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Research Article

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Damping and mechanical properties of poly (methyl methacrylate)/epoxy interpenetrating polymer networks

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ABSTRACT

A series of poly (methyl methacrylate) (PMMA)/epoxy (EP) interpenetrating polymer networks (IPNs) were prepared by sequential method. The functional group change, mechanical properties, morphology, thermal stability and damping properties were investigated. Damping temperature range and maximum tan δ value was increased to 36℃ and 0.484 when the component ratio of PMMA to EP was 20: 80. Thermogravimetric analysis result indicated that the thermal stability of PMMA/EP IPNs was decreased with the increase content of PMMA. Mechanical properties measurement revealed that tensile strength of PMMA/EP IPNs was lower than that of EP, while the impact strength reached a maximum value at the 15% PMMA content.

Keywords: PMMA/EP IPNs, damping properties, thermal stability, mechanical properties.

INTRODUCTION

High vibration level can not only limit the service duration of machine device, but also are undesirable for human healthy. Application of viscoelastic polymer can provide a promise way to avoid these problems [1]. The ability of polymer to dissipate the external vibrational mechanical energy into heat highly depends on the intensity and broadness of damping peaks around their glass transition region. Generally, homopolymers only possess efficient damping ability in a temperature ranged 20-30℃ [2], which is narrow for practical application. The glass transition region can be broadened by different means, such as blending, grafting, copolymerization, or the formation of interpenetrating polymer networks (IPNs) [3]. IPNs are a new class of polymer blends in network form in which at least one component is polymerized and/or cross-linked in the immediate presence of the other [4, 5].The preparing technique of IPNs can be classified into sequential polymerization and simultaneous polymerization [6].

Epoxy (EP) is a kind of important of thermosetting matrix due to their high strength, low shrinkage and excellent resistance to chemical and corrosion [7]. However, EP suffers from brittle behavior when it is cured by amine curing agent [8]. Poly (methyl methacrylate) (PMMA) is a transparent and high ductile thermoplastic resin, and the incorporation of PMMA is a promising alternative for improving the toughness of EP [9, 10]. Yet, there are not many reports about the damping properties and thermal stability of PMMA/EP IPNs. In this paper, we prepare a series of PMMA/EP IPNs using sequential technique to increase the toughness and damping ability of PMMA/EP IPNs. The functional group change, mechanical properties, morphology, thermal stability, and damping properties were all studied.

EXPERIMENTAL SECTION

Synthesis of PMMA/EP IPNs

First, DGEBA was degassed for 1h at 80℃, and MMA was reacted with BPO (0.5% on MMA) at 60℃ for 0.5h to produce PMMA. Second, the IPNs were prepared by mixing the following two mixtures together: one component

being PMMA, and the other one being the mixture of EP and tetraethylenepentamine (14.6% on DGEBA). All PMMA/EP IPNs specimens were cured at 45℃ for 18h, 85℃ for 3h, and postcured at 130℃ for 3h. Detailed IPNs formation is shown in Table 1.

Table 1: Detailed IPNs formation.

	PMMA	DGEBA
IPN-0	-	100
IPN-10	10	90
IPN-15	15	85
IPN-20	20	80
IPN-25	25	75
IPN-30	30	70

Characterization

FT-IR analysis

Fourier transform infrared (FT-IR) spectra was obtained on a Nexus FTIR spectrometer (Thermo Nicolet, USA）with the resolution of 0.019 cm^{-1}.

Mechanical properties

Tensile strength was obtained on a 1341 mode of materials test machine (Instron, UK) with the crosshead speed of 5mm/min. Impact strength of unnotched specimen was carried out on XJJD-50 charpy impact tester (Chengde, China). All tensile and impact strength values were the average of five measurements.

Morphology

Morphology was observed on JSM-5610LV (Hitch, Japan) scanning electron microscope operating at 25 KV. Microphotographs were taken of the tensile fractured surface, which were coated with gold powder prior to testing.

