Dynamically Cured Polypropylene/Novolac Blends Compatibilized with Maleic Anhydride-*g*-Polypropylene

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ABSTRACT: In this article, the dynamic vulcanization process was applied to polypropylene (PP)/Novolac blends compatibilized with maleic anhydride-grafted PP (MAH-*g*-PP). The influences of dynamic cure, content of MAH-*g*-PP, Novolac, and curing agent on mechanical properties of the PP/Novolac blends were investigated. The results showed that the dynamically cured PP/MAH-*g*-PP/Novolac blend had the best mechanical properties among all PP/Novolac blends. The dynamic cure of Novolac improved the modulus and stiffness of the PP/Novolac blends. The addition of MAH-*g*-PP into dynamically cured PP/Novolac blend further enhanced the mechanical properties. With increasing Novolac content, tensile strength, flexural modulus, and flexural strength increased significantly, while the elongation at break dramatically deceased. Those blends with hexamethylenetetramine (HMTA) as a curing agent had good mechanical properties at HMTA content of 10 wt %. Scanning electron microscopy (SEM) analysis showed that dynamically cured PP/MAH-*g*-PP/Novolac blends had finer domains than the PP/MAH-*g*-PP/Novolac blends. Thermogravimetric analysis (TGA) results indicated that the incorporation of Novolac into PP could improve the thermal stability of PP. © 2007 Wiley Periodicals, Inc. J Appl Polym Sci 104: 3337–3346, 2007

Key words: dynamic cure; PP; Novolac resin; compatibilization

INTRODUCTION

Polypropylene (PP) is a commodity polymer used in large quantities in all fields of application. However, it exhibits a relatively low modulus and stiffness compared to the engineering plastics. Glass fiber and inorganic fillers are frequently used to enhance the stiffness, modulus, and dimensional stability of PP.[1,2] Besides, using traditional techniques, various additional attempts are used for the improvement of its properties and the extension of its field of application. Dynamic vulcanization is an effective way to prepare thermoplastic vulcanizates.[3–5] This technology led to a significant number of new thermoplastic elastomer products being commercialized during mid- to late-1980s.[6,7] However, there are few works concerning dynamic vulcanization applied to thermoplastic/thermosetting resin systems.

Jiang et al.[8] has successfully used dynamic vulcanization to prepare a new type of PP/epoxy blends compatibilized with maleic anhydride-grafted PP (MAH-*g*-PP). The dynamic cure of the epoxy resin improved the modulus and stiffness of the PP/epoxy blends. The addition of MAH-*g*-PP increased the impact strength and tensile strength. However, relatively few attempts were made to combine PP with phenolic resin.

The well-known phenolic resin, which is a major class of thermosetting polymer, is widely used in industries for the manufacture of paints, insulating and decorative varnishes, adhesive and cast products owing to its low manufacturing cost, dimensional stability, age resistance, high tensile strength, and chemical reactivity. Therefore, blending phenolic resin with other polymers attract great industrial interests. Chiang et al.[9] have introduced a small amount of resol-type phenolic resins into PP. Significant improvement of strength and thermal stability occurred. Analysis of the results and evaluation of literature data indicated chemical interaction between PP and resol-type phenolic resin. Many approaches have been explored to improve the toughness of Novolac-type phenolic resin by blending with a second modifier such as poly(dimethylsiloxane adipamide) (PDMSA),[10] polyamide,[11,12] fullerenol polyurethane, linear polyurethane,[13] and so forth. Recently, many studies have focused on the miscibility and phase behavior of Novolac blends with thermoplastics.[14–18] It has been found that Novolac resin exhibit miscibility with a number of polar polymers containing carbonyl or carbonate groups. Novolac resin has

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a hydrogen atom attached to an atom of a strongly electronegative element (oxygen), which forms intra molecular hydrogen bonds between the hydroxyl groups of Novolac and the carbonyl groups of MAH-*g*-PP. In such blends, intermolecular hydrogen bonding acts as a dorminate driving force for miscibility.

The aim of this work was to use dynamic vulcanization to make PP/Novolac blends. Since the Novolac resin and PP are immiscible, MAH-*g*-PP was used as a compatibilizer. The influences of dynamic cure, content of MAH-*g*-PP, Novolac, and curing agent on mechanical properties of the PP/Novolac blends were studied. The morphology and thermal stability of the blends was also investigated.

EXPERIMENTAL

Materials

PP, F401 was produced by Liaoning Panjin Petrochemical (China), with a melt flow index (MFI) of 2.3 g/10 min (230°C, 2.16 kg). The Novolac resin was purchased from Qinan Adhesive Materials Factory (China). MAH-*g*-PP with a MAH content of 1 w/w % was prepared by Shanghai Sunny New Technology Development (China). The curing agent, hexamethylenetetramine (HMTA) was produced by Shanghai Chemical Agent Company (China).

Sample preparation

Before blending, PP, MAH-*g*-PP, and the Novolac resin were dried at 70°C under vacuum for about 12 h. Dynamically cured PP/Novolac blends were prepared in the mixing chamber of a Haake Rheometer RC90 at 190°C and 50 rpm. MAH-*g*-PP and PP were first mixed for 2 min, and then the Novolac-type phenolic resin was added. After 2 min, HMTA, the curing agent, was added under continuous mixing. The total mixing time was 10 min. The compound was taken out and compression-molded at 190°C for 20 min, then cold pressed to give samples for testing.

Measurements of Mechanical Properties

The tensile properties were measured using an Instron 4465 Tester according to ASTM D638. Notched Izod impact strengths were tested using a Ray-Ran Universal Pendulum Impact Tester at an impacting pendulum speed of 3.5 m/s according to ASTM D256. Flexural properties were measured using the Instron 4465 Tester and a three-point-loading rig, and the central head was loaded on the specimen at a speed of 1.7 mm/min according to ASTM D790. The Vicat softing temperature was measured using the Ceaft 6921 Tester at a heating rate of 50°C/h and loading of 5 kg according to ASTM D1525.

Scanning electron microscopy

Morphologies of the blends were studied using scanning electron microscopy (SEM, HITACHI-S-2150). SEM micrographs were taken from cryogenically fractured surfaces of specimens. The fractured surfaces were etched by acetone for 10 h at room temperature to remove the Novolac resin phase of uncured PP/Novolac blends and to dissolve the soluble part of the Novolac resin of cured PP/Novolac blends, and then coated with gold for further observation.

