CHAPTER V

RESULTS AND DISCUSSION

5.1 Characterization of Polybenzoxazine Alloys

The curing exotherms of the neat benzoxazine resin (BA-a) and the binary mixtures (BP) between benzoxazine (B) and phenolic novolac resin (P) were shown in Figure 5.1. DSC thermograms revealed the curing exotherm of the BA-a with the onset curing temperature of $170^{o}C$ and the peak maximum at $225^{o}C$. BA-a has been shown to be thermally polymerized either with or without acid catalysts or initiators. The polymerization occurs via a simple ring-opening addition reaction so it does not yield any reaction by-products. At those temperatures, gelation of multifunctional benzoxazine resins takes place at a time period from few minutes (using initiator) to ten minutes or more if no intiator is used [H. Ishida, 1996]. In addition, the thermograms clearly showed that the curing exotherm peak shifted to lower temperature when phenolic novolac content in the binary mixtures increased, for example, the curing peak of BA-a at $225^{o}C$ was shifted to $150^{o}C$ in BP37. These results can be concluded that the addition of phenolic novolac resin to form binary mixtures with benzoxazine resin can substantially reduce the curing temperature of the benzoxazine resin. This result is in good agreement with that has been reported by S. Rimdusit and H. Ishida, 2000.

Considering breath of exotherms, the curing peaks of the binary mixture became broader when phenolic novolac content increased. This signified that the polymerization of the resin mixtures occurred in boarder range of temperature at the presence of phenolic novolac resin. Furthermore, the area under the exothermal peaks slightly increased and then decreased with increasing amount of the phenolic novolac fraction in the binary resin mixtures. The behavior thus suggested only certain fraction of the phenolic novolac would be needed in the resin alloys as the rest of phenolic novolac seems to show no contribution to the network formation in the binary alloy systems.

Relationship between curing enthalpy and the phenolic novolac mass fraction was shown in Figure 5.2. In the other report, benzoxazine resin can be thermally cured while phenolic novolac resin shows no sign of a curing reaction without an addition of initiators or catalysts [S. Rimdusit and H. Ishida, 2000]. Therefore, the observed curing exotherms in Figure 5.1 belong to either the reactions among benzoxazine monomer resin or between benzoxazine and phenolic. The area under the exotherm peak tends to decrease with decreasing the amount of the benzoxazine resin in binary mixtures as seen as theory curing enthalpy. From the plot, the theory curing enthalpy should reduces when phenolic novolac resin content increases approximately in a linear fashion. However, the actual curing enthalpy was calculated from the area under the exothermic peak of Figure 5.1. The actual curing enthalpy of binary mixture curing process normalized with the fraction of benzoxazine resin were higher than the calculated values when phenolic novolac mass fraction are in the range of 0 to 0.2. These may be because of curing enthalpy between benzoxazine and phenolic novolac resin. Phenolic novolac resin, no more than 0.2 of mass fraction, can form chemical bonding to benzoxazine resin. Nevertheless, the actual curing enthalpy tends to be similar to the calculated values when the phenolic novolac mass fraction is more than 0.2. Therefore, the optimal phenolic novolac mass fraction to be effectively alloyed with the benzoxazine resin should be less than 0.2.

The completion of the network formation by the two can be proved by a solubility test of starting resins. In the test, the resin alloy samples (BP91, BP82, and BP73) were immersed in chloroform/methanol mixed solvent at the mass ratio of 70/30 to observe extractable phenolic novolac mass fraction. The extracting time was up to 1 month. Figure 5.3 revealed that BP73 can not resist the solvent extraction and the color change of the solvent was obviously seen even at ten days of the test. The solubility test of these alloys also supported.

Figure 5.4 showed a processing window of BP binary mixtures using a heating rate of 2°C/min. The dynamic viscosity of the resin as a function of temperature was recorded. In the first stage, the uncured monomers in the form of solid powder at room temperature changed to soft solid as the ramp temperature approached its softening point.

At this point, dynamic viscosity of the binary mixtures rapidly decreased with increasing temperature. In the second stage, the binary mixtures became liquid giving lowest range of viscosity. This lowest viscosity range provides a processing window for a compounding process of each resin. At the final stage at higher temperature, the binary mixtures underwent crosslinking reaction past the gel point thus resulting in a rapid increase in the viscosity beyond this transition [S. Rimdusit and H. Ishida, 2002].

From the rheogram of Figure 5.4, the dynamic viscosity of the binary mixtures compared at the same temperature tended to increase with increasing the amount of phenolic novolac resin. The devitrification temperature (liquefying temperature) of these binary mixtures also increased with the increasing amount of the phenolic novolac resin in the binary mixtures. The unmodified BA-a resin exhibited the lowest liquefying temperature of 80°C while BP73 showed the highest liquefying temperature among the tested resins of 120°C. BP91 and BP82 possessed intermediate liquefying temperature between BA-a and BP73. These liquefying behaviors are due to the higher viscosity of the phenolic novolac resin compared to that of the BA-a monomer. On the other hand, the gel point of these binary mixtures tended to decrease with the increasing amount of the phenolic novolac resin in the binary mixtures. The BA-a resin showed the highest gel point at a temperature of 210°C, while those of BP91, BP82, and BP73 are 195°C, 165°C, and 160°C, respectively. This characteristic corresponds with the DSC results (Figure 5.1) that phenolic novolac resin can substantially reduced the curing temperature of BA-a resin. Therefore it acts as an initiator for the ring-opening reaction of the benzoxazine resin. Furthermore, the rheograms also indicated that BP73 has a rather narrow processing window among the three binary mixtures. If the processing window for this wood/resin compounding is considered, BP82 and BP91 are probably more suitable for using as a matrix resin for the compounding with woodflour than BP73.

5.2 Process Condition of Molding Compounds of Polybenzoxazine Alloys

Figure 5.5 showed DSC thermograms of BP91 and its filled systems at the woodflour contents of 50% by weight and 70% by weight. The thermograms at all filler contents revealed the curing exotherms with the same peak maxima of $210^{\circ}C$. This characteristics indicated that the woodflour loading had no effect on the curing reaction, either accelerating or retarding, of these binary alloys or the filler is somewhat inert to the curing reaction. Furthermore, the area under the curing peak expectedly decreased with increasing the woodflour content due to the less amount of the resin with increasing the filler loading.

From the figure, the processing temperature of these alloys was selected at $160^{\circ}C$ because this temperature was high enough to initiate the crosslinking reaction of the alloys. In addition, this temperature was moderate enough for typical wood composite fabrication. Moreover, the degradation temperature of woodflour filler must also be considered to justify the composite processing conditions. As a general rule, curing or melting temperatures should be kept below $200^{\circ}C$, except for short period, in order to achieve wood composites with maximum integrity. Higher temperature can result in the release of volatiles, discoloration, odor, and embrittlement of the wood component [J.A. Youngquist, 1999]. Therefore, the temperature of $160^{\circ}C$ satisfied the above conditions.

The effect of curing time on the woodflour-filled BP91 at 50% by weight of woodflour content using the curing temperature of $160^{\circ}C$ was shown in Figure 5.6. The curing time was varied from 0 to 180 minutes. As the curing time increased, the area under the curing peak steadily decreased signifying the increasing degree of conversion of the curing process. The complete polymerization of the alloy was attained when the curing peak was disappeared. Figure 5.6 revealed that the isothermal curing reaction was complete at 120 minutes at $160^{\circ}C$. The above condition was; therefore, used to cure our polymer alloys and their wood composites.

5.3 Properties of Polybenzoxazine Alloys

Degradation temperature (T_d) is usually one of the key parameters that needs to be considered for high temperature applications of wood composites whereas a limiting oxygen index (LOI) is usually considered for flame resistant capability of wood composites. The larger value of LOI, the harder it is for the material to burn. Generally, in the case of LOI below 22, the material is regarded as "flammable" while for LOI equal or greather than 22, the material is classified as "self extinguishable" [H.T. Chiu *et al.*, 2000]. Table 5.1 summarized the LOI of our polymers and the wood filler used in this study as well as those of some major polymers used in wood composites. From the table, the LOI of phenolic novolac was reported to be as high as 41 [C.A. Harper, 2004] whereas that of the polybenzoxazine obtained from this study was obtained to be about 30. Both polymers are thus classified as self extinguishable-typed materials. Moreover, the LOIs of our polymer alloys sligthly increased compared to BA-a when the phenolic novolac content in the polymer alloys increased. The values were ranging from 30 in the BA-a to a slightly higher value of 31 in BP91, BP82, and BP73. From the previous experiment by DSC thermograms (Figure 5.2), the plot indicated that certain amount of phenolic novolac can react with the BA-a resin. If the phenolic novolac mass fraction was more than 0.2, the amount of the phenolic novolac resin became in excess to completely crosslink with the benzoxazine resin. As a consequence, the LOI of the obtained polymer alloys slightly increased with the amount of the phenolic novolac resin. However, these values were also classified as "self extinguishable". The larger LOI value of the phenolic novolac comparing to that of the BA-a may be due to the more prevalent benzene rings in the phenolic novolac structure resulted in the slightly better flame retardation of the phenolic novolac. From the table, LOIs of our unfilled alloy matrix systems remain much greater than those of polymeric matrices commonly used to produce wood composites such as PE, PP, or PS [C.A. Harper, 2004]. Although PVC may be a good candidate for achieving fire resistant wood composites due to its high LOI value up to 50, the polymer itself upon combustion, can release undesirable HCl gas which is corrosive and toxic.

Figure 5.7 showed heat of combustion (HOC) of BP polymer alloys. HOC slightly decreased when phenolic novolac mass fraction increased from 0.0 to 0.3 because of the slightly low HOC value of the phenolic compared to the polybenzoxazine. The values were in the range of 34-35 kJ/g from BP73 to the neat polybenzoxazine. The HOC values indicated that after ignition and removal of the ignition source, combustion became self-propagating if sufficient heat was generated and radiated back to the material to continue the decomposition process. Therefore, one might expect an inhibited flame propagation as a result of a lower HOC. These implied that the HOC could be a significant parameter in the flammability studies. However, HOC of the polymer alloys used in this research is much lower than those polymeric matrices commonly used to produce wood composites e.g. PP (HOC=43), PE (HOC=44), PS (HOC=40) [C.A. Harper, 2004]. Therfore, the alloys are highly attractive to be used as a fire resistant matrix of natural fiber composites.

The relationship between phenolic novolac mass fraction and char yield of our polymer alloys was depicted in Figure 5.8. From the plot, the char yield of the unfilled polymer alloys clearly increased when the phenolic novolac mass fraction increased. This is due to the higher char yield of the phenolic novolac resin compared to the polybenzoxazine. The polybenzoxazine has a reported char yield about 25-30% while that of the phenolic novolac is 55% from the more prevalent benzene rings in the phenolic novolac structure. Moreover, it was evident that the char yield of the alloys significantly increased when phenolic novolac mass fraction increased from 0.0 to 0.2, with the maximum char yield about 35%. The value (35%) is significant greater than those polymeric matrices often used for making wood composites e.g. PP (char yield=0%), PS (char yield=0%), PE (char yield=0%), and PVC (char yield=11%) [C.A. Harper, 2004]. In the alloys, char yield slightly further increased when phenolic novolac mass fraction increased from 0.2-0.7. The merely marginal improvement in the char yield of the alloys was attributed to the excess amount of the phenolic novolac beyond 20% showed no contribution to the network formation and the thermal integrity of the fully cured alloys.

The relationship between phenolic novolac mass fraction and degradation temperature (T_d) of BP polymer alloys was shown in Figure 5.9. From the thermograms, the T_d of the alloys increased with increasing amount of the phenolic novolac mass fraction from 0.0 to 0.2. The phenolic novolac mass fraction beyond 0.2 resulted in the systematically decrease of T_d. This result indicated that the optimal amount of the phenolic novolac resin that can react with benzoxazine resin was less than 20% by weight. This amount of the phenolic novolac resin was expected to be able to react with the benzoxazine resin to constitute a network structure. This observed behavior was also in good agreement with the heat of reaction analysis and the char yield property of the alloys.

Figure 5.10 showed the glass transition temperatures (T_g) of the polybenzoxazine and the polymer alloys between the benzoxazine and the phenolic novolac resins. All polymer alloys showed only single T_g implying the miscibility of the two resins was obtained. From the plots, T_g of the alloys decreased from 165°C to 112°C when the phenolic novolac mass fraction increased from 0.0 to 0.5. The trend is of linear relationship as seen in the inset of Figure 5.8. This effect is probably because the T_g of phenolic novolac polymer cured with hexamethylenetetramine is 121°C [C.P.R. Nair, 2004] while the BA-a has higher T_g of 165°C. As a result, T_g of the alloy systems were lower with increasing the phenolic novolac content. In addition, the BA-a was found to help improve the T_g of the polymer alloys due to its ability to be self-polymerized and to undergo crosslinking with certain amount of the phenolic novolac.

Flexural modulus and flexural strength of benzoxazine/phenolic novolac alloys were shown in Table 5.2. It was found that the flexural modulus slightly increased whereas flexural strength slightly decreased when phenolic novolac mass fraction increased from 0.1 to 0.3. However, the flexural values were similar when increasing amonut of the phenolic novolac. These implied that the amount of phenolic novolac resin had no significant effect on flexural properties.

