



The effect of a renewable fatty acid derivatives based epoxy diluent on the curing kinetics and thermal properties of epoxy/anhydride systems



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ABSTRACT

The diglycidyl ether of dimer diol (DGEDD) was synthesized and the curing kinetics of diglycidyl ether of bisphenol-A/hexahydrophthalic anhydride/tris-(dimethylaminomethyl)phenol (DGEBA/HHPA/DMP-30) system with and without DGEDD as reactive diluent were investigated by non-isothermal DSC technique with Málek method. The dynamic mechanical properties and thermal stabilities of the cured systems with different contents of DGEDD were evaluated using DMTA and TGA, respectively. The results showed that the activation energy calculated by advanced isoconversional method for DGEBA/HHPA/DMP-30 system with DGEDD was slightly higher than that of DGEBA/HHPA/DMP-30 system without DGEDD, and Šesták-Berggren model can simulate well the curing reaction rates of both systems. DMTA showed that the storage moduli of all the cured systems were similar in glassy region and decreased with increasing DGEDD content in rubbery region, and T_g diminished with increasing DGEDD content. TGA showed that loading DGEDD had little impact on the thermal stabilities of the cured systems.

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1. Introduction

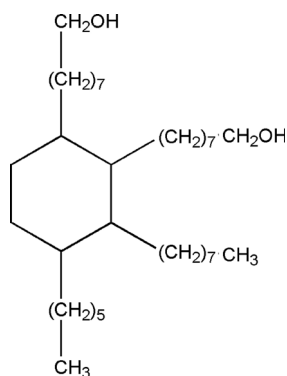
Epoxy resins have a wide range of applications as laminates, moldings, composites, electronic materials, semiconductor encapsulants, coatings, adhesives, and so on, owing to their outstanding mechanical and electrical properties, chemical resistance, adhesion, and low minimal shrinkage [1]. However, the widespread application of epoxy resins is limited in some high-performance fields because the cured epoxy resins, especially with anhydrides as curing agent, are rather rigid and brittle materials. The traditional way to improve the toughness of epoxy resin systems is its modification with various additives and fillers, such as rubber elastomers [2,3], thermoplastics [4,5], or rigid particles [6,7]. Nevertheless, it is well known that the introduction of such modifiers will increase markedly viscosities of resin mixtures and damage the technological properties and some physical mechanical properties of cured epoxy resins. Non-reactive and reactive diluents are also used to make up for this deficiency while reducing viscosity and increasing wetting action of these systems. The reactive diluents, such as diglycidyl ether of triethylene glycol (DGETEG) [8], poly(propylene glycol)diglycidyl ether (PPGDGE) [9] and diglycidyl ether of diethylene glycol (DGE) [10], are involved in the crosslinking network, which has less influence on the

integrated performance of epoxy resins than other additives [11,12].

In recent years, bio-based and eco-friendly polymers derived from renewable resources have attracted extensive attention since they can be produced in large quantities and provide a circulation of carbon in the ecological system. Epoxy resins have already been prepared from some renewable biomass, such as gallic acid [13], lignin [14,15] and rosin [16,17], whose epoxides exhibit comparable properties to those of bisphenol A type epoxy resin but tend to be rigid. Vegetable oil is one of the most important renewable resources because it is mostly inexpensive, biodegradable, easily available in large quantities and eco-friendly [18]. In general, most vegetable oil-based epoxy resins can be used as reactive modifiers or diluents for modification of epoxy resins [19–24] due to their low viscosity, high stability and good flexibility. The dimer diol (trade name Pripol 2033) is a α,ω -difunctional derivative of hydrogenated dimerized linoleic acid resulting from the dimerization and hydrogenation processes, and its molecular structure of the main component of the dimer diol has approximately the form as shown in Scheme 1. So far, Pripol 2033 is mainly used to prepare high-performance acrylate [25] and polyurethane resins [26] with good flexibility and crystalline, strong water-resistance and high weatherability because of its molecular structure including hydroxyl groups, long aliphatic alkyl chains and alicyclic group. Actually, Pripol 2033 based epoxy resin is suggested to be a novel reactive diluent combining toughening and lowering viscosity, however, there are no relative literatures reported to the best of our knowledge.

