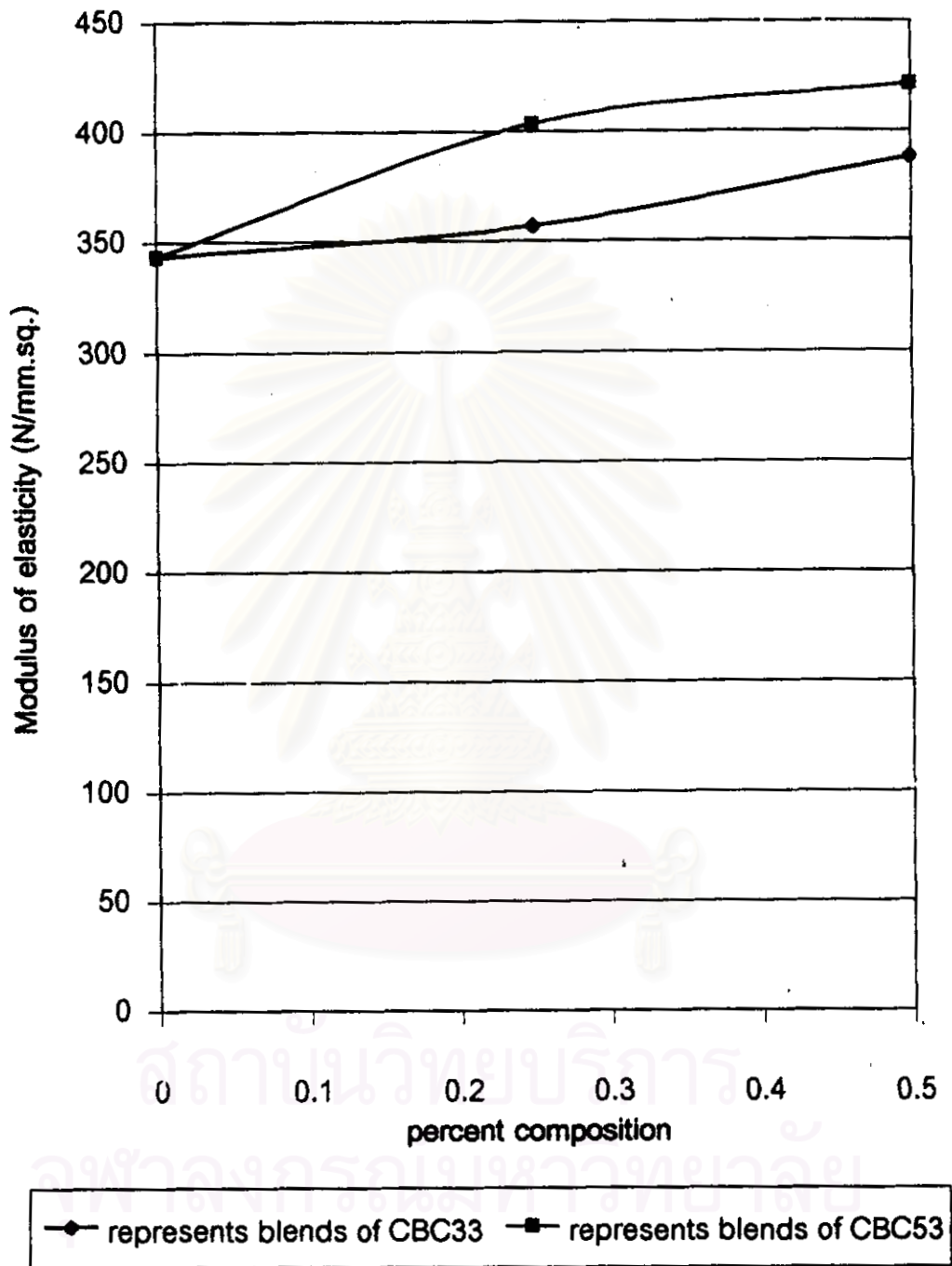


Figure 5-15 Extension of blends with CBC33 and CBC53

Modulus of elasticity of blends with CBC33 and CBC53**Figure 5-16** Modulus of elasticity of blends with CBC33 and CBC53