FTIR analysis

Infrared transmission spectra was obtained using an FTIR spectrometer, model Paragon 1000 from PerkinElmer (USA). The scan range was from 4400 to 400 cm^{-1} with a resolution of 4 cm^{-1}. Samples of Novolac resin powder were prepared by milling Novolac resin with KBr and compressed to a KBr disc for testing. Samples of MAH-*g*-PP and PP/MAH-*g*-PP/Novolac blend were pressed to thin films for testing.

Extraction test

The test was performed to detect the presence of any chemical reaction. The test is based on the fact that PP is fairly soluble in xylene and Novolac is soluble in acetone. The dynamically cured PP/Novolac (70/30) and MAH-*g*-PP/Novolac (70/30) blends were extracted for 75 h to remove the PP. However, the MAH-*g*-PP/Novolac (80/20) blend were extracted in acetone to remove the Novolac. All the samples were prepared in the mixing chamber of a Haake Rheometer (RC90) at 190°C and 50 rpm.

Thermogravimetric analysis

The thermogravimetry was carried out in a PerkinElmer TGA7. The samples were scanned from 30 to 800 or 900°C at a heating rate of 20°C/min under nitrogen atmosphere.

Determination of thermal stability parameters

The initial decomposition temperature (IDT) was determined with the temperature of 5 wt % weight loss of the sample.[19] The temperature at maximum rate of weight loss (T_{max}) was taken from the peak values of the differential thermogravimetric thermograms (DTG). The integral procedure decomposition temperature (IPDT) was calculated from

$$\text{IPDT}(^{\circ}\text{C}) = A^* K^* (T_f - T_i) + T_i$$

where A^* is the area ratio of total experimental curve defined by the total TGA thermogram, K^* the coeffi-
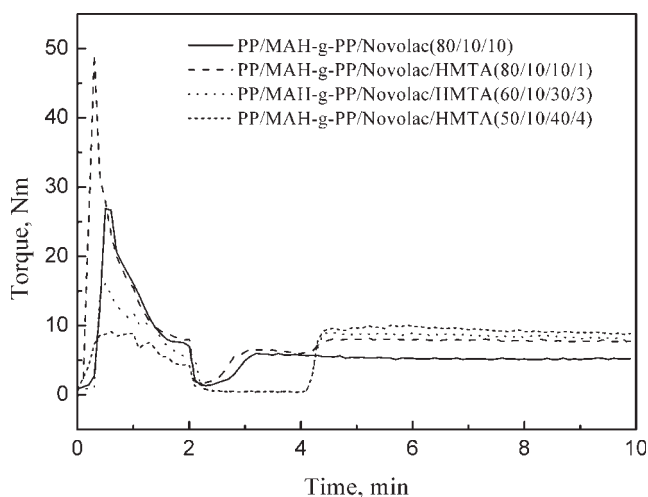
Figure 1 Plot of torque versus time for the PP/Novolac blends at 190°C.

cient of A^*, T_i the initial experimental temperature, and T_f the final experimental temperature. A representation of S_1, S_2, and S_3 for calculating A^* [$A^* = (S_1 + S_2)/(S_1 + S_2 + S_3)$] and K^* [$K^* = (S_1 + S_2)/S_1$] is shown in Figure 9.[20]

RESULTS AND DISCUSSION

Effect of dynamic cure process

Torque measurements can be used to give qualitative information concerning the chemical reactivity and the extent of reaction in the reactively compatibilized blends.[21] Figure 1 gives the relationship between torque and time for the PP/MAH-g-PP/Novolac blends with or without the curing agent HMTA at 190°C. It can be seen that the addition of the curing agent at the mixing time of 4 min leads to an obvious rise of torque. With increasing Novolac resin content, the equilibrium torques of the PP/MAH-g-PP/Novolac blends containing the curing agent increase. This indicates that the Novolac resin has been cured by HMTA during mixing with the molten PP, and this process was named as dynamical cure process

similar to the dynamical vulcanization process of the elastomers in the plastics.

The mechanical properties of PP and PP/Novolac blends are shown in Table I. The addition of 30 wt % Novolac resin increases the flexural modulus, but decreases the impact strength, tensile strength, flexural strength, and elongation at break because of the poor compatibility between PP and Novolac resin. The dynamically cured PP/Novolac (70/30) blend has a higher flexural modulus than the PP and PP/Novolac (70/30) blend, but the other mechanical properties are poorer than the PP. The addition of MAH-g-PP into PP/Novolac blend improves the mechanical properties, except for the elongation at break, in comparison with the PP/Novolac (70/30). But it leads to a slight increase of tensile strength and impact strength when compared with dynamically cured PP/Novolac blend. The dynamically cured PP/MAH-g-PP/Novolac (60/10/30) blend has the best mechanical properties among all the PP/Novolac blends studied in this article. It can be concluded that the dynamic cure of Novolac resin can increase the modulus of the PP/Novolac blend with compatibilizer. At the same time, the addition of Novolac results in a dramatically decrease of elongation at break of all the PP/Novolac blends.

Effect of compatibilizer content

It is well known that compatibilizers have significant effects on the mechanical properties of polymer blends.[22]

Figure 2 shows the effect of the MAH-g-PP content on the mechanical properties of dynamically cured PP/MAH-g-PP/Novolac blends. The impact strength, tensile strength, flexural strength, and flexural modulus increase rapidly with increasing MAH-g-PP content and reach a maximum of 45 J/m, 43.4, 70.5, and 2284 MPa, respectively, at a MAH-g-PP content of 10 wt %. When the MAH-g-PP content is over 10 wt %, the mechanical properties of dynamically cured PP/MAH-g-PP/Novolac blends decreases. Hence, the most suitable MAH-g-PP content is 10 wt %. The compatibilizer can enhance the interaction of the blends between two components, and the