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Scheme 1. The possible structure of the main component of Pripol 2033.

The influence of epoxidized vegetable oil on thermal or mechanical properties of petroleum-based epoxy systems has been investigated by some researches [19–24] but there have been few systematic overall reports regarding the effect on the curing kinetics. In this study, dimer diol Pripol 2033 was used to react with epichlorohydrin in the presence of NaOH and phase transfer catalyst to synthesize the diglycidyl ether of dimer diol (DGEDD, with viscosity about 140 mPa s at 25 °C), which was further applied as a reactive epoxy resin to dilute viscous diglycidyl ether of bisphenol-A (DGEBA). We are interested in the impact of this novel DGEDD on the curing behaviors and properties of DGEBA epoxy systems. Therefore, non isothermal DSC test was used to investigate the curing kinetics of DGEBA/DGEDD mixture resin with hexahydrophthalic anhydride (HHPA) as curing agent and tris-(dimethylaminomethyl)phenol (DMP-30) as curing accelerator. The model-free advanced isoconversional method and model-fitting Málek method were applied to calculate the curing kinetics parameters. In addition, the impact of DGEDD on the dynamic mechanical property and thermal stability of DGEBA/HHPA/DMP-30 system was also studied by DMTA and TGA respectively.

2. Experimental

2.1. Materials

DGEBA (trade name CYD128, equivalent epoxy weight 192.3 g/mol) was purchased from Epoxy Division of China Petrochemical Group Baling Petrochemical Co., Ltd.; HHPA (99.4%) was supplied by Puyang Huicheng Electronic Materials Co., Ltd.; DMP-30 was bought from Sinopharm Chemical Reagent Beijing Co., Ltd.; AR; Pripol 2033 can be available by CRODA. All the raw materials were used as received. DGEDD was synthesized in our lab by means of the method mentioned by the patent [27], and the epoxy equivalent of resultant DGEDD was 351.5 g/mol analyzed by hydride chloride/acetone method.

2.2. Characterization of DGEDD

2.2.1. FT-IR measurements

The FTIR spectrum of DGEDD was recorded on a BRUKER ALPHA FTIR spectroscopy in the range of 4000–400 cm⁻¹ at room temperature with a KBr pellet, and the result is given in Fig. 1. FTIR data ($\nu_{\max}$, cm⁻¹): 3047, 2923, 2853, 1457, 1373, 1339, 1252, 1109, 910 (epoxy group), 843, 762, 722.

2.2.2. ESI-MS

The sample of DGEDD was dissolved in chloroform, and the test was carried out on ESI-MS (Waters Corporation, USA). ESI-MS

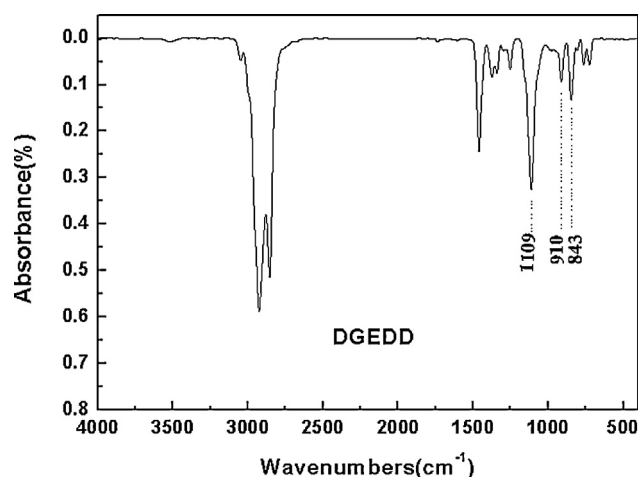


Fig. 1. FTIR spectrum of DGEDD.

data: $[M+1]^+ = 649.8$, $[M+18]^+ = 666.8$, $[M+23]^+ = 671.6$, and $[2M+1]^+ = 1298.7$.