5.4 Properties of Woodflour-filled BP Alloys.

Figure 5.11 showed the limiting oxygen index (LOI) of the woodflour-filled BP alloys. As phenolic novolac mass fraction in the alloys increased from 0 to 0.7, the LOI of the composite specimens, at the same woodflour content of 50% by weight, systematically increased from 25.2 to 28.1. In addition, the LOI changed from 22.8 to 24.4 for those specimens at a constant woodflour content of 70% by weight. The LOI also obviously decreased with increasing woodflour content due to the inherently lower LOI (LOI=21-22) of the woodflour. Thus the resulting wood composites based on BP alloys gave promising fire resistant properties i.e. LOI=25.2-28.1 at 50% by weight of woodflour content, comparing to the currently commercially available systems such as LLDPE-wood fiber composites (LOI= 19.5 at 30% by weight of woodflour content) [B. Li and J. He, 2004].

Rate of burning of our wood composites was shown in Figure 5.12. The figure displayed that the rate of burning decreased when the amount of phenolic novolac resin increased. The rate of burning was reduced from 18.5 mm/min in the polybenzoxazine wood (i.e. phenolic novolac mass fraction = 0.0) to about 14.8 mm/min in BP55 comparing at the same woodflour content of 70% by weight. At woodflour content of 50% by weight, the rate of burning became 17.7 mm/min for the polybenzoxazine wood while those using the alloy, matrices having the phenolic fraction of greater than 20% by weight, were self-extinguishable i.e. the LOI values are above 25. These phenomenon implied that BP82 displayed sufficient fire resistant property. In addition, the rate of burning expectedly increased with increasing the woodflour content as the woodflour is the most flammable species in these wood composites. However, these BP alloy wood composites rendered the much slower rate of burning compared to that of 50% by weight filled sawdust-PP composites, having the burning rate of 31 mm/min [M. Sain et al., 2004].

Heat of combustion (HOC) of woodflour-filled BP82 was shown in Figure 5.13. From the plot, HOC of the composite systems decreased when woodflour content

increased. This is due to lower HOC value of woodflour comparing to the polymers used. (i.e. HOC of BP82 and woodflour are 34 and 19 kJ/g) In general, HOC over 30 kJ/g may be classified as being extremely flammable [UN/SCETDG/19/INF.43]. The HOC of our wood composite systems are 26 and 23 kJ/g at 50% and 70% by weight of woodflour content which are well below that criteria.

TGA experiments of the woodflour-filled BP alloys at different woodflour contents under nitrogen atmosphere were shown in Figure 5.14 (a) and 5.14 (b). Additionally, the relationship between phenolic novolac mass fraction and char yield of woodflour-filled BP alloys was illustrated in Figure 5.15. From the experiments the char yield of the wood composites was found to significantly increase when the phenolic novolac mass fraction increased from 0.0 to 0.2 and the char yield values became relatively unchanged when the phenolic novolac mass fraction was above 0.2. This observation further confirmed that the incorporation of the phenolic novolac above 20% by weight in the polymer alloys had no benefit to the polymer systems and even lowered some of their useful properties. The main reason of these phenomena is probably due to the excess amount of the phenolic resin beyond 20% by weight provided no contribution to the network structure of the alloys. The char yield at 50% by weight of woodflour was higher than that at 70% by weight of woodflour that the amount of the phenolic novolac resin to be fully reacted with the benzoxazine resin should not exceed 20% by weight of the BP alloys. The char yields of systems were ranging from 32.4% to 36% at the 70% by weight of woodflour content and from 36% to 40% at the 50% by weight of the woodflour content. The values are much higher compared to that of LLDPE-wood-fibre composite, at 30% by weight of wood content, i.e. having char yield of only 0.98% at $700^{\circ}C$ [B. Li and J. He, 2004].

The effect of phenolic novolac mass fraction on degradation temperature (T_d) of the woodflour-filled BP alloys was also shown in Figure 5.16. The T_d of the composites increased when the phenolic novolac mass fraction increased from 0.0 to 0.2 and the Td became relatively unchanged when the phenolic novolac mass fraction was above 0.2. This observation is again due to the excess amount of the phenolic resin beyond 20% by

weight giving no contribution to the network structure of the alloys. Moreover, the T_d was found to decrease with increasing the woodflour content as the woodflour possesses lower T_d of only 265°C while those of the phenolic novolac and the polybenzoxazine are 343°C and 334°C respectively.

Flexural properties of the woodflour-filled BP alloys as a function of the phenolic novolac mass fraction were shown in Figure 5.17 and 5.18. From Figure 5.17, the flexural moduli of the composites at various phenolic novolac mass fraction from 0 to 0.5 were similar; therefore, there was insignificant effect from the addition of phenolic novolac on the resulting composite strength in the considered range of the alloy composition. At the different woodflour contents, the flexural modulus of the 70% by weight of woodflour-filled composites gave slightly higher value than those of the 50% by weight of woodflour-filled composites. This is due to the fact that the wood has a flexural modulus as high as 9.7 GPa while the polybenzoxazine has a flexural modulus of about 4.7 GPa and the phenolic novolac has a modulus of 2.5 GPa. Moreover, the increase in the amount of woodflour caused an increase in the modulus of the composites due to the reinforcing capability of the woodflour to the alloy matrice. The average flexural modulus of our wood composites was ranging from 5.5-6.3 GPa and 6.0-6.6 GPa at 50% by weight and 70% by weight of the woodflour, respectively. In this work, flexural modulus of the woodflour-filled BP alloys are significantly higher than those of other reported wood polymer composites, i.e. wood-polypropylene composites with 40% by weight of woodflour content (3.03 GPa) [J.A. Youngquist, 1999], wood flake-reinforced HDPE composites with 50% by weight of wood content (2.7 GPa) [P.W. Balasuriya et al., 2001], wood flake-reinforced HDPE composites with 70% by weight of wood content (3.1 GPa) [P.W. Balasuriya et al., 2001], and woodflour-filled unsaturated polyester/styrene composites with 40% by weight of woodflour content (5.44 GPa) [N.E. Marcovich et al., 2001]. Moreover, the flexural modulus of our wood systems are higher than those of the current commercial products (i.e. particleboard-grade composite, particleboard flooring-product-grade composite and medium-density fiberboard (MDF) composite which have flexural moduli in range of approximately 0.5-3 GPa [J.A. Youngquist, 1999].

In Figure 5.18, flexural strength of our wood composites showed similar values when the amount of the phenolic novolac increased from 0.0 to 0.5. The flexural strength of the BP wood composites are ranging from 52-68 MPa in both filler contents. The flexural strengths were relatively high value comparable to those of natural wood. These results indicated that the resin alloys can be substantially adhered to the woodflour surface. At different woodflour contents, the flexural strengths were similar in value since the flexural strength of both the polybenzoxazine and the woodflour are about the same, i.e. 76 GPa for the polybenzoxazine and 66 GPa for the wood. Moreover, the flexural strengths of our wood systems were higher than those of the commercial wood flake-reinforced HDPE composites i.e. flexural strength of 31 MPa and 18 MPa at 50% by weight and 70% by weight of wood content [P.W. Balasuriya et al., 2001].

The effect of the phenolic novolac mass fraction of the alloy matrices on the dynamic mechanical properties of their wood composites was also examined. At room temperature, the storage moduli of the composites increased with increasing woodflour content as seen in Figure 5.19. The moduli of the 70% by weight of woodflour-filled polybenzoxazine and that of the unfilled polybenzoxazine were 3.8 GPa and 2.7 GPa respectively. Moreover, the rubbery plateau moduli of the woodflour-filled systems had values greater than that of the unfilled system. The significant enhancement of the composite's modulus by the addition of woodflour implied a strong interfacial bonding between the matrix and the reinforcing filler.

Figure 5.20 showed the loss modulus curves of the woodflour-filled BP alloys with 70% by weight of woodflour content and of the unfilled polybenzoxazine. The maximum peak temperature in the loss modulus curve was used as a glass-transition temperature (T_g) of the specimen. From the figure, the T_g of unfilled polybenzoxazine was 170°C whereas the T_g of the 70% by weight woodflour-filled polybenzoxazine was up to 200°C. This T_g value increased with increasing the amount of the woodflour because of the greater T_g of the woodflour i.e. 240°C [www.uwsp.edu]. Furthermore, the T_g of our wood composites at 70% by weight of woodflour content were similar, i.e. 200-

218°C, when the amount of phenolic novolac in the alloy matrices increased from 0.0 to 0.2.