Work done of blends with CBC33 and CBC53

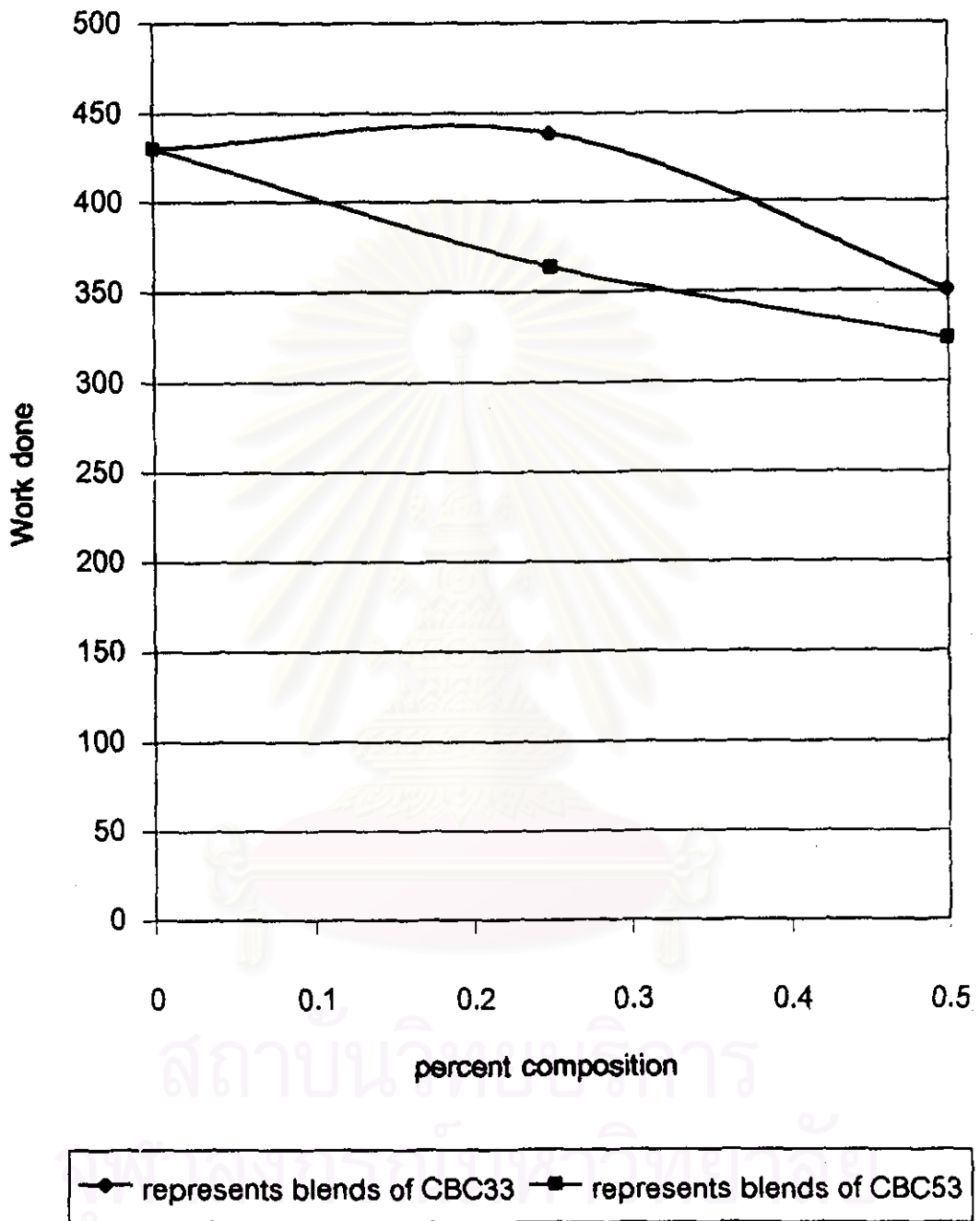


Figure 5-17 Work done of blends with CBC33 and CBC53

5.3 Thermal Property

The differential thermal analysis was done by using differential scanning calorimeter (DSC) to determine the number and the locations of the glass transition temperatures. Glass transition temperature (T_g) is a characteristic of the amorphous part of a polymer. At T_g , a dramatic change occurs in the local movement of polymer chains, which leads to large changes in physical properties. These properties include density, specific heat, mechanical modulus and mechanical energy absorption, as well as many other properties [Brandup and Immergut, 1989].