2.3. DSC measurement

The curing reactions of DGEBA/DGEDD/HHPA/DMP-30 systems were manipulated by using a differential scanning calorimeter (Q20, TA Instruments) under a nitrogen flow of 50 mL/min. Formulas of DGEBA/DGEDD/HHPA/DMP-30 systems are listed in Table 1.

About 5–6 mg fresh reaction mixture was sealed in an aluminum DSC crucible, and immediately subjected to a temperature scanned from 40 to 250 °C using an empty crucible as standard reference. The heating rate was controlled at 5, 10, 15 and 20 °C/min, respectively, for systems A and D, and 10 °C/min for the others in Table 1.

2.4. DMTA measurement

The cured epoxy samples (30 mm × 6 mm × 2 mm) were tested on a dynamic mechanical analyzer (Rheometric Scientific DMTA V) under single cantilever bending mold and a frequency of 1 Hz at a heating rate 5 °C/min. The temperature ranged from –50 °C to well above the glass transition temperatures.

2.5. TGA measurement

Thermo gravimetric analysis (TGA) was performed on a TA Q500 instrument by scanning the cured epoxy resins from 25 to 600 °C at a heating rate of 10 °C/min under nitrogen atmosphere.

Table 1

Formulas of DGEBA/DGEDD/HHPA/DMP-30 systems (parts by weight).

Epoxy resin system	Epoxy resin			HHPA	DMP-30
	DGEBA	DGEDD	Viscosity (mPa s)		
A	100	0	11272	80.0	1
B	90	10	4521	76.4	1
C	80	20	3119	72.8	1
D	70	30	1267	69.1	1
E	60	40	839	65.5	1
F	50	50	689	61.9	1

3. Results and discussion

3.1. Non-isothermal curing behaviors of DGEBA/DGEDD/HHPA/DMP-30 systems

The DSC thermographs of non-isothermal curing reactions of systems A, B, C, D, E and F at a constant heating rate of 10 °C/min are shown in Fig. 2. One can see from Fig. 2 that the overall reaction heat reduces from 334.9 J/g (system A) to 271.4 J/g (system F) and the peak maximum temperatures almost have slight increases with increasing the amount of diluent DGEDD. This is a result of the lower concentration of functional groups in DGEDD than that in DGEBA [28], and this fact may lead to a result that the crosslinking density of the cured epoxy systems declines gradually as DGEDD is merged into the crosslinking network more and more.

Fig. 3 shows the non-isothermal DSC curves of systems A and D at a heating rate of 5, 10, 15 and 20 °C/min respectively and the curing behaviors of both systems will be discussed in detail below.

3.2. The calculation of activation energy

The curing reaction of epoxy resins with anhydride as a hardener catalyzed by tertiary amines is a complex process including lots of elementary reactions. The diversity of activation energy (E_α) values is related to the evolution of different reactions during the curing [29], which contributes to better understanding curing behaviors of epoxy resin systems. The variation of E_α with fractional conversion (α) can be determined with the advanced isoconversional kinetic analysis method developed by Vyazovkin [30–32]. This method is one of model-free isoconversional methods, which abides by the isoconversional principle that the reaction rate is only a function of the temperature at a constant conversion. The relationship between E_α and α can be constructed by this method without assuming any certain kinetic model [32–34]. The main analytic equations for this method in a non-isothermal curing process with a linear heating program can be expressed as follows:

$$\Phi(E_\alpha) = \sum_{i=1}^n \sum_{j \neq i}^n \frac{J[E_\alpha, T_i(t_\alpha)]}{J[E_\alpha, T_j(t_\alpha)]} = \min \quad (1)$$

$$J[E_\alpha, T_i(t_\alpha)] \equiv \int_{t_\alpha - \Delta\alpha}^{t_\alpha} \exp\left[\frac{-E_\alpha}{RT_i(t)}\right] dt \quad (2)$$