SEM micrographs in Figure 5.21 (a) showed the uniform dispersion of woodflour particles in our BP matrix. The relatively low melt viscosity of the resin alloy resulted in the good distribution of the filler while in Figure 5.21 (b) the fracture surface of this filled systems reveal substantial adhesion having smooth and continuous interface between the filler and the matrix. The micrograph revealed no gap between the two components. The potentially strong interface of our filled systems comfirmed the enhanced mechanical and thermal properties of the resulting composites.
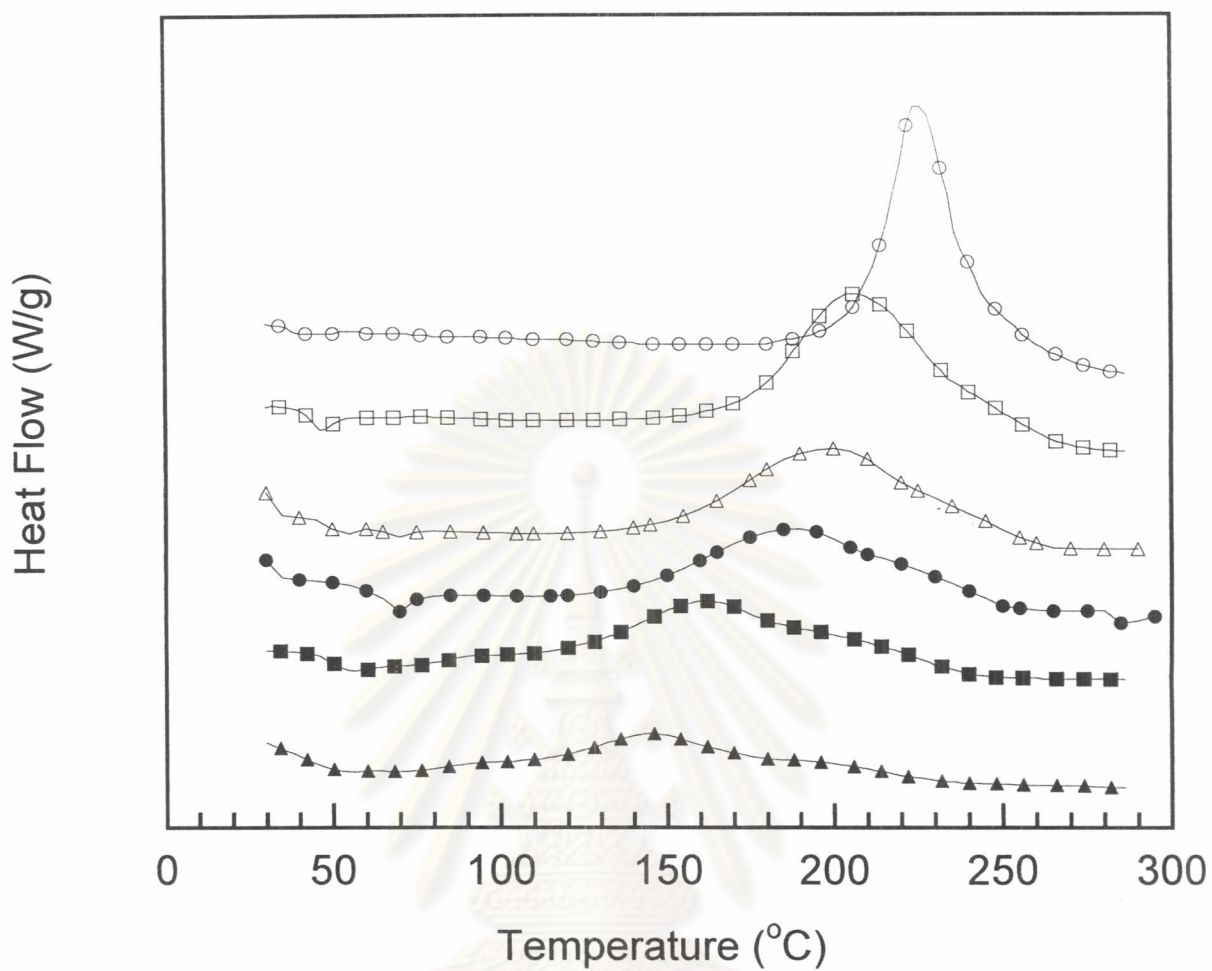
Figure 5.1: DSC thermograms of BP mixtures : (o) BA-a, (□) BP91, (Δ) BP82, (●) BP73, (■) BP55, (▲) BP37.
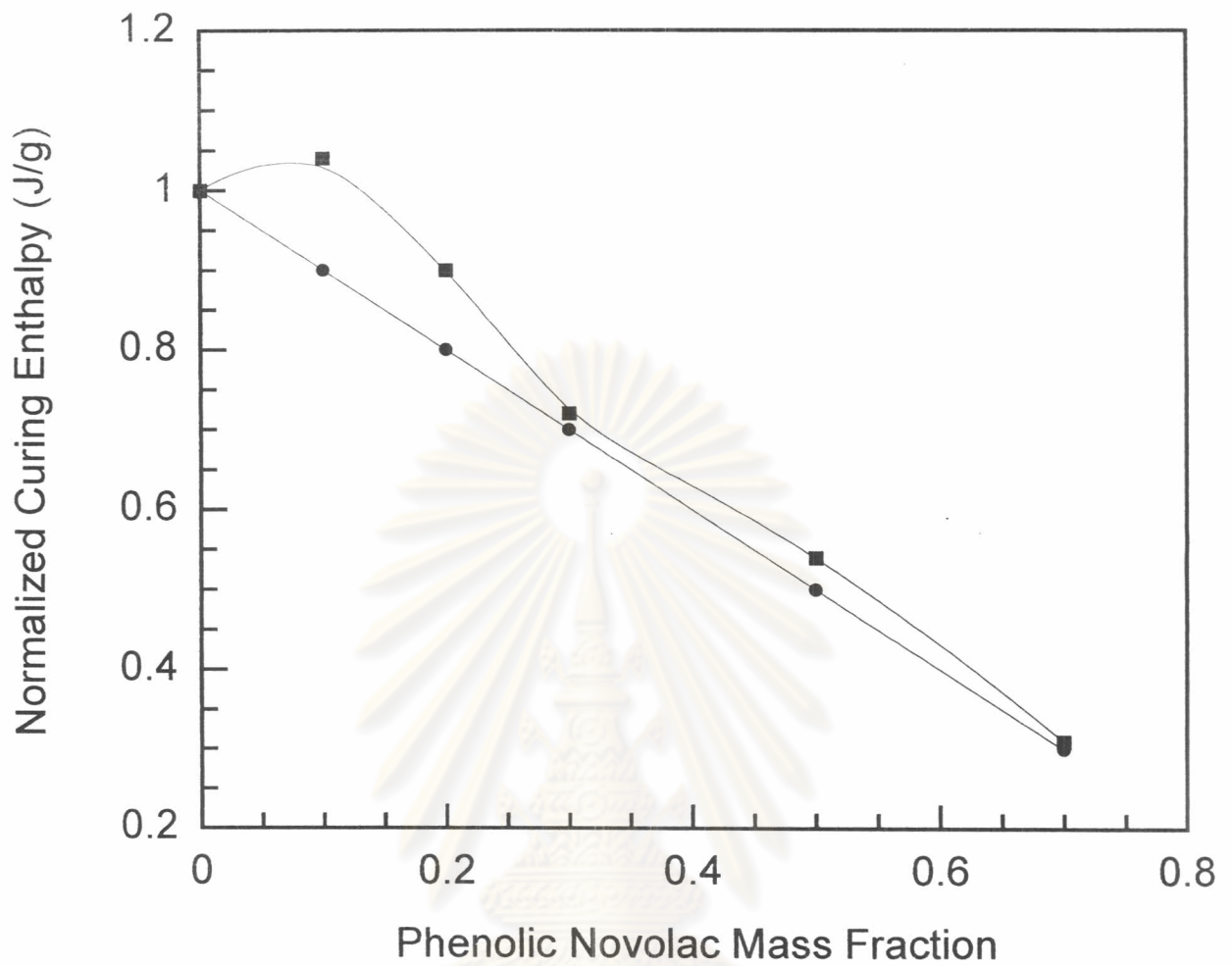
Figure 5.2: Normalized curing enthalpy of BP mixtures : (●) calculated, (■) actual.