5.3.1 Glass transition temperature of blends with CBC33

The glass transition temperatures of pure polycarbonates and their blends with CBC33 detected by differential scanning calorimeter (DSC) were shown in Table 5-5.

Table 5-5 The glass transition temperature (T_g) of polycarbonates and blends of CBC33 detected by DSC at each weight percent of CBC33.

| Percent CBC33 | Glass transition temperature (°C) | | | |
|------------------|-----------------------------------|-------|-------|-------|
| | PCM7 | PCM10 | PCM12 | Bayer |
| 0 | 151.5 | 147.9 | 148.6 | 146.1 |
| 0.25 | 150.7 | 146.8 | 147.6 | 145.9 |
| 0.5 | 146.5 | 143.1 | 146.2 | 144.6 |
| 1.0 | 141.5 | 139.8 | 146.1 | 143.6 |

From Table 5-5, it can be seen that the glass transition temperatures (T_g) of polycarbonates rich phase in the blends at each weight percent of CBC33 were depressed from the T_g of 100 percent PC (0 percent by weight of CBC33) for all polycarbonates. For example, T_g of PCM7 was depressed from 151.5 °C (0% by weight of CBC33) to 141.5 °C (1% by weight of CBC33). It can be seen that the addition of 1 percent by weight of CBC33 reduced the glass transition temperature of PCM7 for 10 °C. This phenomenon proved that CBC33 can act as a plasticizer of PC. However, the T_g of Bayer decreased only 3 °C when adding 1 % by weight of CBC33 in the PC.

Moreover, the melting temperature of CBC33 in the blends cannot be observed in DSC thermograms at low weight percent CBC33 with PC. The disappearance of the melting temperature of CBC33 in the blends should be due to low content of CBC33 in the blends such that it cannot be detected by DSC.

5.3.2 Glass transition temperature of blends with CBC53

The glass transition temperatures of pure polycarbonates and their blends with CBC33 detected by differential scanning calorimeter (DSC) were shown in Table 5-6.

Table 5-6 The glass transition temperature (T_g) of polycarbonates and blends of CBC53 detected by DSC at each weight percent of CBC53.

| Percent CBC53 | Glass transition temperature ($^{\circ}\text{C}$) | | | |
|------------------|---|-------|-------|-------|
| | PCM7 | PCM10 | PCM12 | Bayer |
| 0 | 151.5 | 147.9 | 148.6 | 146.1 |
| 0.25 | 148.9 | 146.7 | 148.3 | 145.9 |
| 0.5 | 148.8 | 143.9 | 147.7 | 144.8 |
| 1.0 | 146.6 | 142.9 | 143.2 | 144.8 |

From Table 5-6, it can be seen that the glass transition temperatures (T_g) of polycarbonates rich phase in the blends at each weight percent of CBC53 were depressed from the T_g of the pure PC (0 percent by weight of CBC33). For example, T_g of PCM7 was depressed from 151.5 $^{\circ}\text{C}$ (0% by weight of CBC53) to 146.6 $^{\circ}\text{C}$ (1% by weight of CBC53). It can be seen that the addition of 1 percent by weight of CBC33 reduced the glass transition temperature of PCM7 for 5 $^{\circ}\text{C}$. This phenomenon proved that CBC53 can act as a plasticizer of PC. However, the T_g of Bayer decreased only about 2 $^{\circ}\text{C}$.

Moreover, the melting temperature of CBC53 in the blends cannot be observed in DSC thermograms at low weight percent CBC33 with PC. The disappearance of melting temperature of CBC53 in the blends should be due to low content of CBC33 in the blends such that it cannot be detected by DSC.