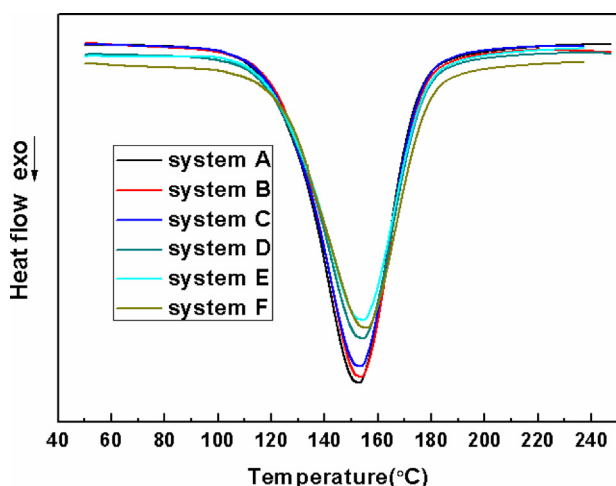


Fig. 2. DSC curves of DGEBA/DGEDD/HHPA/DMP-30 systems with the heating rate of 10 °C/min.

where the subscripts i and j represent ordinal numbers of thermal measurements performed under different heating programs ($i, j = 1, \dots, n$); $\Delta\alpha$ is the small increment of fractional conversion and $\Delta\alpha$ is set as 0.01; J is the temperature integral.

According to the advanced isoconversional kinetic analysis method, the temperature integral in a small fractional conversion range, J , can be approximately calculated with a trapezoidal rule after evaluating t_α with a nonlinear interpolation method. The value of temperature integral is substituted in Eq. (1) to obtain $\Phi(E_\alpha)$, of which minimization is the effective activation energy at a certain fractional conversion. Fig. 4 shows the dependence of the effective activation energy for systems A and D on fractional conversion range from 0.05 to 0.95.

From Fig. 4, one can observe that the overall variation trends of E_α values are basically identical with the increase of α from 0.05 up to 0.95 for systems A and D. Meanwhile, E_α values of system D are higher than those of system A under corresponding conversions and the difference between these two systems is growing. This reveals that diluent DGEDD increases the curing reaction energy barrier of the epoxy system. The possible reason might be considered that the irregular nonlinear structure and long nonpolar alkyl chain with chemical inertness in the molecular structure of DGEDD may prevent the epoxy groups and anhydride groups from getting close to each other, and this fact may lead to its lower reactivity and higher activation energy. As the curing reaction proceeds, the ratio of DGEDD moiety in the crosslinking network keeps rising gradually, which makes the overall reaction energy barrier greater and greater.

In the range of $0.05 \leq \alpha \leq 0.45$, the E_α values of system A increase from approximate 70.7 to 76.1 kJ/mol. Analogously, E_α values of system D increase from about 73.4 to 79.9 kJ/mol in the conversion range from 0.05 to 0.49. At early curing reaction stages, the growing molecular weight leads to the increase of viscosity under linear heating conditions, and the propagation of polymer chains plays the more dominant role on the overall energetic barrier than the steadily elevated temperature. When the curing reaction process further progresses, the propagation of polymer chains and the elevated temperature tend to be in a dynamic equilibrium status. Consequently, the apparent activation energy is practically constant that E_α values of system A and system D float, respectively, in the range from 76.1 to 77.1 kJ/mol and 79.9 to 80.3 kJ/mol when α lies from 0.45 to 0.76 and from 0.49 to 0.66, respectively. When $\alpha > 0.76$, E_α values of system A increases from 77.1 to 83.3 kJ/mol; similarly, when $\alpha > 0.66$, E_α values of system D increases from 80.3 to 91.3 kJ/mol. The relationship between E_α and α suggests that the elevated temperature could not compensate the effect of the propagation of polymer chains efficiently. The average value of E_α during this curing process is calculated to be 76.0 kJ/mol for system A and 79.4 kJ/mol for system D in the conversion range from 0.05 to 0.95, respectively.