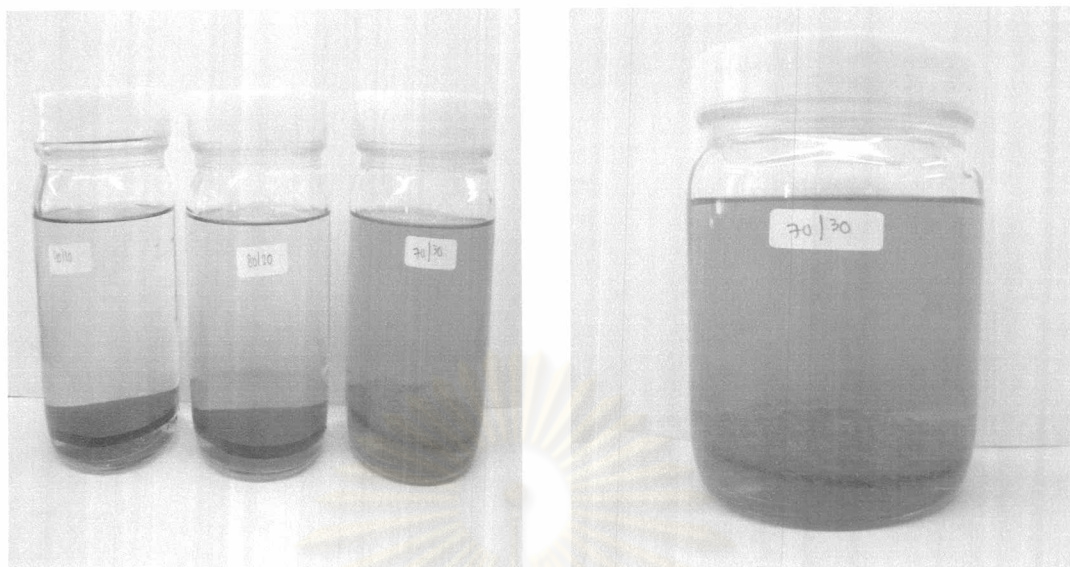
Figure 5.3: Solvent extraction of BP alloys using chloroform / methanol (70/30).
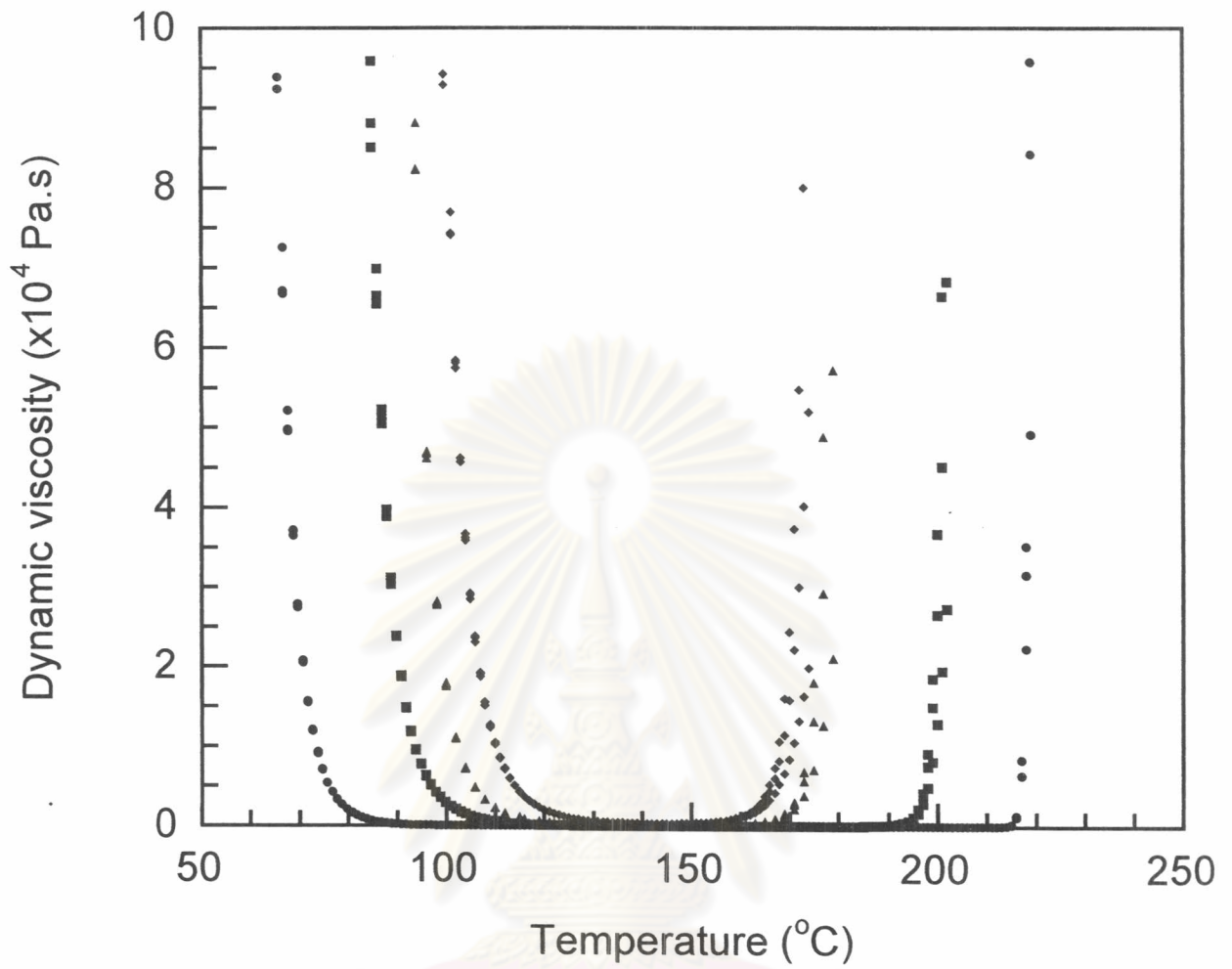
Figure 5.4: Processing window of BP mixtures at heating rate of 2°C/min :
(•) BA-a, (■) BP91, (▲) BP82, (♦) BP73.
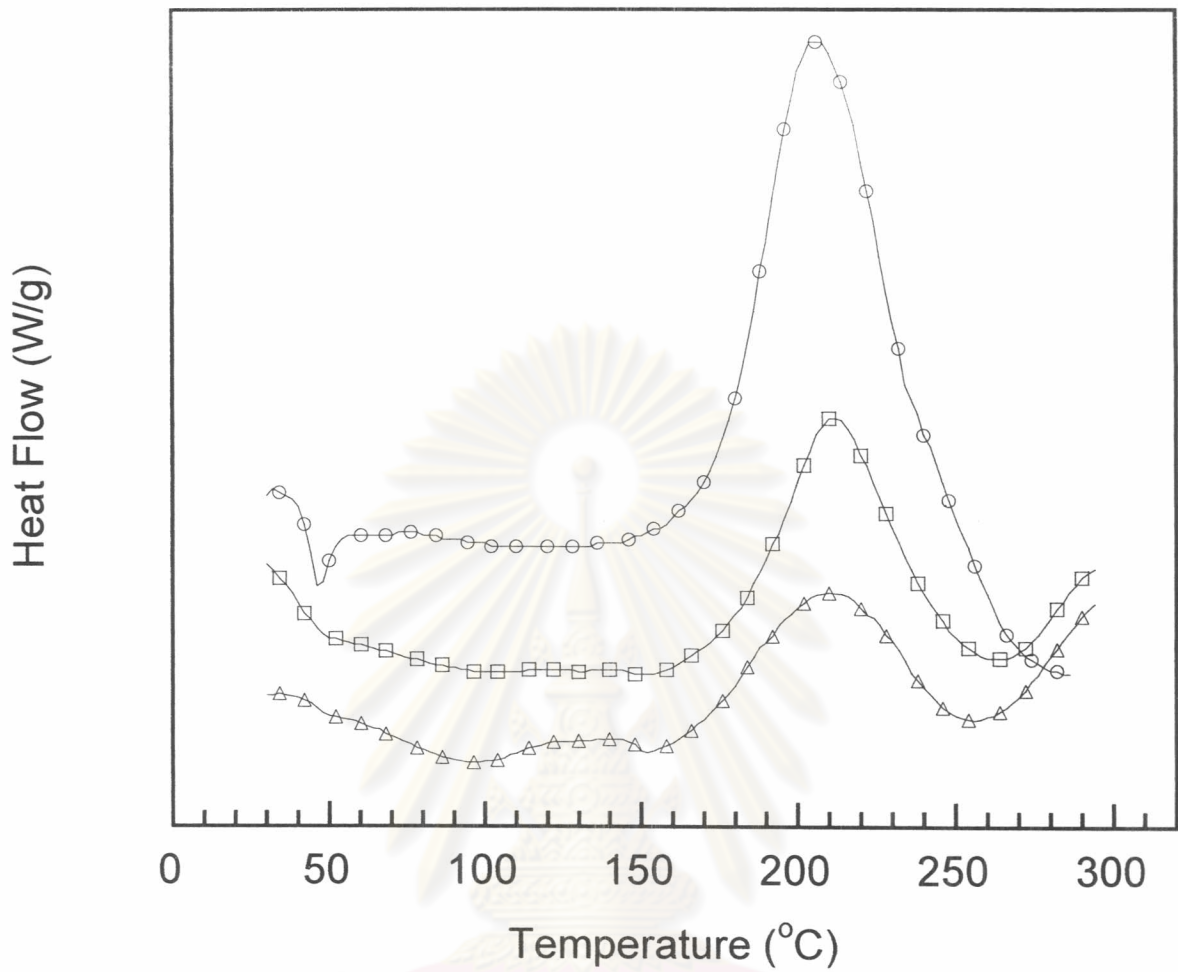
Figure 5.5: DSC thermograms of woodflour-filled BP91 at three different woodflour content : (o) 0% by weight WF, (□) 50% by weight WF, (Δ) 70% by weight WF.
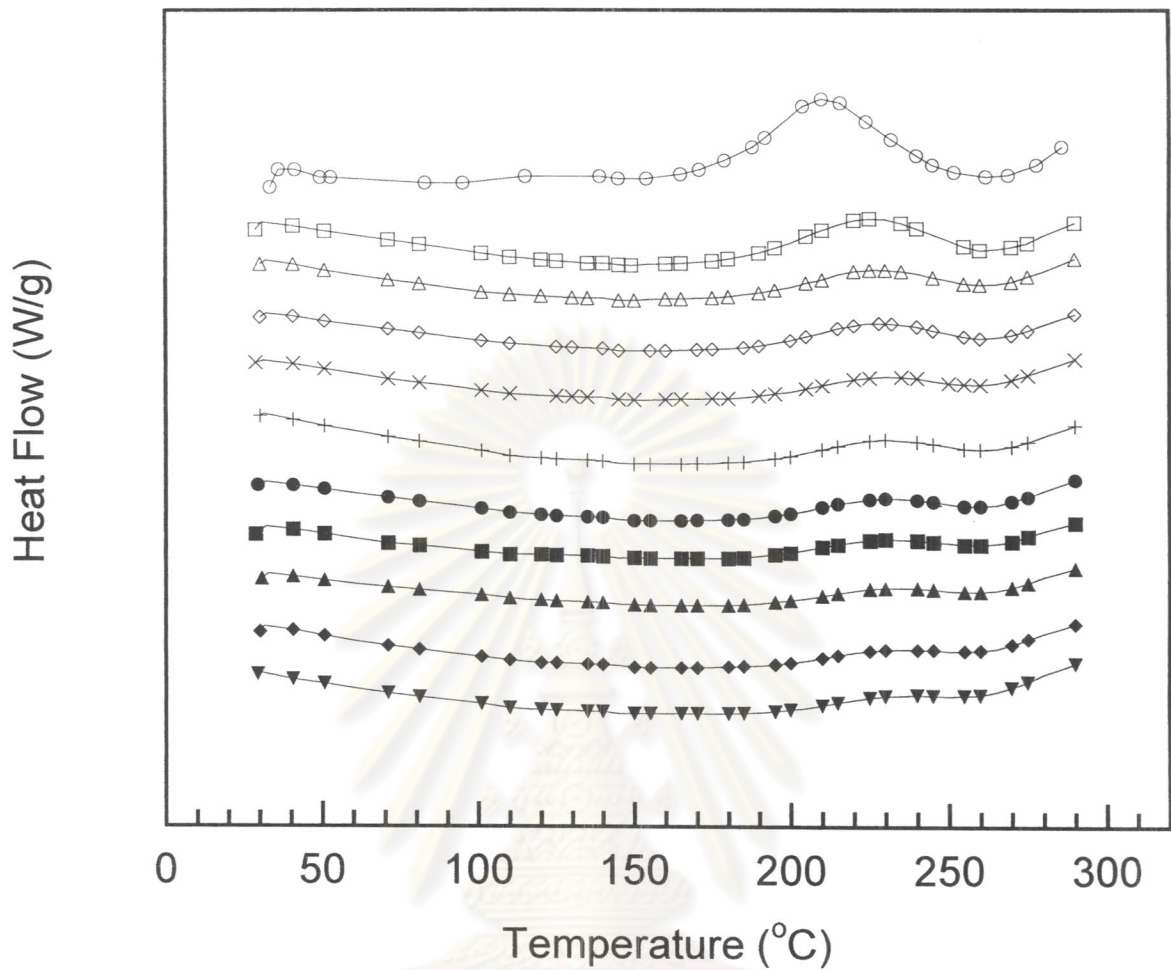
Figure 5.6: Effect of curing time on woodflour-filled BP91 at 50% by weight of woodflour content at isothermal curing temperature of 160°C : (○) 0 min, (□) 45 min, (Δ) 60 min, (◊) 75 min, (x) 90 min, (+) 105 min, (●) 120 min, (■) 135 min, (▲) 150 min, (♦) 165 min, (▼) 180 min.