Thermal stability analysis

Thermogravimetric analysis curves were obtained on STA 449 analyzer (Netzsch, Germany) at the heating rate of 5℃/min, with the temperature ranged from 40 to 600℃ in nitrogen atmosphere.

Damping properties

Damping behavior was analyzed by Pyris 7e dynamic mechanical analyzer（PerkinElmer, USA）over the temperature ranged from 40 to 140℃ at a heating of 5℃/min at 1 HZ. DMA spectra were taken on rectangle specimens with the dimension of 20mm×7mm×1.5mm in tensile mode.

RESULTS AND DISCUSSION

FT-IR analysis

Figure 1 shows the FT-IR spectra of PMMA, EP and IPN-10. From Fig.1(a), the bands at 1725cm^{-1} and 1632cm^{-1} are due to the stretch vibration of –C=O and –C=C- in PMMA. From Fig. 1(b), the band at 911cm^{-1} is due to the stretch vibration of epoxide group in EP. As can be seen from Fig.1(c), the characteristic band of double bond and epoxide group completely disappear in IPN-10, suggesting the formation of PMMA/EP IPNs.

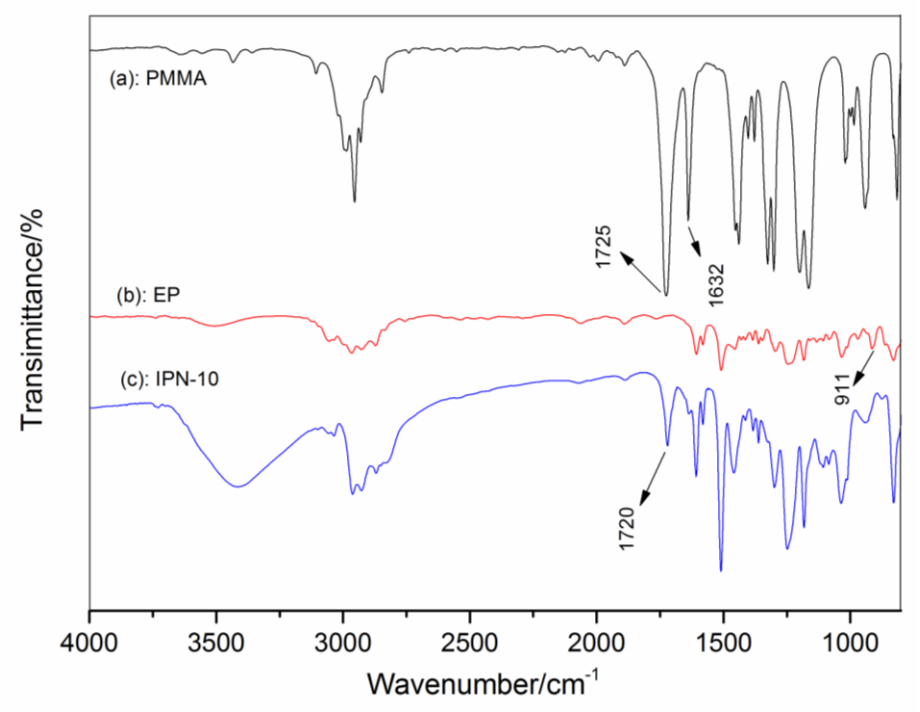

Figure 1: FT-IR spectra of (a) PMMA, (b) EP and (c) IPN-10

Mechanical properties

Figure 2 shows the tensile and impact strength of different PMMA/EP IPNs. It can be seen that the tensile strength of PMMA/EP IPNs was lower than that of EP, which can be explained by the plasticizing influence of dispersed PMMA particles embedded in EP network [11]. In terms of impact measurement, when the PMMA content was beyond 15%, the impact strength decreased sharply from 7.7 to 2.9kJ/m^2. This indicates that the introduction of PMMA can significantly improve the toughness of EP.