3.3. Non-isothermal model-fitting kinetics

In general, most curing kinetics starting with a basic rate equation can be described on the assumption that the reaction exotherms are proportional to the fractional conversion by Eq. (3) [14,35,36]:

$$\frac{d\alpha}{dt} = \frac{dH/dt}{\Delta H} = k(T)f(\alpha) \quad (3)$$

where α is the fractional conversion or the extent of curing reaction; $d\alpha/dt$ is the curing rate; dH/dt is the heat flow rate; ΔH is the total heat of reaction; $f(\alpha)$ is a function of fractional conversion and represents the kinetic model; $k(T)$ is the rate constant and is usually assumed to follow the Arrhenius equation, thus $d\alpha/dt$ is

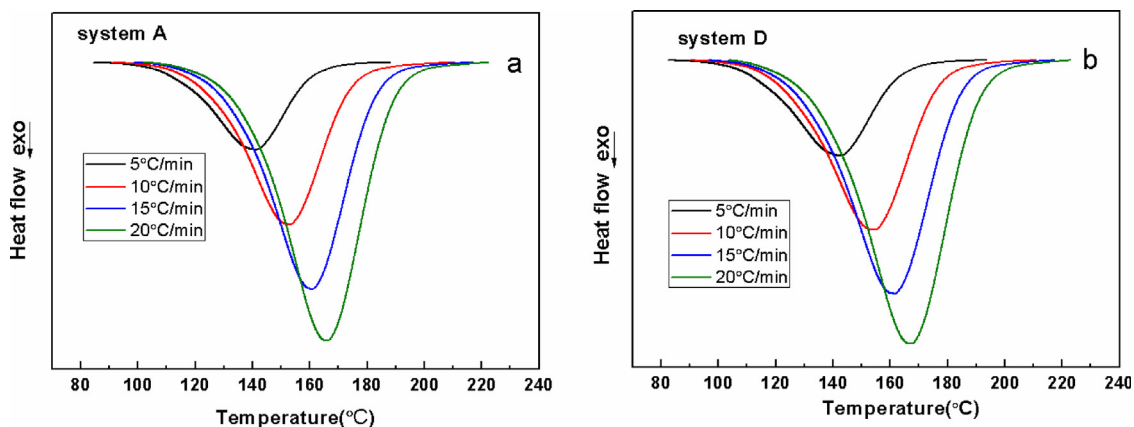


Fig. 3. DSC curves of system A (a) and system D (b) with heating rates of 5, 10, 15 and 20 °C/min.

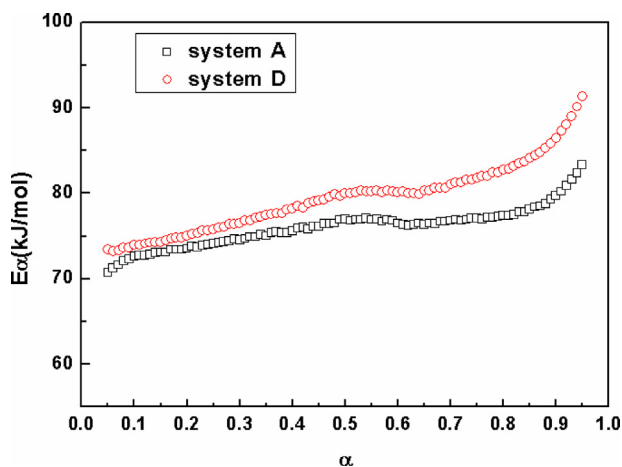


Fig. 4. Dependence of effective activation energy of systems A and D on the fractional conversion.

expressed as:

$$\frac{d\alpha}{dt} = A \exp\left(\frac{-E_a}{RT}\right) f(\alpha) \quad (4)$$

where A is the pre-exponential factor; E_a is the activation energy; R is the gas constant ($8.314 \text{ J mol}^{-1} \text{ K}^{-1}$); T is the absolute temperature.