Table 5.1 Limiting oxygen index (LOI) of BP alloys compared with typical matrices for wood composites.

Matrix	Limiting oxygen index (LOI)
Polybenzoxazine	30
BP91	31
BP82	31
BP73	31
Phenolic Novolac Resin [*]	41
Polypropylene [*]	17
Polyethylene [*]	18
Polystyrene [*]	18
Polyvinylchloride [*]	50

* Ref : C.A. Harper, HANDBOOK OF BUILDING MATERIALS FOR FIRE PROTECTION, McGRAW-HILL, New York (2004).
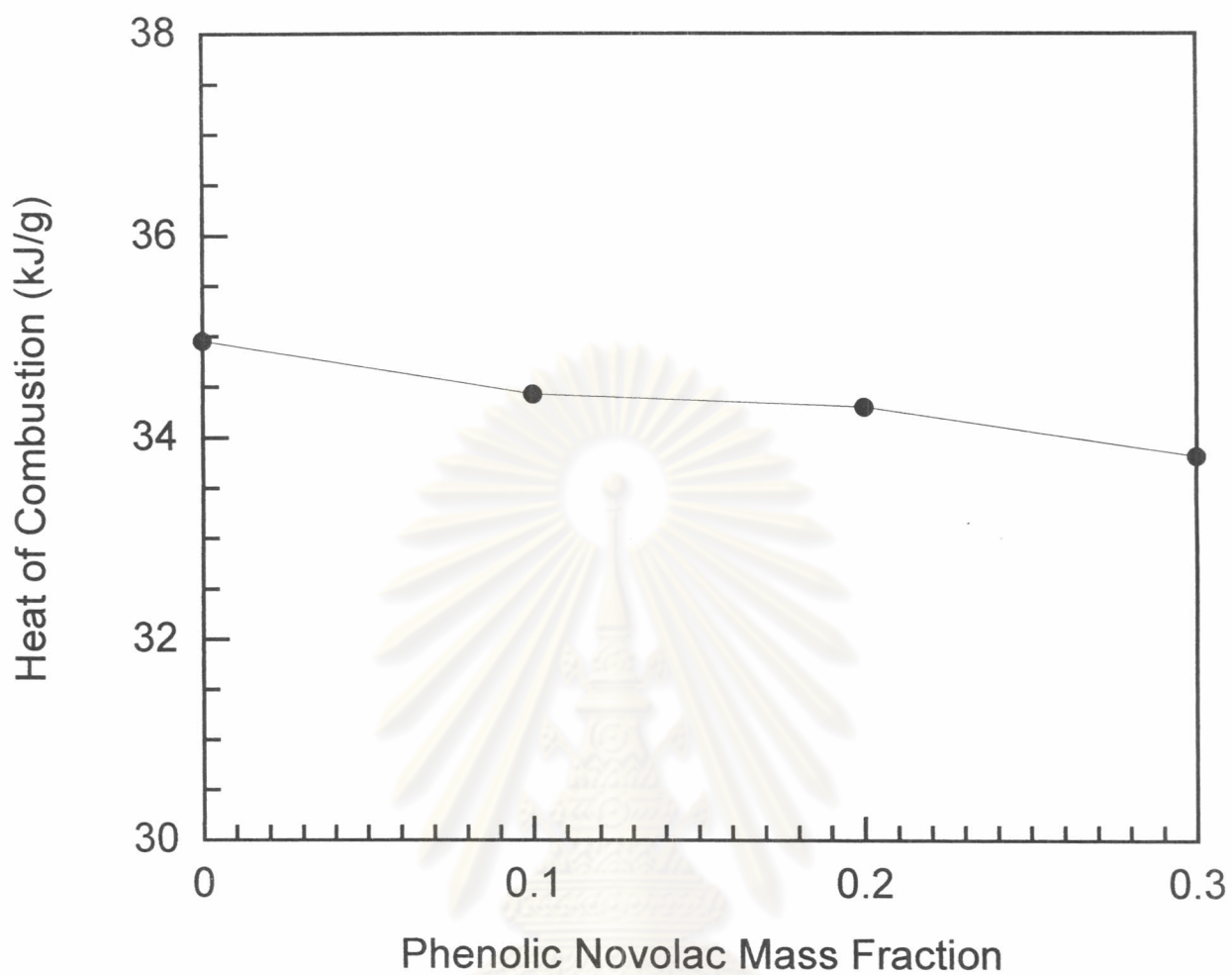
Figure 5.7: Heat of combustion of BP alloys.
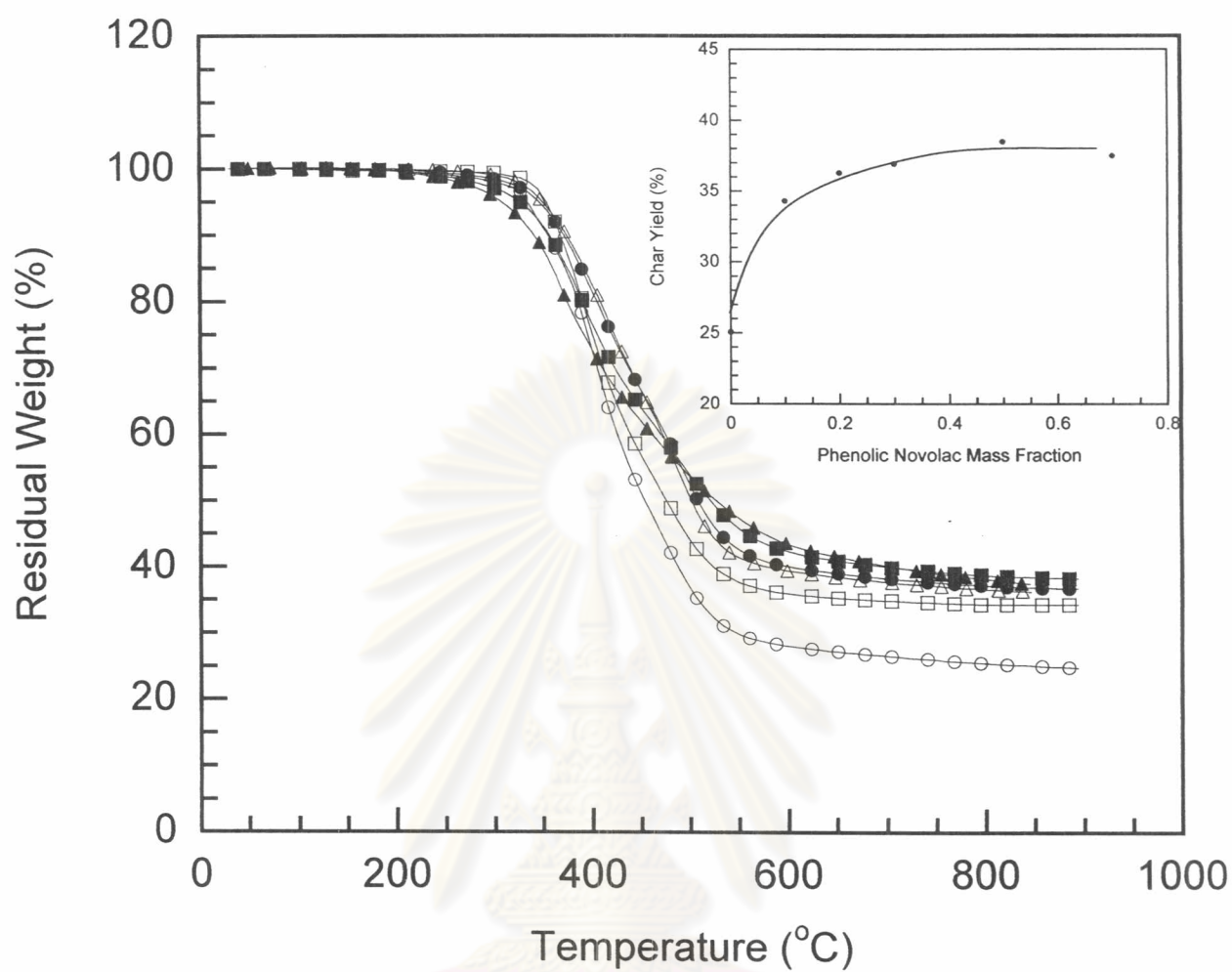
Figure 5.8: TGA thermograms of BP alloys : (○) BA-a, (□) BP91, (Δ) BP82, (●) BP73, (■) BP55, (▲) BP37.
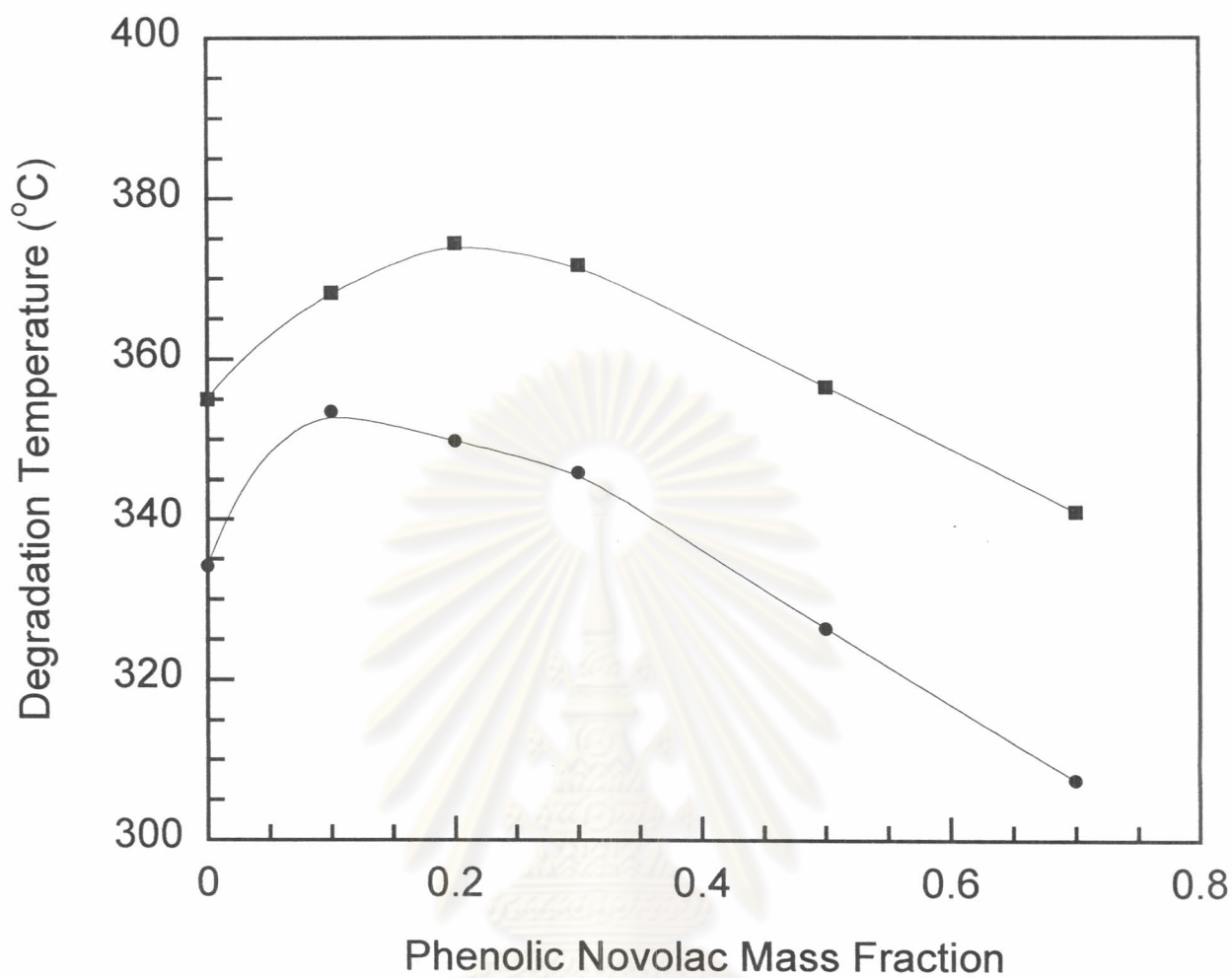
Figure 5.9: Degradation temperature of BP alloys : (●) 5% weight loss, (■) 10% weight loss.
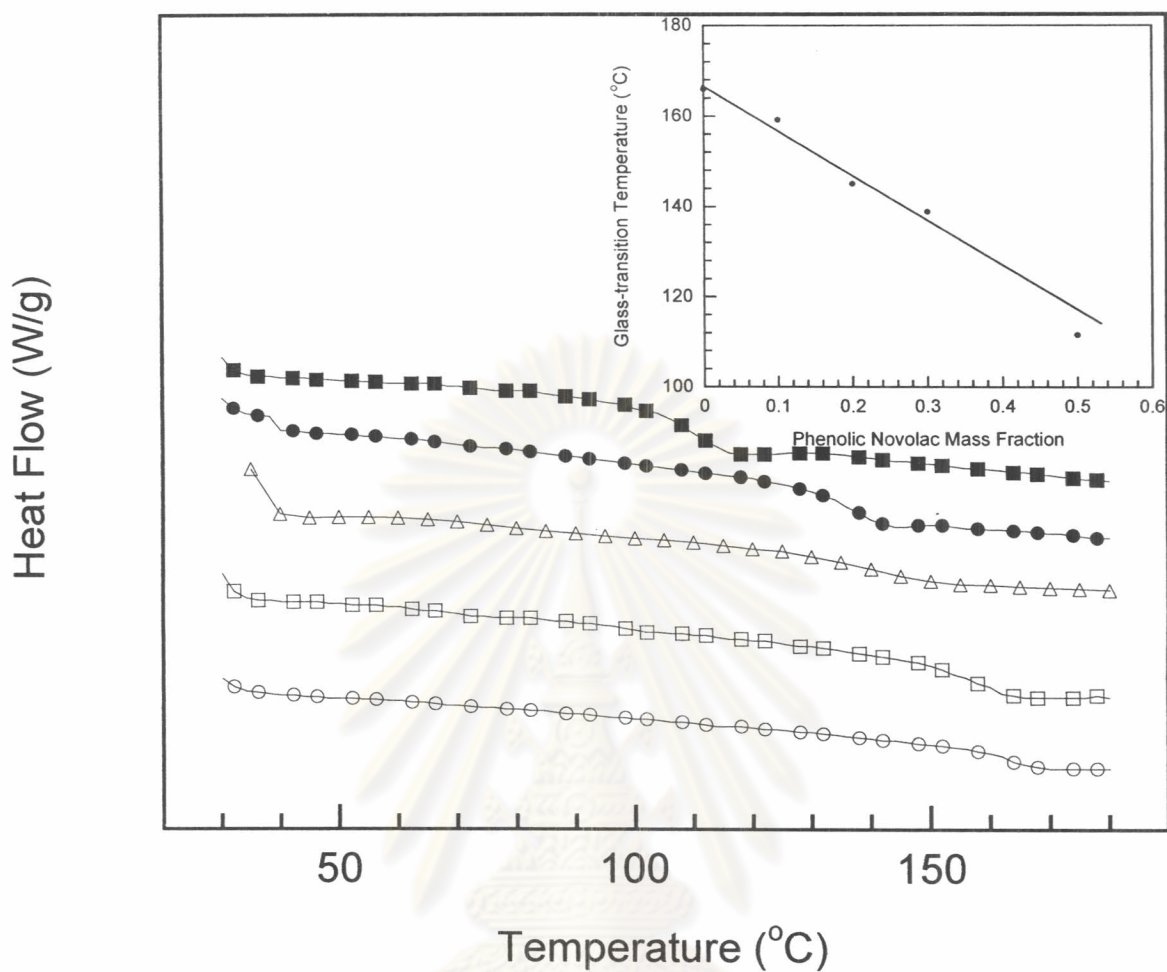
Figure 5.10: DSC thermograms showing glass-transition temperature of
BP alloys : (○) BA-a, (□) BP91, (△) BP82, (●) BP73, (■) BP55.