5.4 Comparison of the Effects of CBC33 and CBC53 on PC

Both CBC33 and CBC53 can act as plasticizers of polycarbonates as previously discussed in section 5.1.3 (Effects of CBC33 on PC) and section 5.1.4 (Effects of CBC53 on PC). However, it is interesting to consider which is the better plasticizer for PC.

The question was solved by comparing the decreasing viscosity of the PC in the blends with CBC33 and CBC53 at the same weight percent. The better plasticizer is the one that can decrease the viscosities of the PC in the blends more than the others. The viscosity comparison of the blends with CBC33 and CBC53 at 1 percent weight were shown in Table 5-7 – Table 5-10.



สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

Table 5-7 Comparison of the viscosities of blends of PCM7 with CBC33 and CBC53 at 1% by weight.

| shear rate | Shear viscosity (s^{-1}) | | |
|------------|------------------------------|------------|------------|
| | PCM7 | PCM7+CBC33 | PCM7+CBC53 |
| 1800 | 322.9 | 33.1 | 30.53 |
| 2400 | 270.7 | 30.22 | 27.43 |
| 3000 | 236.4 | 27.29 | 23.78 |
| 3600 | 203.4 | 24.3 | 21.44 |
| 4800 | 174.3 | 20.3 | 16.22 |
| 6000 | 146.8 | 16.86 | 13.83 |
| 8400 | 104 | 14.24 | 11.05 |

Table 5-8 Comparison of the viscosities of blends of PCM10 with CBC33 and CBC53 at 1% by weight.

| shear rate | Shear viscosity (s^{-1}) | | |
|------------|------------------------------|-------------|-------------|
| | PCM10 | PCM10+CBC33 | PCM10+CBC53 |
| 1800 | 162.4 | 28.35 | 26.64 |
| 2400 | 145 | 27.82 | 22.21 |
| 3000 | 133.4 | 26.13 | 19.9 |
| 3600 | 121.8 | 25.79 | 15.41 |
| 4800 | 102.1 | 22.84 | 13.62 |
| 6000 | 93.21 | 20.91 | 11.33 |
| 8400 | 83.5 | 19.07 | 9.12 |

Table 5-9 Comparison of the viscosities of blends of PCM12 with CBC33 and CBC53 at 1% by weight.

| Shear rate | Shear viscosity (s^{-1}) | | |
|------------|------------------------------|-------------|-------------|
| | PCM12 | PCM12+CBC33 | PCM12+CBC53 |
| 1800 | 248.9 | 35.07 | 28.4 |
| 2400 | 219.8 | 32.23 | 25.57 |
| 3000 | 193.7 | 28.46 | 22.03 |
| 3600 | 162.3 | 23.69 | 19.73 |
| 4800 | 147.2 | 19.22 | 16.52 |
| 6000 | 125.8 | 17.66 | 14.12 |
| 8400 | 100.3 | 16.72 | 13.33 |

Table 5-10 Comparison of the viscosities of blends of Bayer with CBC33 and CBC53 at 1% by weight.

| shear rate | Shear viscosity (s^{-1}) | | |
|------------|------------------------------|-------------|-------------|
| | Bayer | Bayer+CBC33 | Bayer+CBC53 |
| 1800 | 172.2 | 60.12 | 39.24 |
| 2400 | 142.5 | 55.57 | 37.53 |
| 3000 | 135.8 | 50.36 | 36.35 |
| 3600 | 116.9 | 46.85 | 33.75 |
| 4800 | 109.8 | 39.29 | 32.53 |
| 6000 | 106.5 | 37.87 | 31.08 |
| 8400 | 103.6 | 30.4 | 27.26 |

The comparison of PC blends with CBC33 and CBC53 are presented in Figure 5-18 – Figure 5-21. For all polycarbonates, it can be seen that CBC53 reduced the shear viscosity of polycarbonates more than CBC33. It can be suggested that the molecular chains of CBC53 were longer than CBC33 so they can easier lubricate the polycarbonate. Moreover, the CBC53 has a widely useful temperature range compared to CBC33. CBC53 has mesophase between 64 °C to 317 °C and CBC33 has mesophase between 223 °C to 327 °C. It can be seen that CBC53 has mesophase temperature range closed to the processing temperature range of PC. The result showed that the CBC53 was the better plasticizer of PC than the CBC33.



สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

Comparison of the viscosity of blends of PCM7 with CBC33 and CBC53

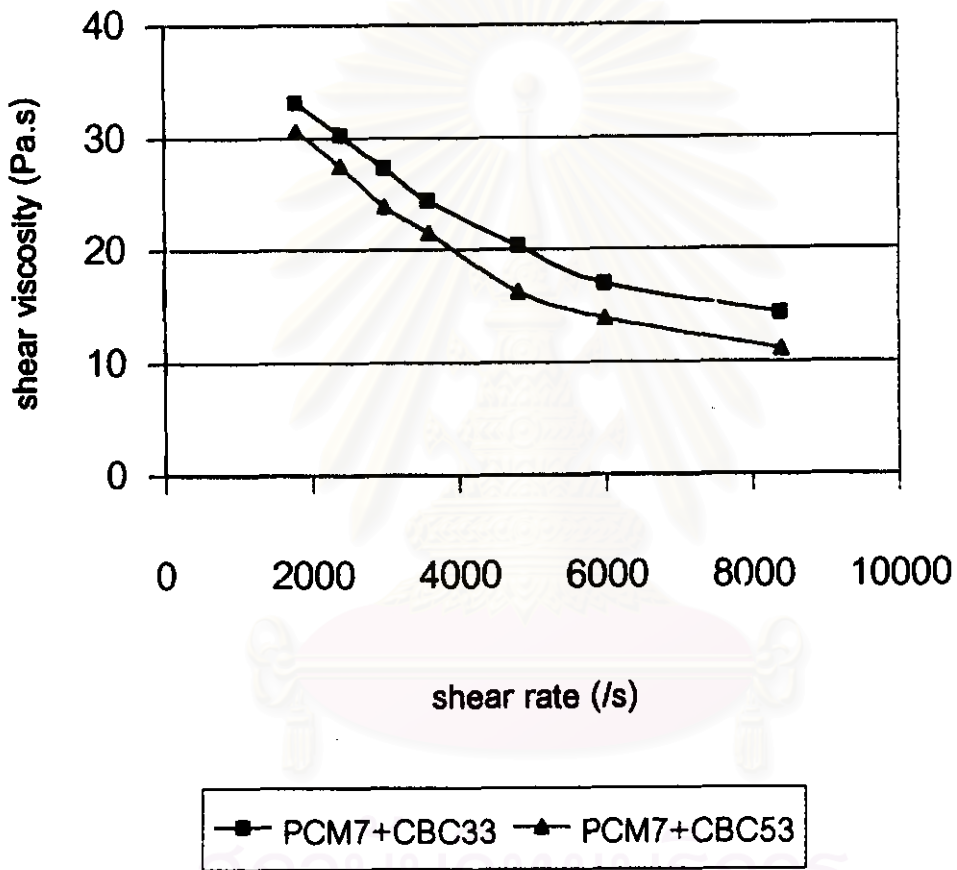


Figure 5-18 Comparison of the viscosity of blends of PCM7 with CBC33 and CBC53

Comparison of the viscosity of blends of PCM10 with