Málek method [35,37,38] is implemented to determine a suitable kinetic model to characterize and compare the curing

process of these two systems in this work. According to Málek method, the kinetic model can be obtained by means of the shape and maximum of two characteristic functions $y(\alpha)$ and $z(\alpha)$. The average activation energy estimated by the advanced isoconversional method in the conversion range from 0.05 to 0.95 is used to calculate the functions of $y(\alpha)$ (Eq. (5)) and $z(\alpha)$ (Eq. (6)), respectively:

$$y(\alpha) = \frac{d\alpha}{dt} \exp(\chi) \quad (5)$$

$$z(\alpha) = \pi(\chi) \left(\frac{d\alpha}{dt} \right) \frac{T}{\beta} \quad (6)$$

where β is the heating rate; χ equals to E_a/RT and $\pi(\chi)$ can be approximately calculated by the 4th rational expression of Senum and Yang [39]:

$$\pi(\chi) \approx \frac{\chi^3 + 18\chi^2 + 88\chi + 96}{\chi^4 + 20\chi^3 + 120\chi^2 + 240\chi + 120} \quad (7)$$

The curves of $d\alpha/dt$, normalized $y(\alpha)$ and $z(\alpha)$ versus α for systems A and D under the heating rate of 10 °C/min are shown in Fig. 5. The fractional conversions at the maximum value of $d\alpha/dt$, normalized $y(\alpha)$ and $z(\alpha)$ are set as α_p , α_M and α_p^∞ respectively, which are listed in Table 2.

It is appropriate to employ the two-parameter Šesták–Berggren kinetic model (SB(m, n)) [35,37,40] to describe the curing process of both system A and system D because of the fact that $0 < \alpha_M < \alpha_p^\infty$ and $\alpha_p^\infty \neq 0.632$, which are in line with the

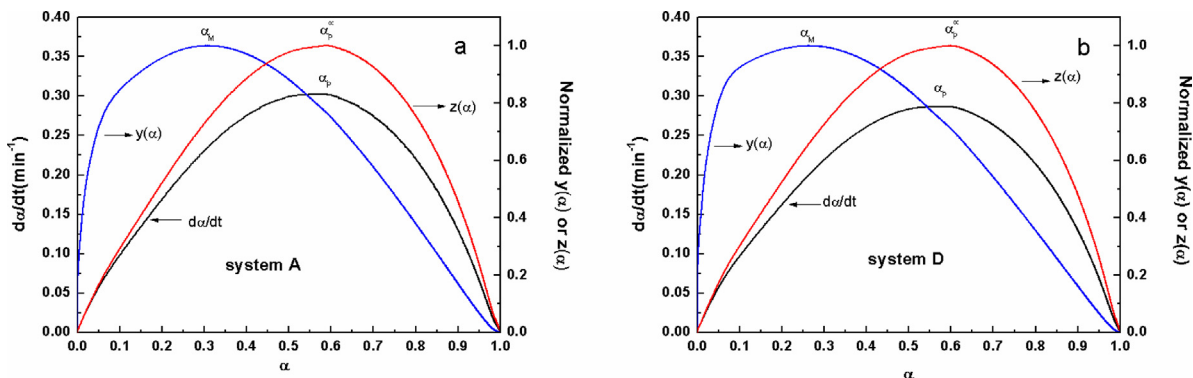


Fig. 5. Variation of experimental reaction rate ($d\alpha/dt$), normalized $y(\alpha)$ and normalized $z(\alpha)$ versus fractional conversion for system A (a) and system D (b) with the heating rate of 10 °C/min.