Table 5.2 Flexural modulus and strength of BP alloys.

Phenolic Novolac Mass Fraction	Flexural Modulus (GPa)	Flexural Strength (MPa)
0.0[*]	4.7	76
0.1	4.7±0.2	107±0.5
0.3	5.3±0.2	87±0.5

* Ref.: C. Jusilp *et al.*, The 2nd Asian Particle Technoloy Symposium, Penag Malaysia, 17-19th Dec 2003
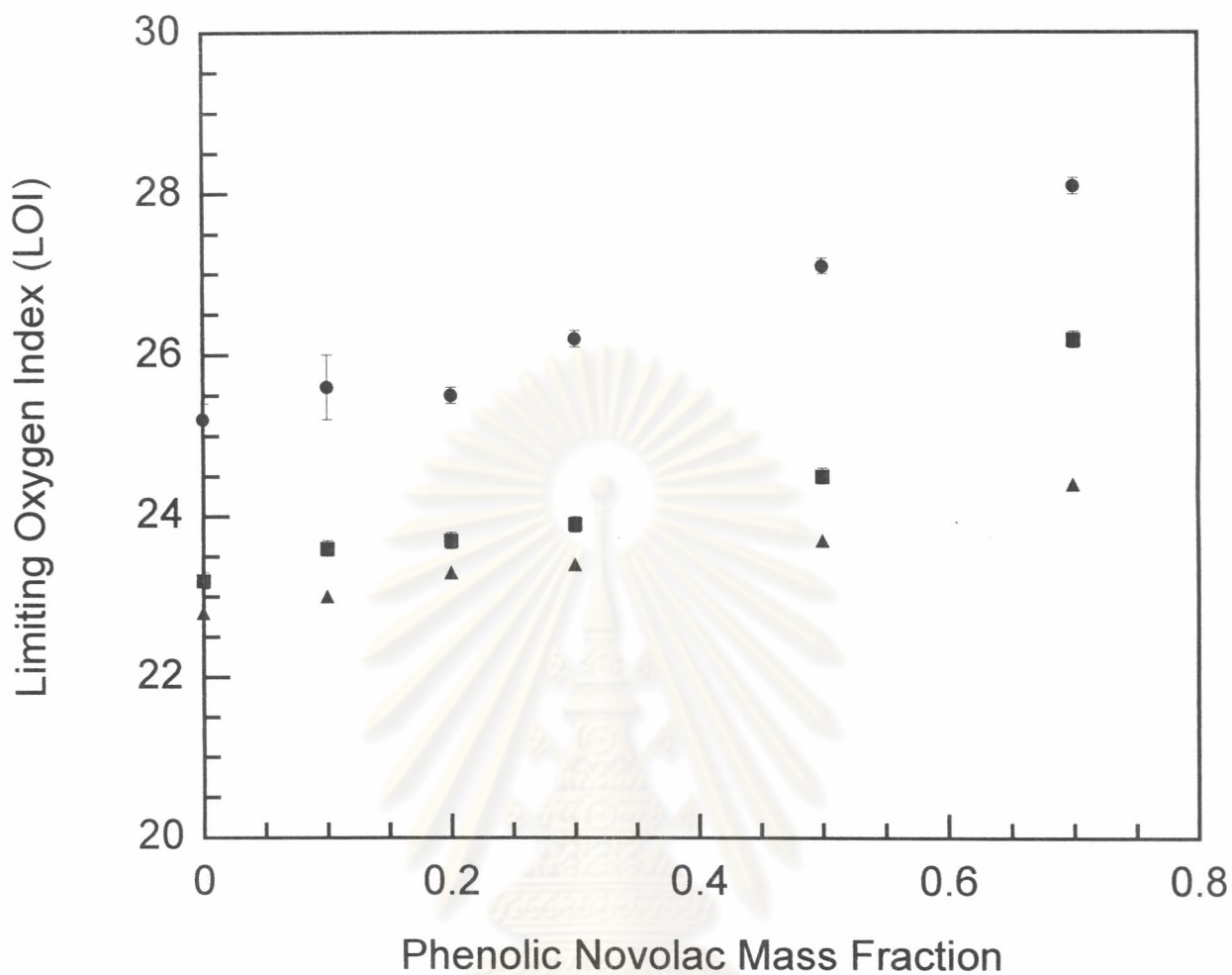
Figure 5.11: Limiting oxygen index (LOI) of woodflour-filled BP alloys at
three filler contents : (●) 50% by weight WF, (■) 60% by
weight WF, (▲) 70% by weight WF.
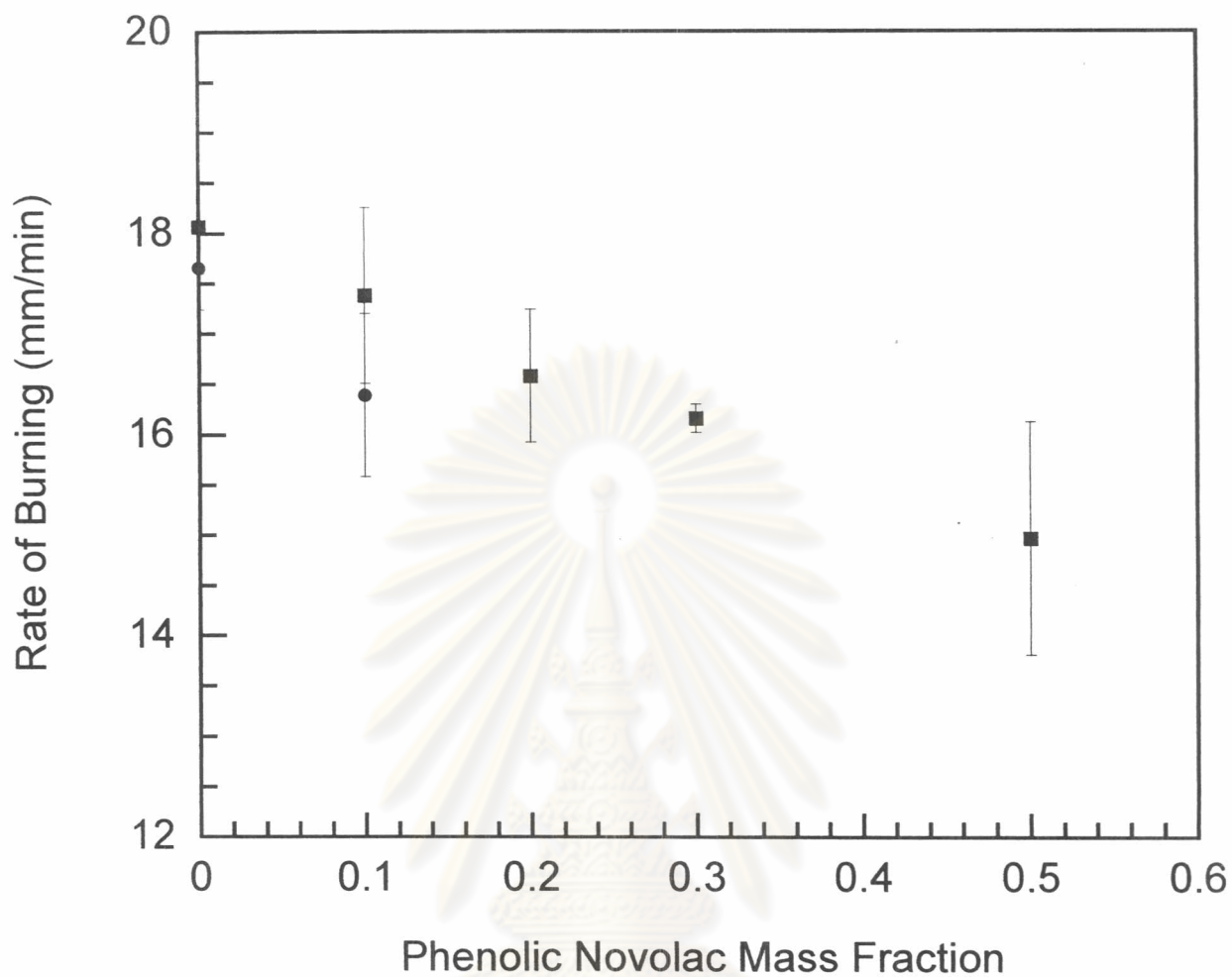
Figure 5.12: Rate of burning of woodflour-filled BP alloys at two different
filler contents : (●) 50% by weight WF, (■) 70% by weight
WF.
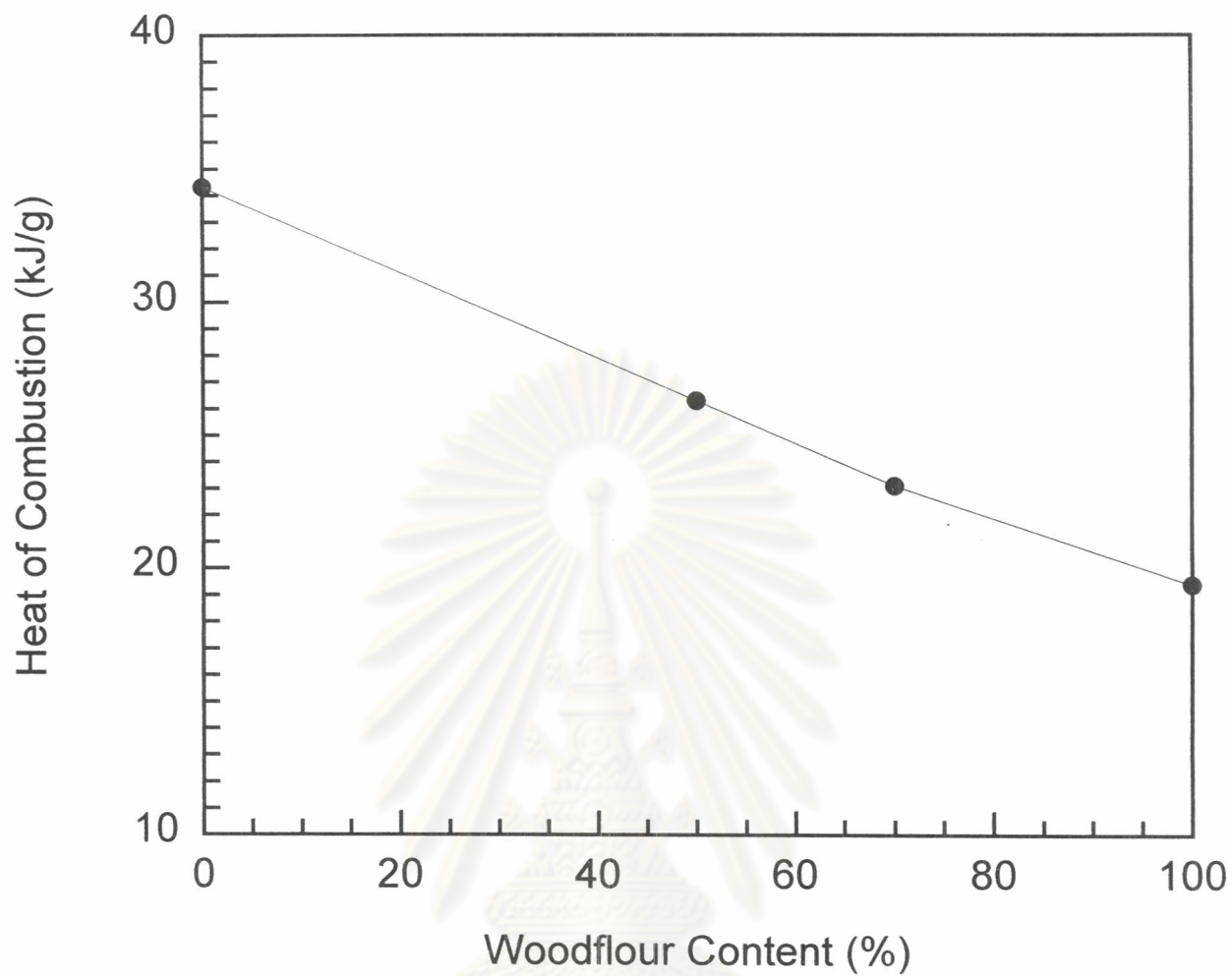
Figure 5.13: Heat of combustion of woodflour-filled BP82.
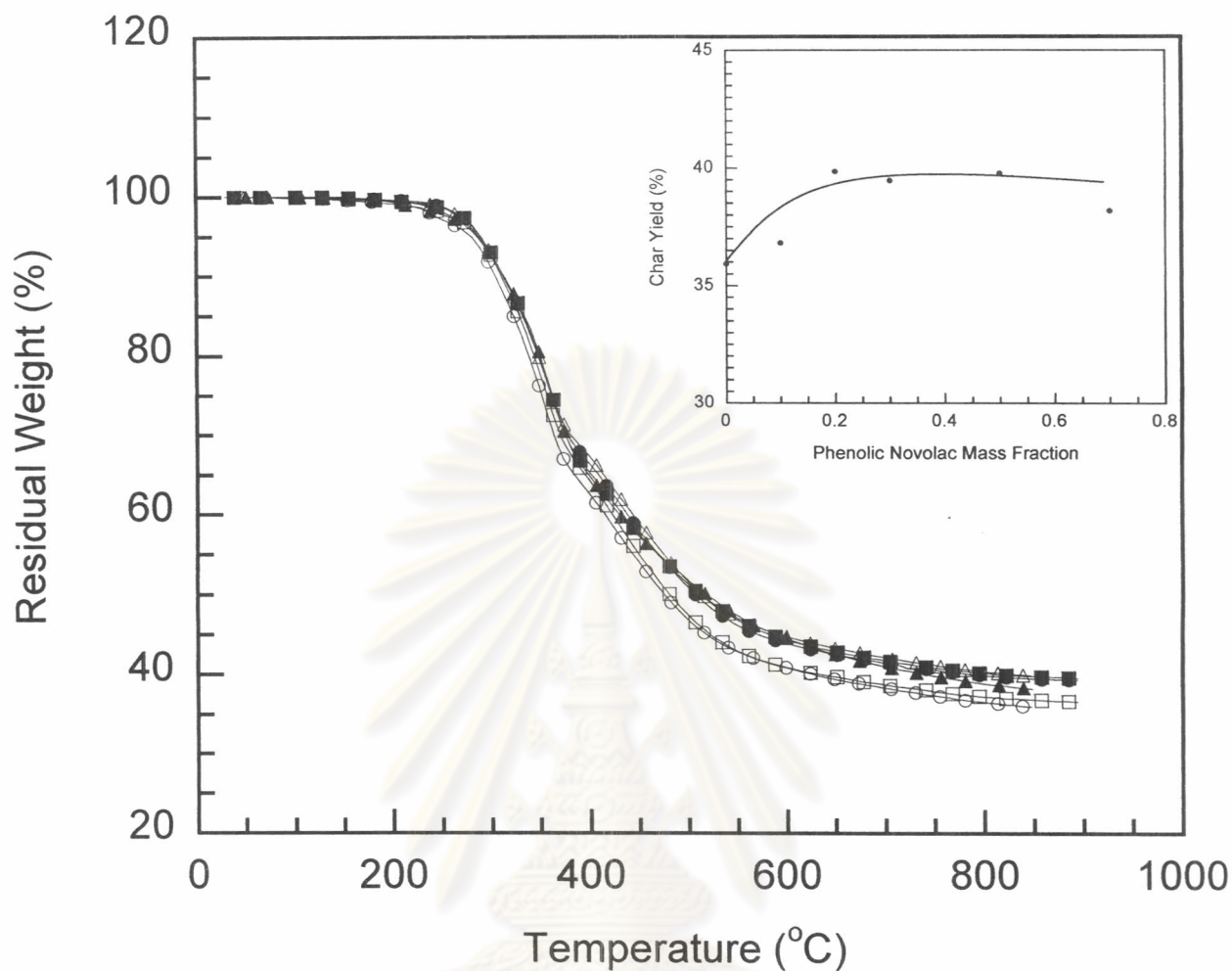