TABLE I
Mechanical Properties of the PP/Novolac Blends

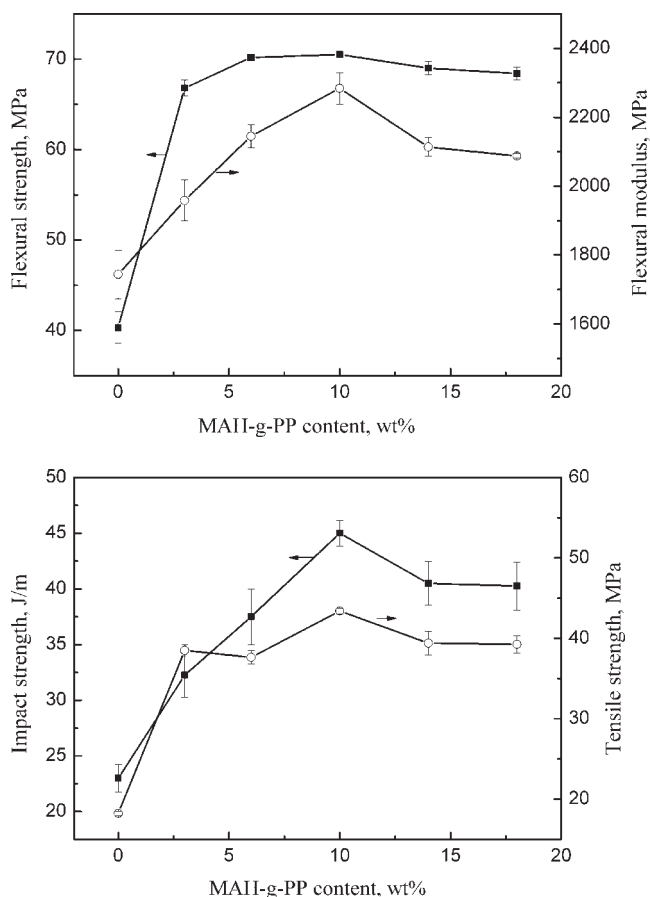| Composition	Impact strength (J/m)	Tensile strength (MPa)	Elongation at break (%)	Flexural strength (MPa)	Flexural modulus (MPa)
PP	30.9	33.0	230	43.8	1210
PP/Novolac (70/30)	23.5	16.0	2.74	32.3	1445
PP/MAH-g-PP/Novolac (60/10/30)	26.0	23.3	2.17	35.4	1523
PP/Novolac/HMTA (70/30/3)	23.0	18.2	2.72	36.8	1684
PP/MAH-g-PP/Novolac/HMTA (60/10/30/3)	45.0	43.4	4.60	70.5	2284

Figure 2 The effect of MAH-*g*-PP content on the mechanical properties of dynamically cured PP/MAH-*g*-PP/Novolac blends. Formulation: (PP+MAH-*g*-PP) 70, Novolac 30, HMTA 10 parts (per 100 parts of Novolac).

addition of the suitable amount of the compatibilizer obviously improves the mechanical properties of the blends, but further increasing the amount of the compatibilizer cannot prefer to the mechanical properties. A similar result was reported by Liu et al.[23]

Effect of Novolac content

Figure 3 shows the effect of Novolac content on the mechanical properties of dynamically cured PP/MAH-*g*-PP/Novolac blends. The flexural modulus of the blends increase rapidly with increasing Novolac content, and 5 wt % Novolac increases 51% flexural modulus than the ordinary PP/MAH-*g*-PP blend. The flexural strength and tensile strength of the dynamically cured PP/MAH-*g*-PP/Novolac blends reach maximum at the Novolac content of 30 wt %. However, excessive crosslinked Novolac leads to the increase of brittleness. The impact strength of blends increase slightly with increasing Nocolac resin and reach maximum at the Novolac content of 10 wt %, while the elongation at break decrease rapidly.

Effect of curing agent content

Novolac resin can form highly crosslinked structure by curing agent. Different kinds of curing agents have different effects on the mechanical properties of blends because of the different crosslinking density and structure. HMTA is a conventional crosslinking agent used for Novolac resin owing to its advantage.
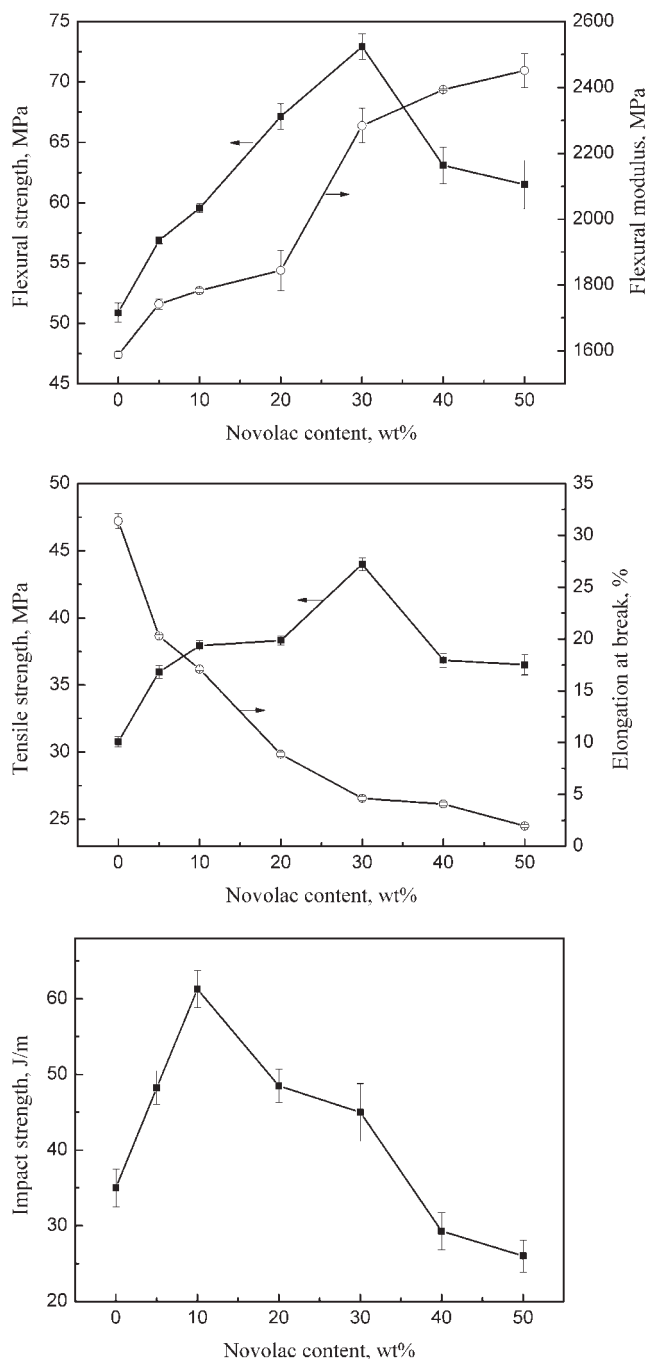

Figure 3 The effect of Novolac content on mechanical properties of dynamically cured PP/MAH-*g*-PP/Novolac blends. Formulation: (PP+Novolac) 90, MAH-*g*-PP 10, Novolac variable, and HMTA 10 parts (per 100 parts of Novolac).