Table 2
Characteristic peak conversion values of $d\alpha/dt$, $y(\alpha)$ and $z(\alpha)$ for systems A and D.

Epoxy resin system	β (°C/min)	α_p	α_M	α_p^∞
A	5	0.585	0.304	0.604
	10	0.571	0.305	0.586
	15	0.551	0.326	0.585
	20	0.555	0.323	0.580
D	5	0.582	0.248	0.603
	10	0.577	0.264	0.599
	15	0.568	0.279	0.595
	20	0.562	0.283	0.592

judgment of Málek's standards [35]. The SB(m, n) model can be expressed by Eq. (8):

$$\frac{d\alpha}{dt} = k(T)f(\alpha) = Ae^{-X}\alpha^m(1-\alpha)^n \quad (8)$$

where m and n represent the reaction orders and $m+n$ is the overall order of reaction.

The Eq. (8) can be transformed into the Eq. (9):

$$\ln\left[\left(\frac{d\alpha}{dt}\right)\exp(\chi)\right] = \ln A + n \ln[\alpha^{m/n}(1-\alpha)] \quad (9)$$

where m/n is equivalent to $\alpha_M/(1-\alpha_M)$ [35].

According to Eq. (9), n and $\ln A$ of systems A and D can be gained by the slope and intercept of the fitting lines of $\ln[(d\alpha/dt)\exp(\chi)]$ versus $\ln[\alpha^{m/n}(1-\alpha)]$ in the range of $0.20 \leq \alpha \leq 0.95$ (Fig. 6), respectively. The values of the kinetic parameters are summarized in Table 3.

As a result, the explicit kinetic equation for the curing reactions of system A (Eq. (10)) and system D (Eq. (11)) can be achieved as follows:

$$\frac{d\alpha}{dt} = \beta \frac{d\alpha}{dt} = 2.364 \times 10^9 \exp\left(\frac{-75978}{RT}\right) \alpha^{0.549} (1-\alpha)^{1.196}, \alpha \in [0, 1] \quad (10)$$

$$\frac{d\alpha}{dt} = \beta \frac{d\alpha}{dt} = 5.066 \times 10^9 \exp\left(\frac{-79398}{RT}\right) \alpha^{0.431} (1-\alpha)^{1.174}, \alpha \in [0, 1] \quad (11)$$

From Eqs. (10) and (11), one can see that the pre-exponential factors for both system A and system D are the same order of magnitude and furthermore the values of m and n have no obvious changes after loading of DGEDD (30 parts by weight) to DGEBA/HHPA/DMP-30 (system A). Fig. 7 shows the comparison of the

experimental curing rates (dots) with the simulated ones (full lines) calculated by an ordinary differential equation solver program based on the 4th-order Runge–Kutta method. The initial values were set as $\alpha = 0.01$ when $T = 75.93^\circ\text{C}$ for system A and $\alpha = 0.005$ when $T = 75.93^\circ\text{C}$ for system D. In Fig. 7, the simulated curves of $d\alpha/dt$ versus α match the experimental ones, which indicates that the kinetic equations deduced with SB(m, n) model can give a good description of the curing process for both systems.

3.4. Dynamic mechanical properties

Fig. 8 shows the effect of diluent DGEDD on the dynamic mechanical properties of DGEBA/HHPA/DMP-30 system. It is noted that the storage moduli of these six systems in glassy region show little difference because of the similar main structure in the crosslinking network while the storage moduli in rubbery region decline slightly with increasing DGEDD/DGEBA ratios. There may be two reasons for this phenomenon. On the one hand, the introduction of diluent DGEDD seems to render the cured epoxy mixture systems a lower crosslinking density than DGEBA/HHPA/DMP-30 system without DGEDD. On the other hand, the ratio of the rigid molecular chains is decreasing and that of flexible molecular chain is gradually increasing in the crosslinking network as more and more DGEDD is loaded.