Figure 5.14 (a): TGA experiment of woodflour-filled BP alloys at 50% by weight of woodflour content : (○) BA-a, (□) BP91, (△) BP82, (●) BP73, (■) BP55, (▲) BP37.
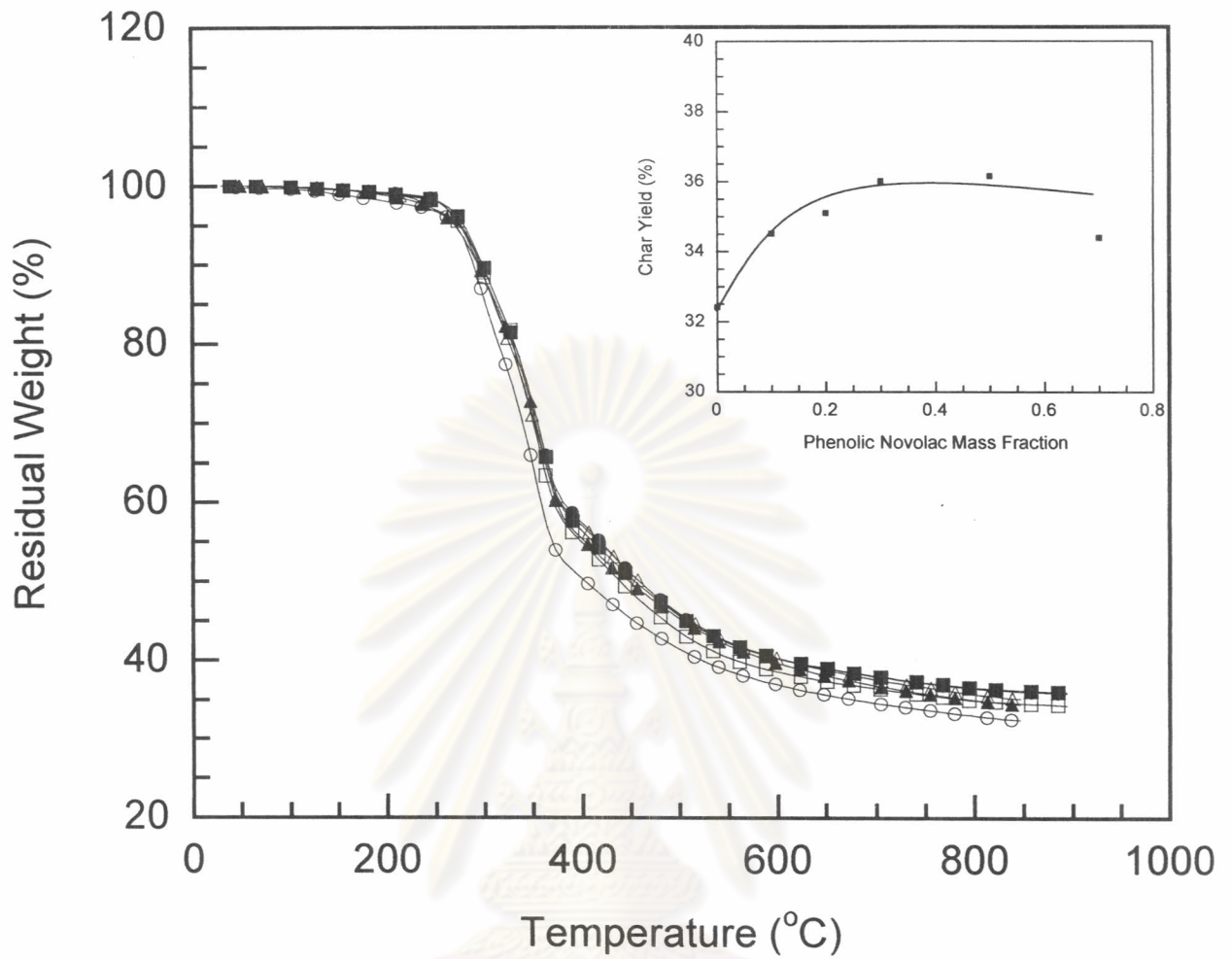
Figure 5.14 (b): TGA experiment of woodflour-filled BP alloys at 70% by weight woodflour content : (○) BA-a, (□) BP91, (Δ) BP82, (●) BP73, (■) BP55, (▲) BP37.
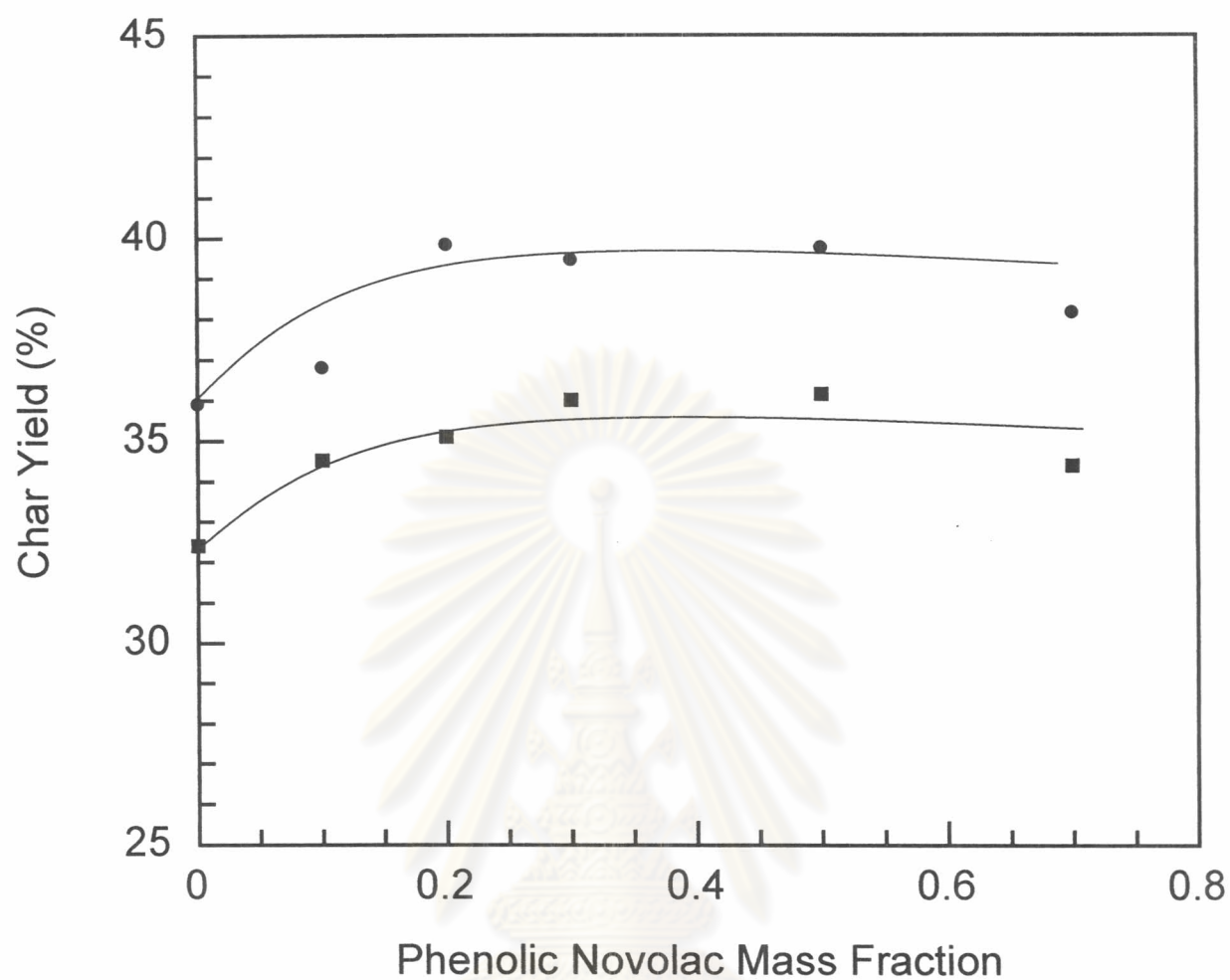
Figure 5.15: Char yield of woodflour-filled BP alloys : (●) 50% by weight
WF, (■) 70% by weight WF.
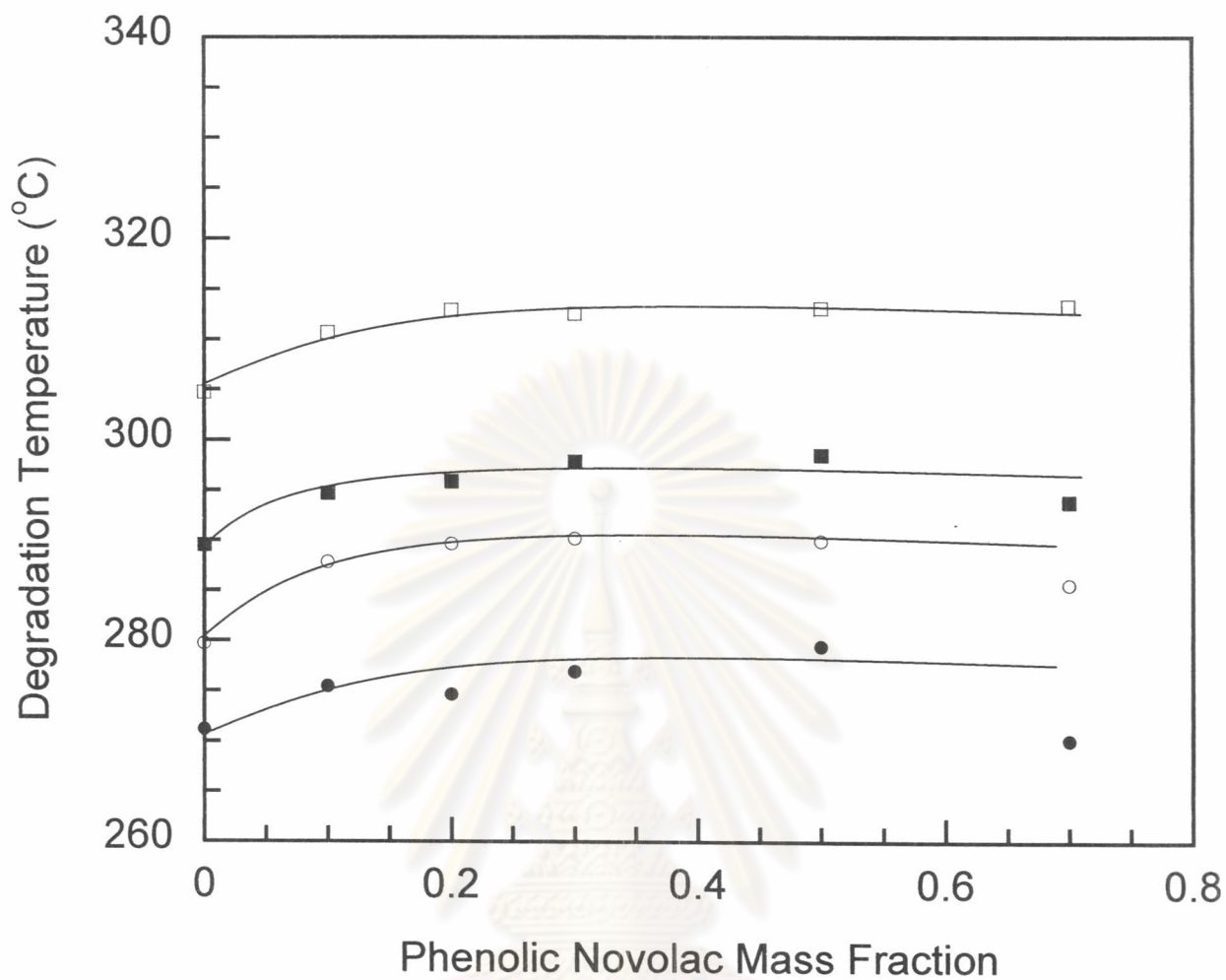
Figure 5.16: Degradation temperature of woodflour-filled BP alloys : (○)
5% weight loss 50% by weight WF, (□)10% weight loss 50%
by weight WF, (●) 5% weight loss 70% by weight WF, (■)
10% weight loss 70% by weight WF.
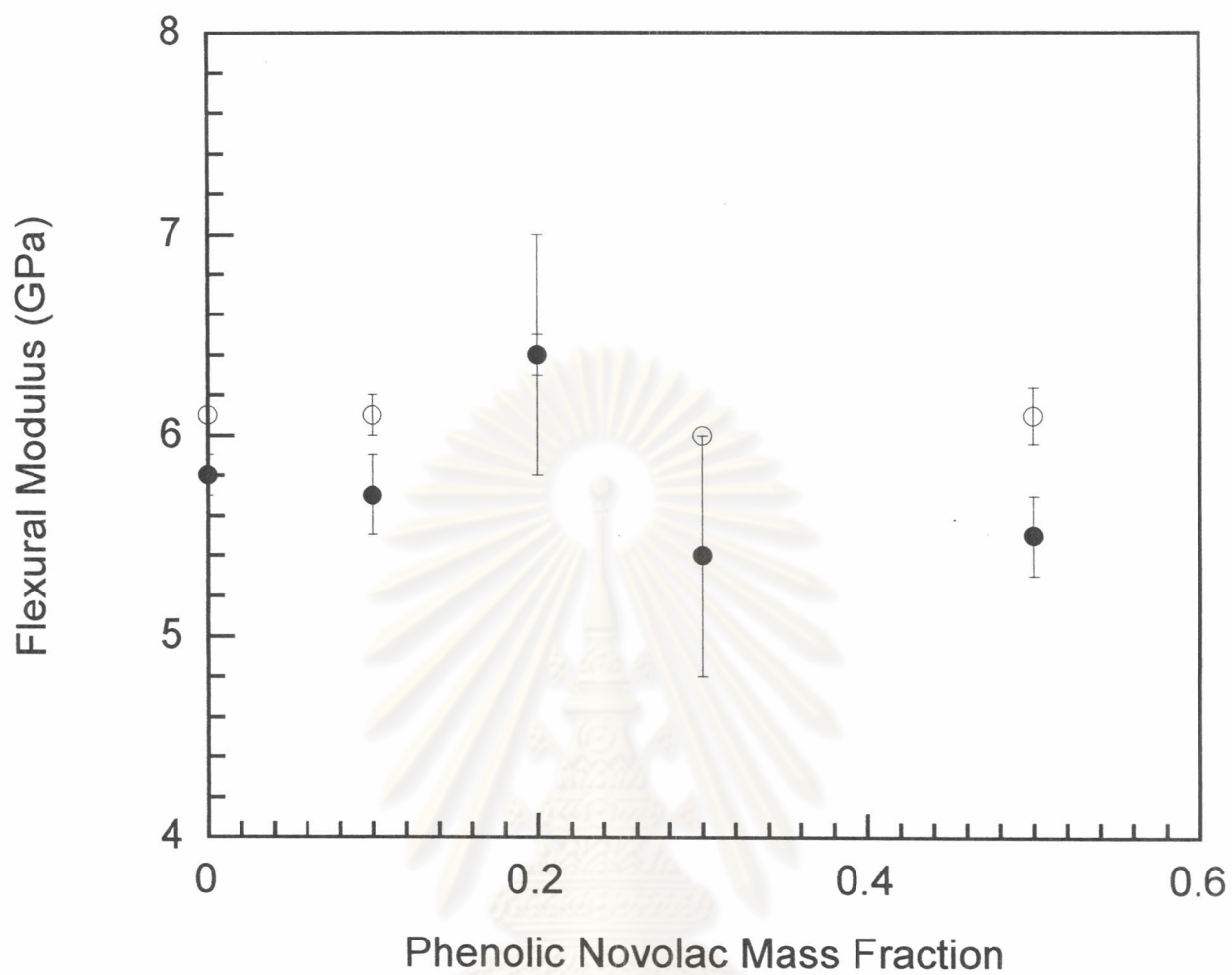
Figure 5.17: Flexural modulus of woodflour-filled BP alloys : (●) 50% by weight WF, (o) 70% by weight WF.