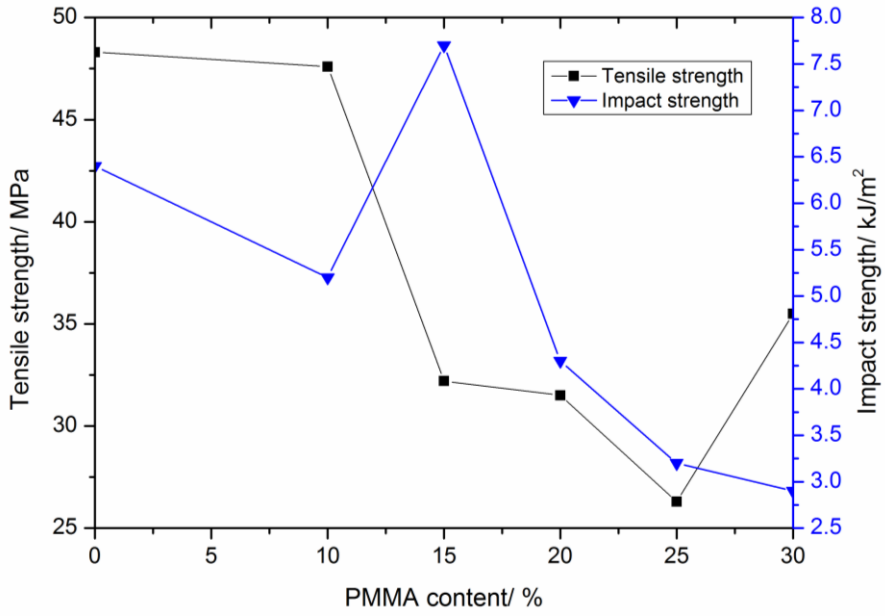

Figure 2: Mechanical properties of PMMA/EP IPNs

Morphology

SEM micrographs of impacted fractured surface of specimens are shown in Figure 3. There are many distinct linear cracks in IPN-0, which indicates the brittle behavior of epoxy. The incorporation of 10%, 20% and 30% PMMA into EP results in a more homogeneous morphology, confirming the formation of interpenetration and entanglement

between PMMA and EP.