CBC33 and CBC53

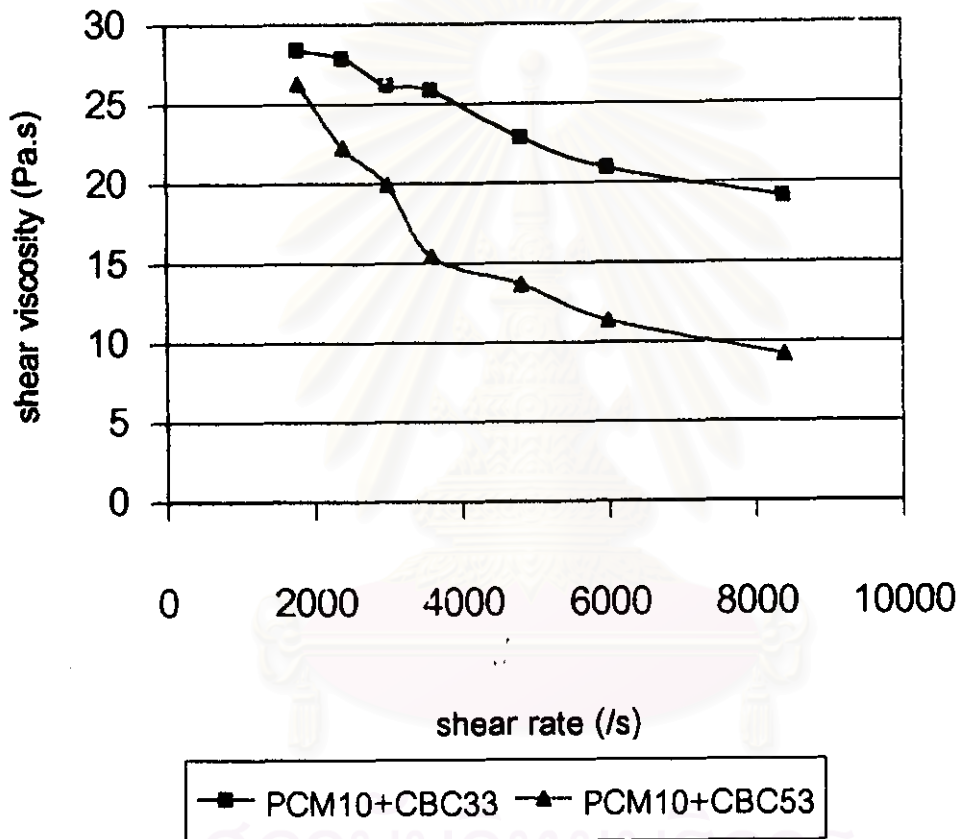


Figure 5-19 Comparison of the viscosity of blends of PCM10 with CBC33 and CBC53

Comparison of the viscosity of blends of PCM12 with CBC33 and CBC53

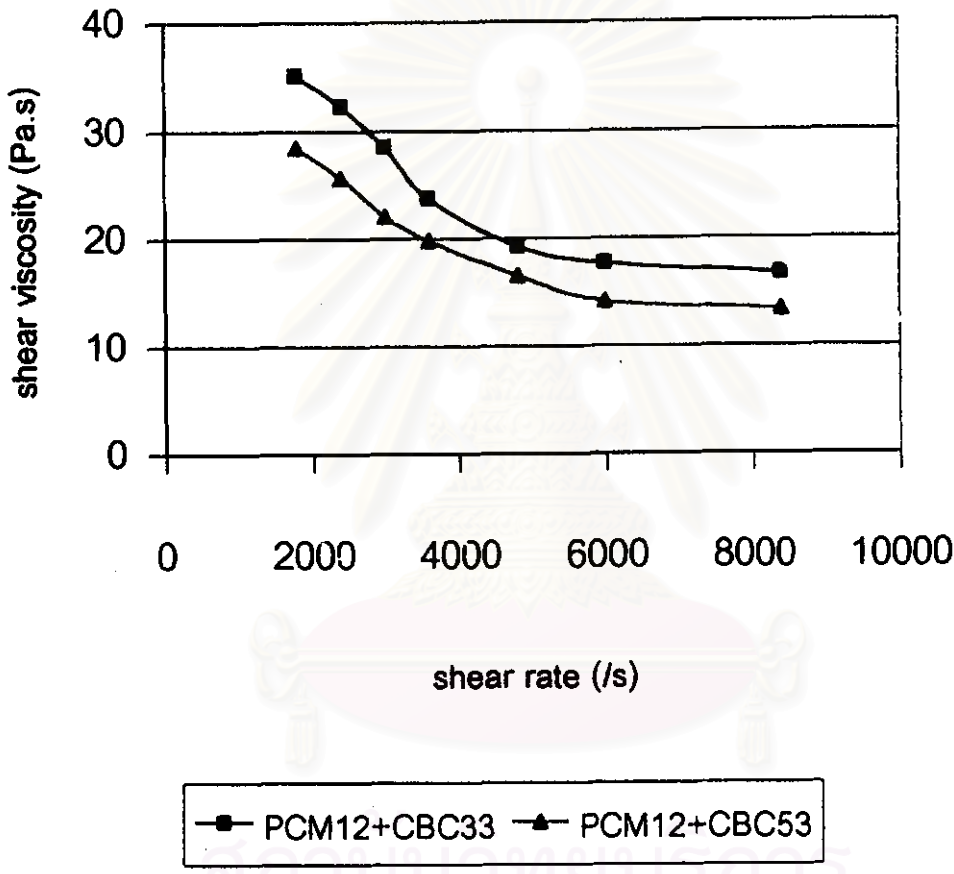