The HMTA content is critical to the curing rate and the chemical structure of the fully cured resins.[24]

Figure 4 shows the effect of HMTA content on mechanical properties of the dynamically cured PP/MAH-g-PP/Novolac blends. It can be seen that the tensile strength, impact strength, flexural strength, and flexural modulus of the blends increase rapidly with increasing HMTA content and reach a maximum at 10 wt % HMTA. When the HMTA content is over 10 wt %, the Novolac has been cured totally, leading to significant decrease of impact strength, but other mechanical properties of blends declined slightly. Hence, a suitable HMTA content is 10 wt % (10 parts per 100 parts by the weight of Novolac).

FTIR analysis

The FTIR spectra of the Novolac resin, MAH-g-PP, and MAH-g-PP/Novolac blends are shown in Figure 5. As seen in Figure 5(a), the spectrum of MAH-g-PP shows the characteristics of a saturated
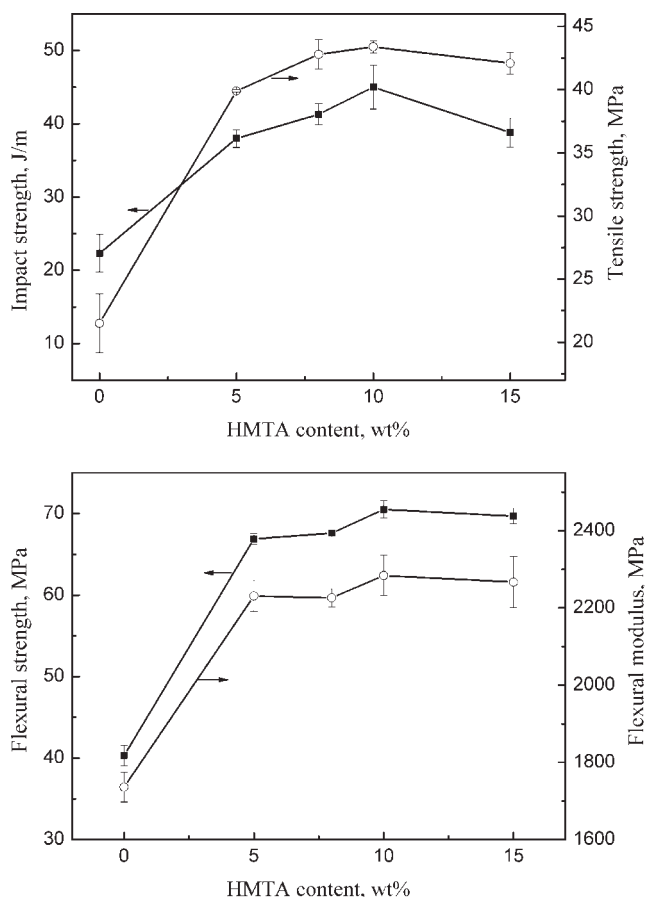
Figure 5 FTIR spectra of (a) MAH-g-PP (b) Novolac resin (c) MAH-g-PP/Novolac.

Figure 4 The effect of HMTA content on the mechanical properties of dynamically cured PP/MAH-g-PP/Novolac blends. Formulation: PP 60, MAH-g-PP 10, Novolac 30, and HMTA variable (relative to Novolac content).
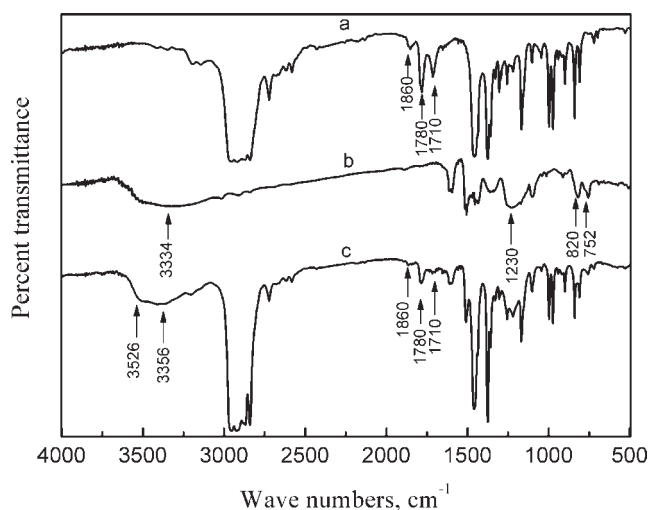
ring anhydride.[25] The bands at 1860 and 1780 cm^{-1} are attributed to the symmetrical and unsymmetrical stretching modes of C=O. The band at 1710 cm^{-1} is attributed to the C=O band of maleic acid.

As seen from Figure 5(b), the spectrum in this region of pure Novolac may be considered to be composed of two components: a broad band centered at 3334 cm^{-1}, which is attributed to the self-asssociated hydroxyl, that is, hydrogen-bonded hydroxyl groups, and a relatively narrow band at 3519 cm^{-1}, which is assigned to non-associated, free hydroxyl groups.[26] At the same time, the characteristic absorption peak of the C—OH band of phenol appeared at 1230 cm^{-1}. The spectra of the Novolac at 752 and 820 cm^{-1} show characteristic absorption peaks of ortho- and para-substituted phenolic hydrogen.

In the case of the MAH-g-PP/Novolac blend [Fig. 8(c)], characteristic absorption peak of MAH could be still seen. The results suggested that the maleic anhydride groups of MAH-g-PP do not react with the OH of the Novolac resin. The esterification rection will only take place in the presence of catalysts (e.g., H_2SO_4 and $AlCl_3$). However, upon blending with MAH-g-PP, the nonassociated hydroxyl band at 3519 cm^{-1} apparently remains constant for all composition in the blend, but the associated hydroxyl band at 3334 cm^{-1} shift to higher frequency 3356 cm^{-1} after the addition of MAH-g-PP, indicating that there is hydrogen-bonding interaction between the hydroxyl groups of Novolac and the carbonyl groups of MAH.[14] The results can further interpret why the addition of MAH-g-PP slightly increased the mechanical properties of PP/Novolac blend (Table I).