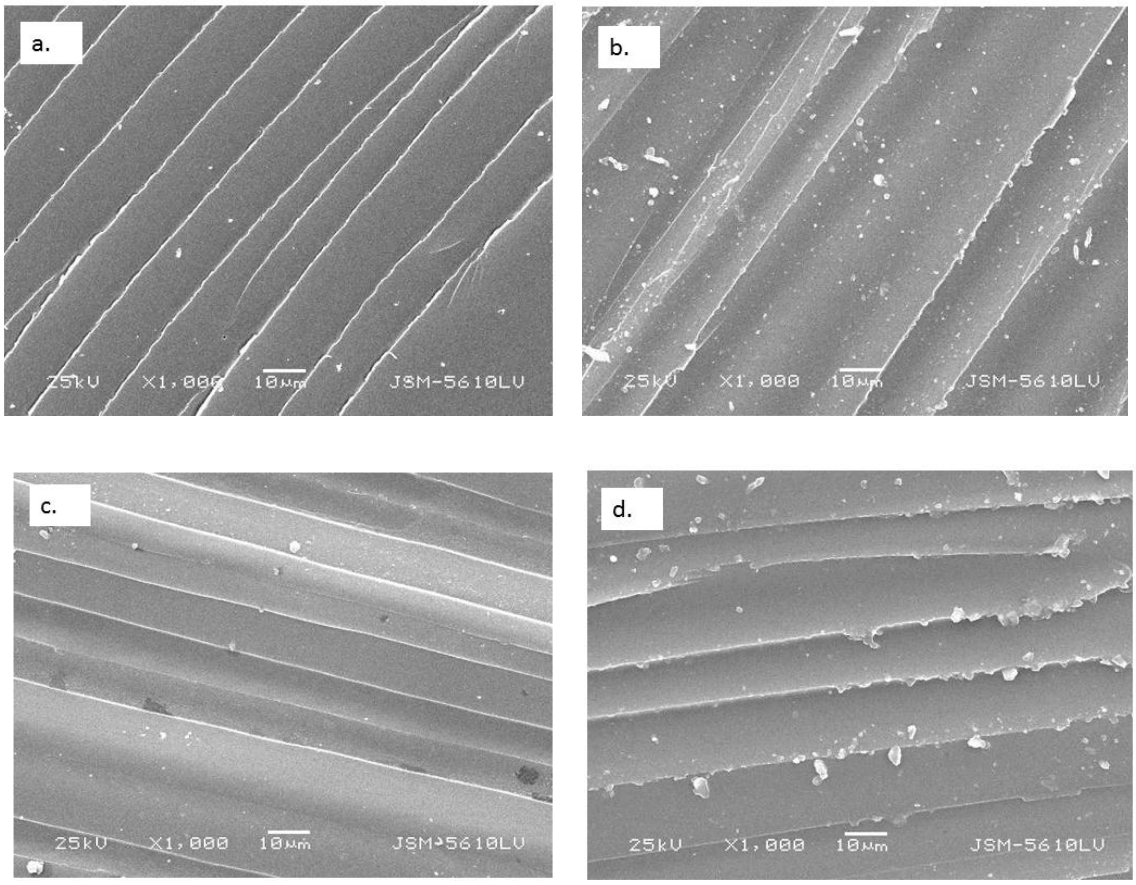

Figure 3: SEM micrographs of (a) IPN-0, (b) IPN-10, (c) IPN-20 and (d) IPN-30

Thermogravimetric analysis

Themogravimetric analysis (TGA) results are shown in Figure 4. The thermal degraded temperature is defined as that the weight loss of IPNs is 5% [12]. From Fig.4, the degraded temperature of pure EP was 313℃. With the addition of 10, 15 and 20% PMMA, the degraded temperature decreased to 250, 210 and 181℃. This may be explained by the fact the plasticizing influence of dispersed PMMA impart the thermal stability of EP. Thus, it can be found the thermal stability of PMMA/EP IPNs was decreased with increased content of PMMA.