Figure 5-20 Comparison of the viscosity of blends of PCM12 with CBC33 and CBC53

Comparison of the viscosity of blends of PCM12 with
CBC33 and CBC53

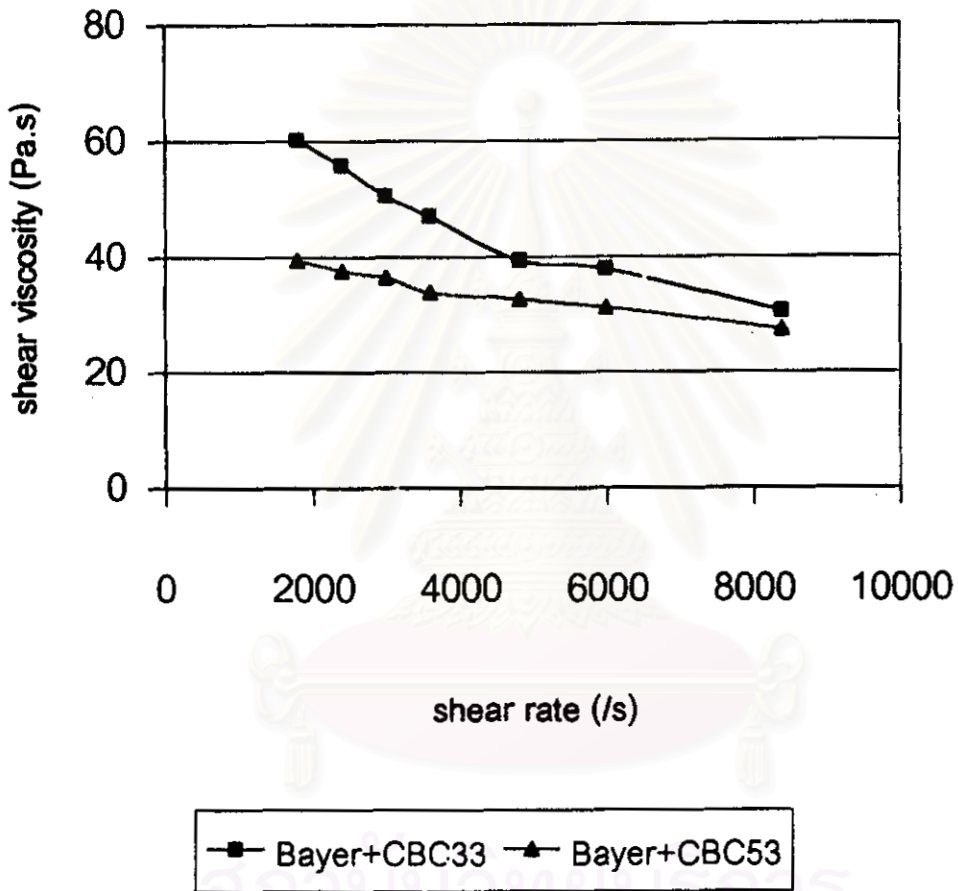


Figure 5-21 Comparison of the viscosity of blends of Bayer with CBC33 and CBC53