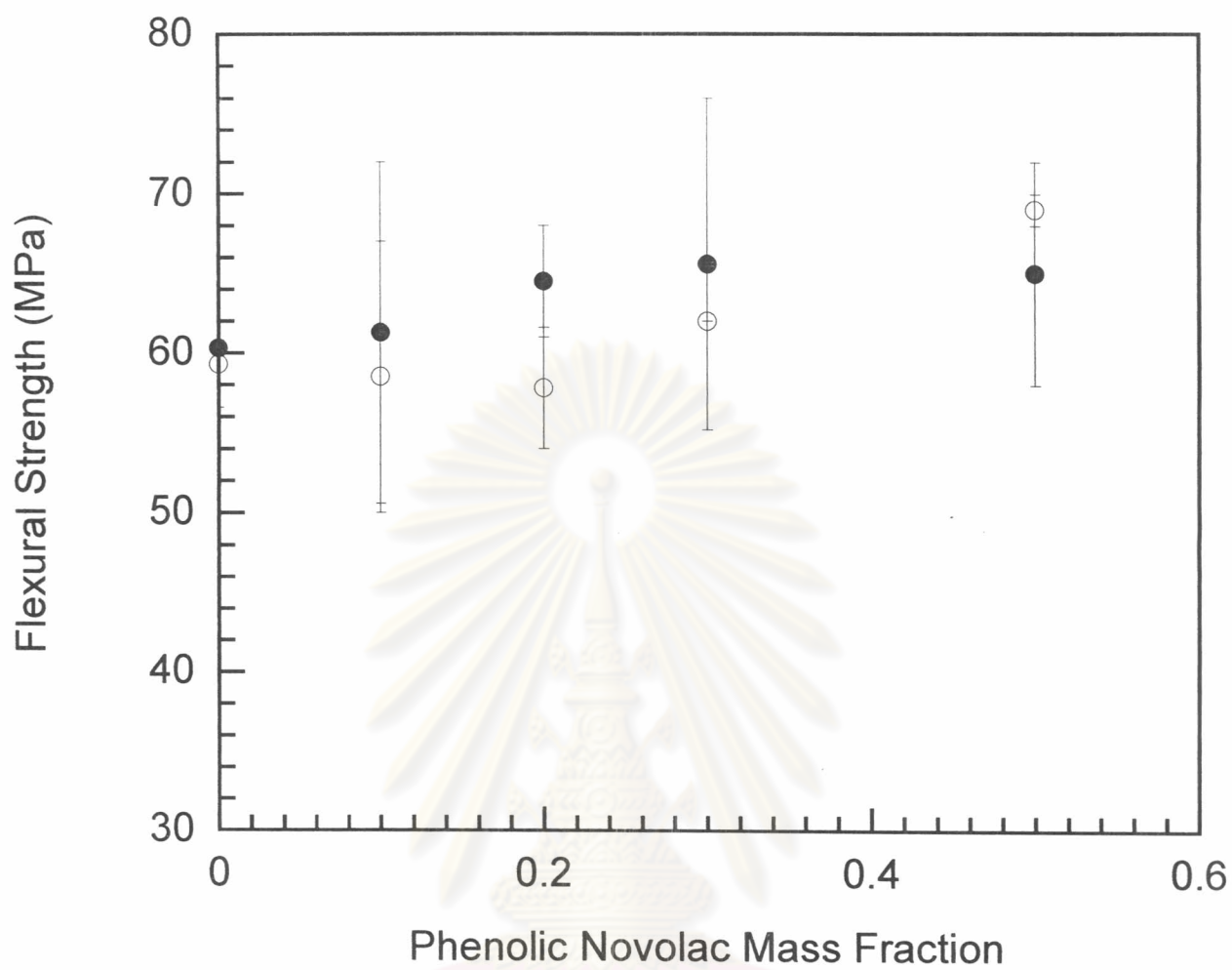
Figure 5.18: Flexural strength of woodflour-filled BP alloys : (●) 50% by weight WF, (o) 70% by weight WF.
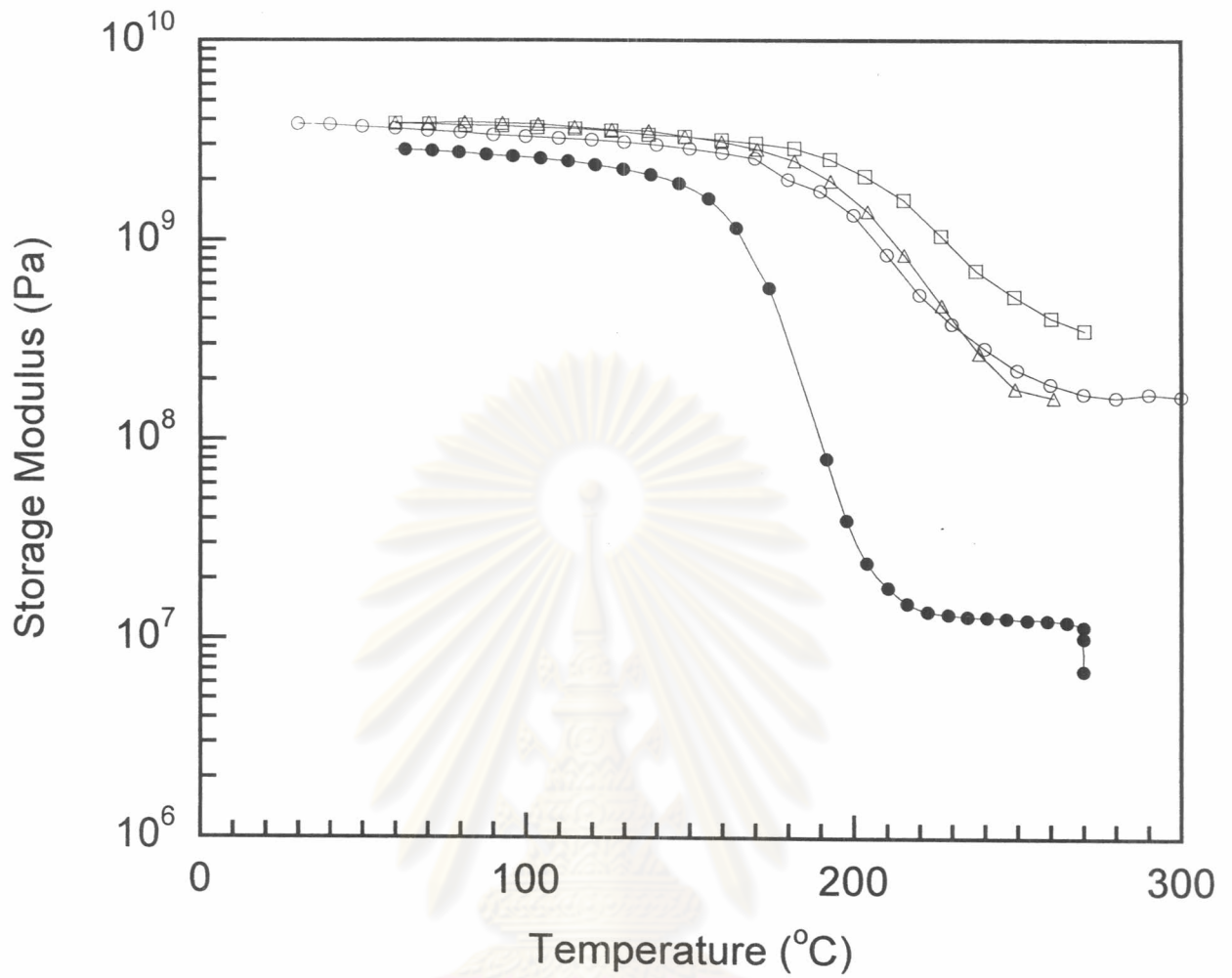
Figure 5.19: Storage modulus of woodflour-filled BP alloys as a function of temperature at 70% by weight of woodflour content : (○) BA-a, (□) BP91, (Δ) BP82, and (●) unfilled BA-a.
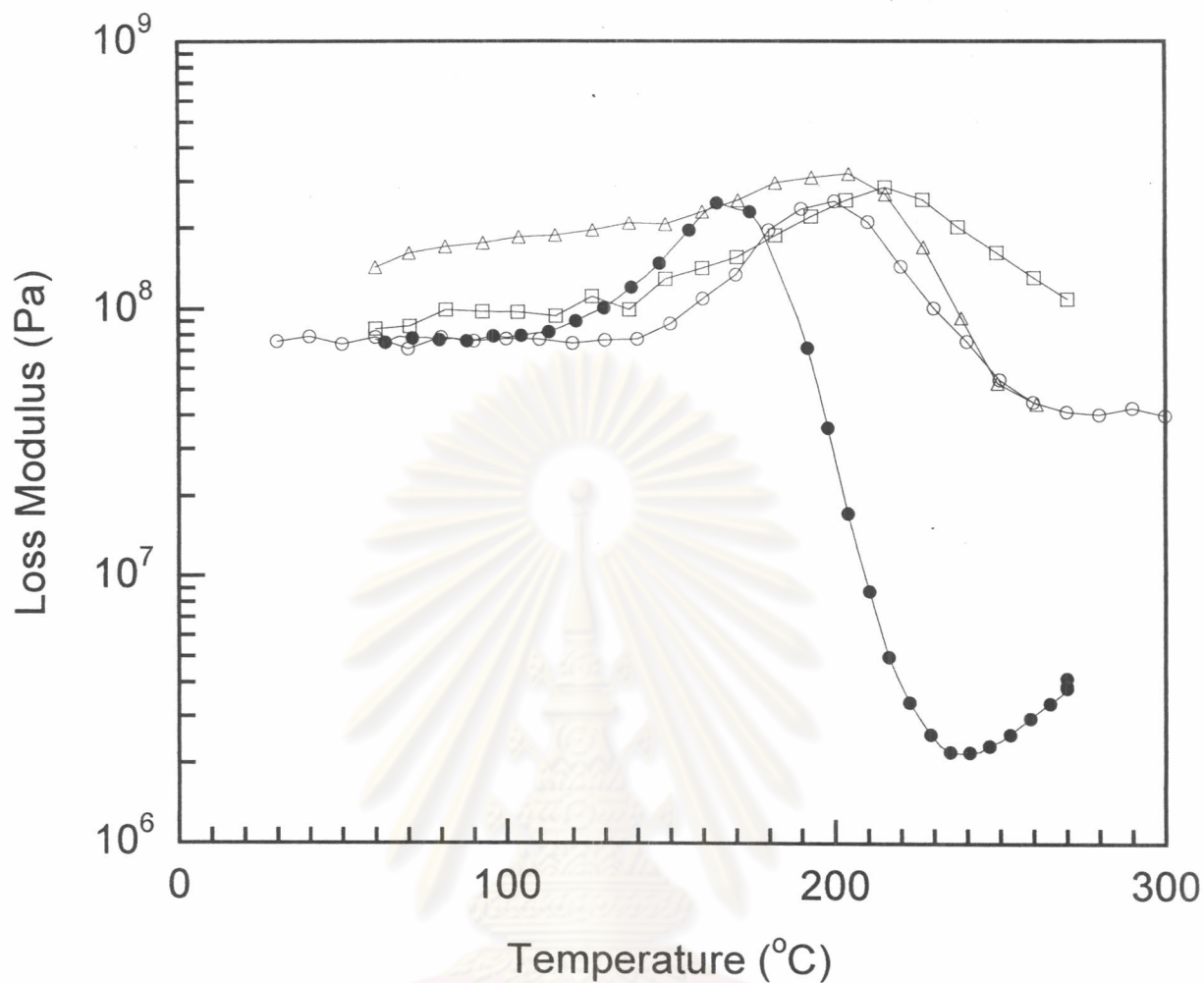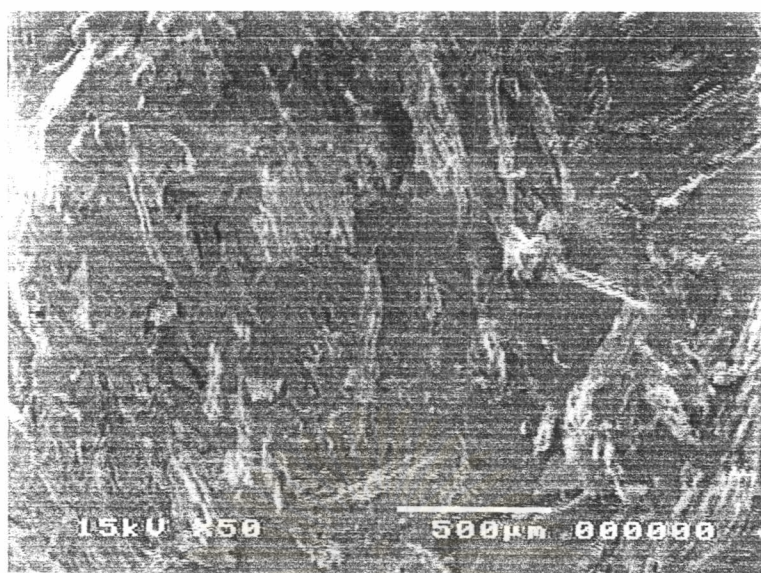
Figure 5.20: Loss modulus of woodflour-filled BP alloys as a function of
temperature at 70% by weight of woodflour content : (○) BA-a,
(□) BP91, (Δ) BP82, and (●) unfilled BA-a.

(a)

(b)

Figure 5.21: SEM micrographs of the fracture surface : (a) the dispersion of 20% by weight of woodflour in BP82, and (b) adhesion of 20% by weight of woodflour in BP82.