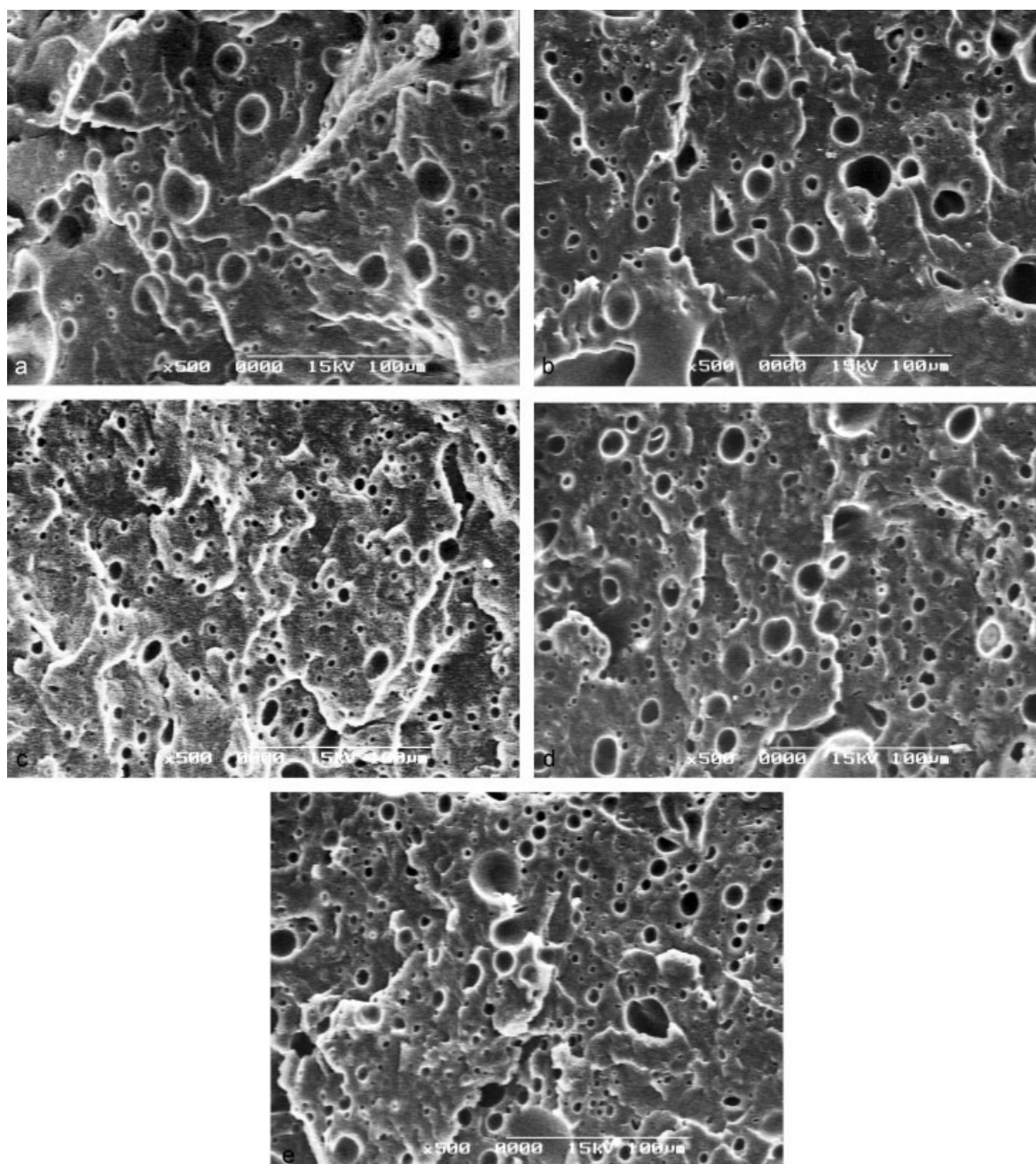| Composition	Soluble part in acetone (%)	Insoluble part in acetone (%)
Novolac	99.8	0.2
MAH-g-PP/Novolac (80/20)	19.4	80.6
	Soluble part in xylene (%)	Insoluble part in xylene (%)
PP	99.6	0.4
PP/Novolac/HMTA (70/30/3)	68.2	31.8
MAH-g-PP/Novolac/HMTA(70/30/3)	56.5	43.5

Figure 6 SEM of PP/Novolac blends compatibilized with MAH-g-PP (etched in acetone for 10 h at room temperature) (a) 0 wt % MAH-g-PP, (b) 5 wt % MAH-g-PP, (c) 10 wt % MAH-g-PP, (d) 15 wt % MAH-g-PP, and (e) 18 wt % MAH-g-PP.
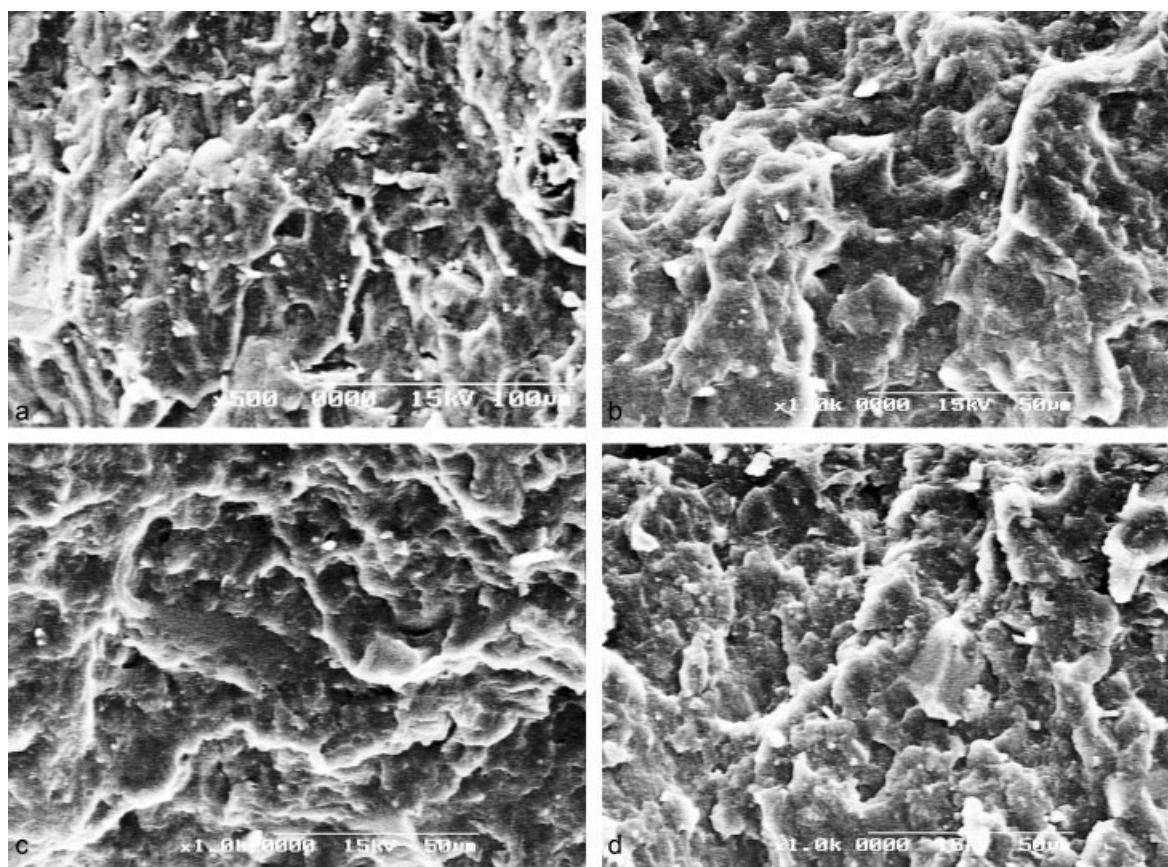
Figure 7 SEM of dynamically cured of PP/Novolac blend compatibilized with MAH-*g*-PP (a) 0 wt % MAH-*g*-PP, (b) 6 wt % MAH-*g*-PP, (c) 10 wt % MAH-*g*-PP, and (d) 18 wt % MAH-*g*-PP.