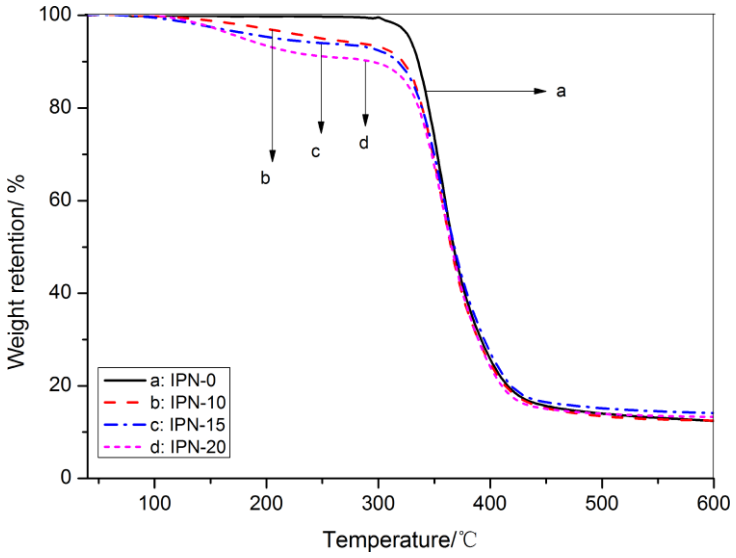

Figure 4: TGA thermograms of (a) IPN-0, (b) IPN-10, (c) IPN-15 and (d) IPN-20

Damping properties

The tanδ is the ratio of mechanical dissipation energy to storage energy and it is an indicator of damping ability of polymer materials. In addition, tanδ value of excellent damping polymers should be high than 0.3 over a broaden temperature range at a fixed frequency [13]. Figure 5 and Table 2 show tanδ vs. temperature curves and some damping data of PMMA/EP IPNs. From Fig.5, a shoulder on the peak of tanδ appeared at IPN-10, which indicates that the low loading of PMMA introduces incompatibility between PMMA and epoxy. Also, it can be found that the addition of PMMA into epoxy results in the decrease of glass transition temperature (T_g).

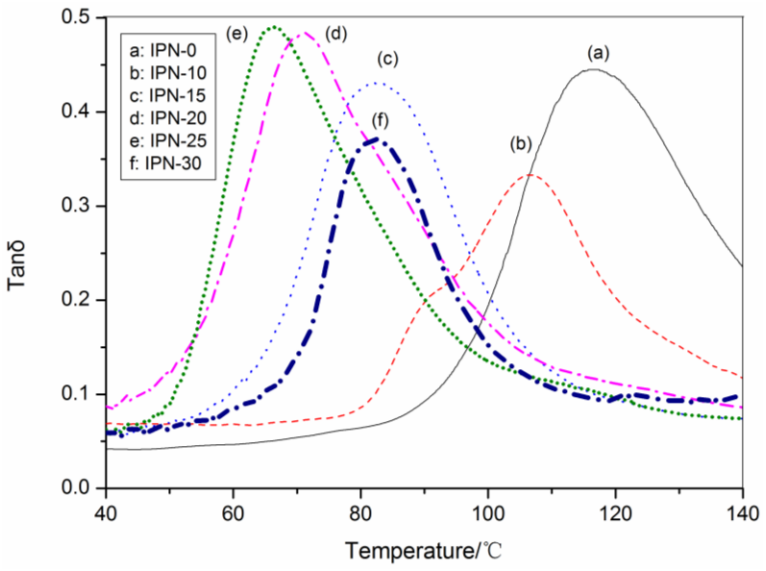

Figure 5: Dependence of tanδ versus temperature of different IPNs

From Table 2, the damping temperature range and maximum tanδ of pure EP are 28℃ and 0.445, respectively. By loading of 20% PMMA, the PMMA/EP IPNs exhibit excellent damping properties, and $(tan\delta)_{max}$ value and damping temperature range could be increased to 0.484 and 36℃, which indicates the composition ratio exerted much influence on the damping properties of PMMA/EP IPNs. It is well known that damping properties of polymers is mainly attributed to the intramolecular friction and molecular relaxation of different polymer chain. When the PMMA content was relatively lower than 20%, the formation of IPNs network and microphase separation (shown in Fig.5) improved the damping ability of PMMA/EP IPNs. When the PMMA content increased higher than 20%, the degree of interpenetration and entanglement increased, which restricted the chain mobility and damping properties.

Table 2: Damping properties of different PMMA/EP IPNs

	T_g/ ℃	$(tan\delta)_{max}$	Temperature range with tanδ>0.3/ ℃
IPN-0	116.7	0.445	105～133
IPN-10	106.6	0.333	102～127
IPN-15	82.6	0.430	73～96
IPN-20	70.8	0.484	58～94
IPN-25	66.1	0.490	53～81
IPN-30	82.1	0.371	72～92

CONCLUSION

A series of PMMA/EP IPNs were prepared by sequential technique. Result of dynamic mechanical thermal analysis showed that the effective damping temperature range was broadened and maximum tanδ value was increased through the introduction of PMMA into EP to form IPNs. Thermal property analysis results revealed that the thermal degraded temperature decreased with increased content of PMMA content. The tensile strength of PMMA/EP IPNs was lower than pure EP, while the impact strength could be increased to7.7 kJ/m^2 at the PMMA content of 15%.

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