Solvent extraction

On the basis of different solubility of homopolymers, acetone is selected as the solvent to remove the Novolac of MAH-*g*-PP/Novolac (80/20) blend. However, xylene is selected as the solvent to remove the PP of dynamically cured MAH-*g*-PP/Novolac and PP/Novolac blends. Table II shows the results of solvent extraction of MAH-*g*-PP/Novolac, dynamically cured PP/Novolac, and MAH-*g*-PP/Novolac blends. From Table II, it can be see that the Novolac used in this study is almost totally soluble in acetone (>99%), whereas PP is insoluble. While performing the extraction test, the weight fractions of soluble and insoluble parts of the prepared blends are found to correspond to the composition of the blends. This suggests that no chemical reaction, such as grafting or partial crosslinking, has taken place between Novolac and MAH-*g*-PP.

To further confirm the effect of MAH-*g*-PP on dynamically cured reaction, dynamically cured PP/Novolac and MAH-*g*-PP/Novolac blends are continuously extracted in xylene for 75 h due to good solubility of PP in xylene. The results show that PP is absolutely extracted from dynamic cure of PP/Novolac. However, in the case of dynamic cure of MAH-

g-PP/Novolac blend, 56.5 wt % of MAH-*g*-PP is extracted. The results suggest that MAH can react with HMTA. It was reported that $HOCH_2NHCH_2OH$, $HOCH_2OCH_2OH$, and $HOCH_2OH$ could be produced from HMTA because of hydration and oxidation when the curing action between Novolac and HMTA started at 90–120°C.[24] Consequently, there is a possibility of the formation of graft copolymer between MAH-*g*-PP and cured Novolac resin.

Morphology of compatibilized blends

The physical–mechanical properties of blends are regarded to depend on the average particle size, particle size distribution, and some molecular features (such as average molecular mass, degree of crosslinking, etc.) of the modifier forming the dispersed phase in the blends except recipe and processing conditions.

The effect of MAH-*g*-PP as compatibilizer on the morphology of the PP/Novolac and dynamically cured PP/Novolac blends are shown in Figures 6 and 7. And the size of the dispersed Novolac phase versus the volume fraction of MAH-*g*-PP is shown in Figure 8.
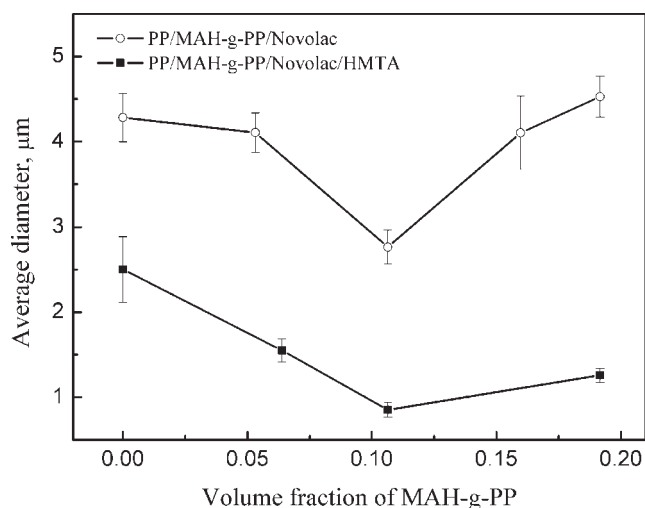
Figure 8 Effect of volume fraction of MAH-*g*-PP on the domain size of the dispersed phase of PP/Novolac and dynamically cured PP/Novolac blends.

Figure 6(a–d) shows PP/Novolac blends containing 0, 5, 10, 15, and 18 wt % MAH-*g*-PP, respectively. For PP/Novolac blend [Fig. 6(a)], the Novolac resin is dispersed as spherical particles with an average diameter of about 4.3 μm in the PP matrix, and the boundaries between the dispersed phase and the PP matrix are distinct. The addition of 5 wt % MAH-*g*-PP causes a slight reduction in domain size. With 10 wt % MAH-*g*-PP, the domain size evidently decreases and reaches the minimum of 2.6 μm. However, further addition of compatibilizer increases the domain size. It indicates that the content of compatibilizer has an optimum content.

Figure 7(a–d) show the effect of MAH-*g*-PP on the morphology of dynamically cured PP/Novolac blends. The cured Novolac resin is dispersed as particles in the PP matrix, and the average diameter of the particles is far smaller than that of PP/Novolac blends at the same content of compatibilizer. The trend of dynamically PP/Novolac blends is similar to the results of PP/Novolac blends compatibilized with MAH-*g*-PP. It suggests that the dynamic cure of the Novolac resin can prevent the Novolac particles from aggregation in the PP matrix, which results in finer domains in dynamically cured PP/MAH-*g*-PP/Novolac blends. Moreover, the formation of graft copolymer acts as an emulsifier at the interface and thus further reduces the interfacial tension. George et al.[27] have reported that the compatibilizers react with PP and form graft copolymer, which led to small and uniform distribution of NBR phase.

Thermal behavior analysis

One of the most widely accepted methods for studying the thermal properties of polymeric materials is thermogravimetry, which by means of integral and derivative thermogravimetric curves, provides information about characteristics and extent of degradation of polymeric materials.[28] The thermal stability of the materials is assessed with two parameters: IDT and IPDT. IDT indicates the apparent thermal stability of materials. On the other hand, IPDT exhibits the materials inherent thermal stability, that is, the decomposition characteristics of the volatile composition of materials.[20] Furthermore, vicat softing temperature is a method to evaluate the thermal behavior of materials. Thermograms and thermal stability parameters of the PP, Novolac, and PP/Novolac blends are shown and collected in Figures 10 and 11 and Table III.

The difference in degradation behavior of the blends could be clearly read from the DTG thermograms. On the basis of the numbers of peaks in the DTG thermograms, the weight loss processes of the blends are considered in several stages. From Figure 10, it can be seen that PP and different PP/Novolac blends have only one thermal degradation step taken place. However, pure Novolac resin has three thermal degradation steps according to Figure 11.

Pure Novolac has good flame retardancy and gives high char yield and good thermal properties because of the aromatics structure of Novolac resin.[29] The TGA curve of Novolac resin in Figure 11 shows 5% of weight loss before 236°C, mainly because of excess phenol, aldehyde, and water. About 408°C is considered as the main temperature range of decomposition, and thermal weight loss is about 37%. Total thermal weight loss for Novolac resin is accumulated as 40.5% when the temperature reaches 900°C.

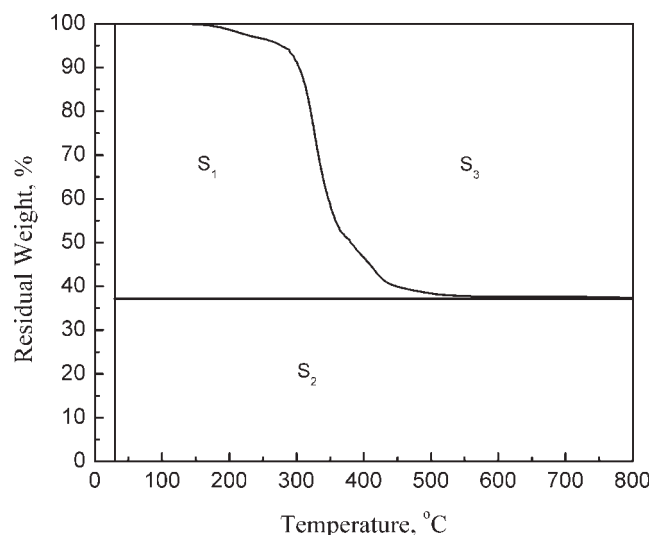Pure PP has the lowest IPDT compared to PP/Novolac blends. The degradation of PP started at

Figure 9 Schematic representation of S_1, S_2, and S_3 for A^* and K^* (in nitrogen at a heating rate of 20°C/min).
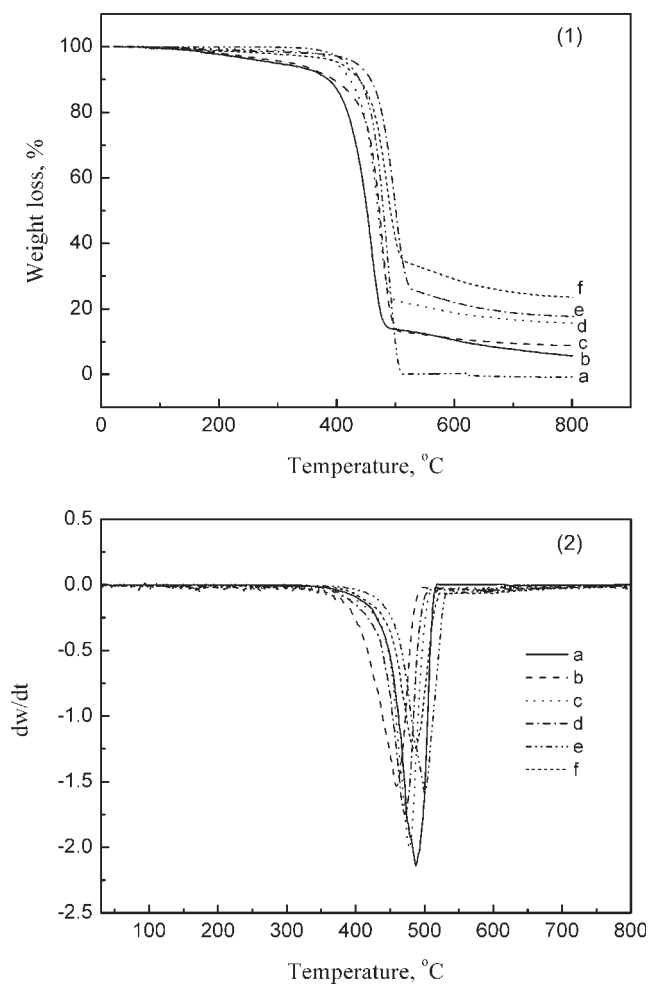
Figure 10 (1) TGA and (2) DTG thermograms of PP and the PP/Novolac blends. (a) PP; (b) PP/Novolac = 70/30; (c) PP/MAH-PP/Novolac = 60/10/30; (d) PP/Novolac/ HMTA = 70/30/3; (e) PP/MAH-PP/Novolac/HMTA = 60/10/30/3; (f) PP/MAH-PP/Novolac/HMTA = 40/ 10/50/5.
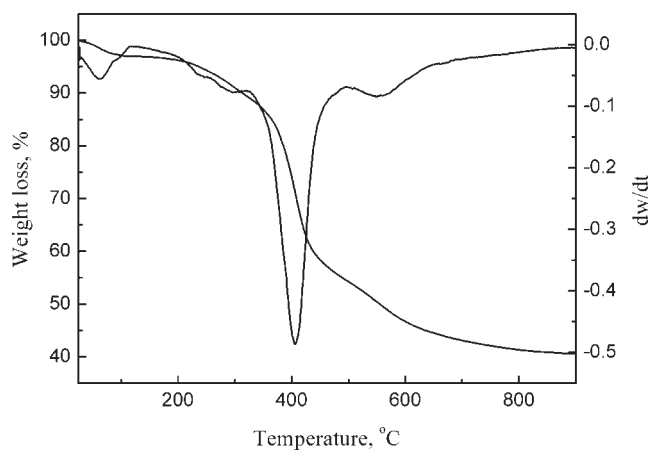

Figure 11 The TGA and DTG thermograms of Novolac resin in nitrogen.

temperature, pure PP decomposes rapidly at about 489°C and produces a large amount of combustion gases without any substance remaining.

Addition of Novolac resin into PP decreased IDT and significantly increases IPDT of PP. The dynamically cured PP/MAH-*g*-PP/Novolac blend has the highest IDT, IPDT, and char yield among all the PP/Novolac blends. The results show that the dynamical cure of Novolac resin can improve the thermal stability of PP, and the incorporation of MAH-*g*-PP into the blends can further improve the thermal stability. George et al.[30] suggested that the thermal degradation of the polymer blends depends not only on the thermal stability of components but also on the morphology and the extent of interaction between the phases. The increase in IDT and IPDT of PP/MAH-*g*-PP/Novolac blends is attributed to the better interaction when compared with the PP/Novolac blends. And it is observed that the higher the content of dynamical cure Novolac is, the more the charred residue remains. That is, the higher the content of Novolac, the more thermally stable the blends are.

Meanwhile, the vicat softing temperature of materials is also shown in Table III. It was found that PP has relatively low vicat softing temperature. The additions of dynamic cure Novolac to PP significantly

418°C and finished at 505°C. The weight loss in this temperature region, 418–505°C, corresponds to the formation of volatile products, which arose from the random chain scission and intermolecular transfer involving tertiary hydrogen abstractions from the polymer by the primary radical.[30] With increasing

TABLE III
Thermal Stability Parameters of the PP, Novolac, and PP/Novolac Blends

Composition	IDT (°C)	T_{max} (°C)	Char yields (%)	IPDT (°C)	Vicat softing temperature (°C)
PP	418.1	489.6	0	471.8	94.7
PP/Novolac (70/30)	295.6	459.4	5.7	513.5	80.1
PP/MAH-*g*-PP/Novolac (60/10/30)	323.2	481.6	8.8	566.4	88.3
PP/Novolac/HMTA (70/30/3)	399.4	470.1	15.7	657.9	110.3
PP/MAH-PP/Novolac/HMTA (60/10/30/3)	433.2	502.8	17.7	735.0	142.9
PP/MAH-PP/Novolac/HMTA (40/10/50/5)	405.2	489.7	23.4	830.4	141.6
Novolac	236.8	408.4	40.5	1500	

increased vicat softing temperature of PP. It is also found that the introduction of MAH-*g*-PP as compatibilizer into the blends can further increase vicat softing temperature of PP. The results are similar to TGA analysis and can be interpreted in the same way.

CONCLUSIONS

A novel dynamically cured PP/Novolac blends compatibilized with MAH-*g*-PP is prepared. The dynamically cured PP/MAH-*g*-PP/Novolac blend has better mechanical properties than corresponding uncured PP/Novolac, uncured PP/MAH-*g*-PP/Novolac and dynamically cured PP/Novolac blends. The dynamic cure of Novolac resin leads to an improvement in the modulus of the PP/MAH-*g*-PP/Novolac blends. With increasing Novolac content, the tensile strength, flexural modulus, and flexural strength increased significantly, while the elongation at break dramatically deceased. The impact strength is also affected by the presence of the Novolac. Those blend made using HMTA as a curing agent has good mechanical strength at HMTA content of 10 wt %.

SEM analysis shows that PP/Novolac blends compatibilized with MAH-*g*-PP has finer domains than that of PP/Novolac blends. Dynamicallly cured Novolac can further decrease the size of dispersed phase. TGA results indicate that the incorporation of Novolac into PP can improve the thermal stability of PP. The dynamically cured PP/MAH-*g*-PP/Novolac blends have the best thermal stability among all the PP/Novolac blends.

References

1. Karger, K. J.; Czigany, T. Compos A 1998, 29, 1319.
2. López-Manchado, M. A.; Arroyo, M. Polymer 2000, 41, 7761.
3. Gessler, M. U.S. Pat. 3,037,954 (1962).
4. Fisher, K. U.S. Pat. 3,758,643 (1973).
5. Coran, A. Y.; Patel, R. P. Rubber Chem Technol 1980, 53, 141.
6. Coran, A. Y.; Patel, R. P.; Williams, D. Rubber Chem Technol 1982, 55, 116.
7. Coran, A. Y.; Patel, R. P. Rubber Chem Technol 1983, 56, 211.
8. Jiang, X. L.; Huang, H.; Zhang, Y.; Zhang, Y. X. Polym Compos 2004, 12, 29.
9. Chiang, W. Y.; Wu, W. C.; Pukanszky, B. Eur Polym J 1994, 30, 573.
10. Hung, A. Y. C.; Wang, F. Y.; Ma, C. C. M.; Sun, Y. M. J Appl Polym Sci 2002, 86, 984.
11. Wang, F. Y.; Ma, C. C. M.; Wu, H. D. J Appl Polym Sci 1999, 74, 2283.
12. Hung, A. Y. C.; Wang, F. Y.; Ma, C. C. M.; Wu, H. D. Eur Polym J 2003, 39, 225.
13. Ma, C. C. M.; Sung, S. C.; Wang, F. Y.; Chiang, L. Y.; Wang, L. Y.; Chiang, C. L. J Polym Sci Part B: Polym Phys 2001, 39, 2436.
14. Zhong, Z. K.; Guo, Q. P. Polymer 1997, 38, 279.
15. Mekhilef, N.; Hadjiandreou, P. Polymer 1995, 36, 2165.
16. Wang, F. Y.; Ma, C. C. M.; Hung, A. Y. C.; Wu, H. D. Macromol Chem Phys 2001, 202, 2328.
17. Kuo, S. W.; Lin, C. L.; Chang, F. C. Polymer 2002, 43, 3943.
18. Huang, M. W.; Kuo, S. W.; Wu, H. D.; Chang, F. C.; Fang, S. Y. Polymer 2002, 43, 2479.
19. Park, S. J.; Cho, M. S. J Mater Sci 2000, 35, 3523.
20. Wu, C. S.; Liu, Y. L.; Chiu, Y. C.; Chiu, Y. S. Polym Degrad Stab 2002, 78, 41.
21. Shieh, Y. T.; Liao, T. N.; Chang, F. C. J Appl Polym Sci 2001, 79, 2272.
22. Huang, Y. Q.; Liu, Y. X.; Zhao, Z. H. J Appl Polym Sci 1998, 69, 1505.
23. Liu, X.; Huang, H.; Xie, Z. Y.; Zhang, Y.; Zhang, Y. X. Polym Test 2003, 22, 9.
24. Zhang, X. Q.; Looney, M. G.; Solomon, D. H. Polymer 1997, 38, 5835.
25. Li, C. Q.; Zhang, Y.; Zhang, Y. X. Polym Test 2003, 22, 191.
26. Chen, W. J.; Wu, J.; Jiang, M. Polymer 1998, 39, 2867.
27. George, S.; Joseph, R.; Thomas, S. Polymer 1995, 36, 4405.
28. Remiro, P. M.; Cortazar, M.; Calahorra, E.; Calafel, M. M. Polym Degrad Stab 2002, 78, 83.
29. Lee, K.; Yoon, K.; Kim, J.; Bae, J.; Yang, J.; Hong, S. Y. Polym Degrad Stab 2003, 81, 173.
30. George, S.; Varughese, K. T.; Thomas, S. Polymer 2000, 41, 5485.