The glass transition temperature (T_g) is defined as the peak temperature of a damping ($\tan \delta$) curve. From Fig. 8, one can see that loading DGEDD from 0 to 50 parts by weight lowers the glass transition temperature from 146.8°C (system A) to 88.5°C (system F) and concurrently increases the effective damping temperature regions (the temperature range where the $\tan \delta$ values are larger than 0.3) from 15.1°C (system A) to 26.7°C (system F), which is caused by better movement ability of aliphatic segments in DGEDD at the lower temperature. The values of the single $\tan \delta$ peak, which demonstrates that these mixed systems are homogeneous and there no exists phase separation in visibility, are decreasing along with increasing DGEDD content because the irregular nonlinear structure in DGEDD structure may lead to larger free volumes in cured bulks and the lower energy dissipation for the lower friction between the molecules.

3.5. Thermal stabilities

When DGEDD is incorporated with DGEBA in different ratios, the cured epoxy systems exhibit similar thermal stabilities, as shown in Fig. 9. The relevant thermal stability parameters of the cured epoxy systems are listed in Table 4. The data in Table 4 indicates that the reactive diluent DGEDD has little influence on

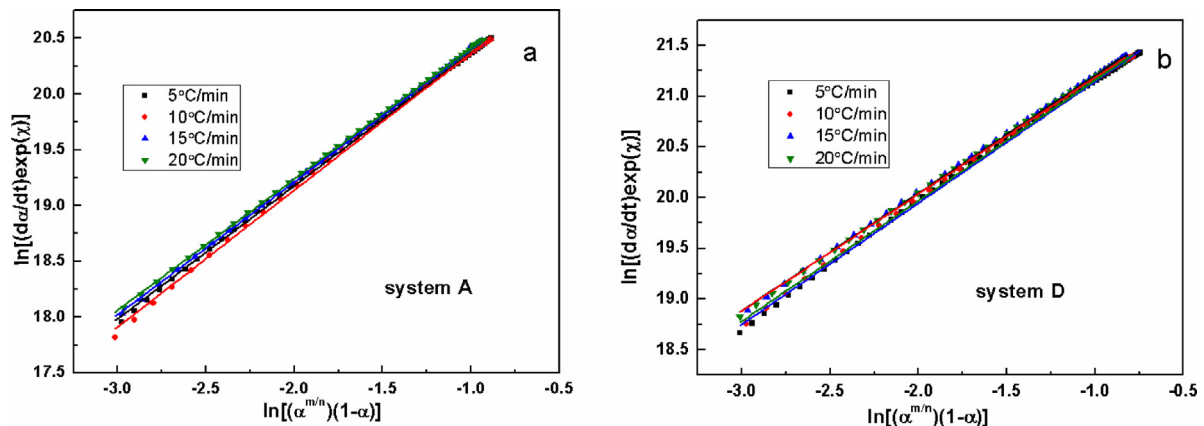


Fig. 6. Plots of $\ln[(d\alpha/dt)\exp(\chi)]$ against $\ln[\alpha^{m/n}(1-\alpha)]$ in the conversion range from 0.2 to 0.95 for systems A (a) and D (b) at heating rates of 5, 10, 15 and $20^\circ\text{C}/\text{min}$.

Table 3Calculated kinetic parameters m , n and $\ln A$ for SB(m , n) model for systems A and D.

Epoxy resin system	β ($^{\circ}\text{C}/\text{min}$)	n	Mean	m	Mean	$\ln A$ (min^{-1})	Mean
A	5	1.193	1.196 ± 0.023	0.520	0.549 ± 0.024	21.5644	21.5837 ± 0.0137
	10	1.227		0.540		21.5941	
	15	1.190		0.576		21.5926	
	20	1.173		0.561		21.5837	
D	5	1.197	1.174 ± 0.022	0.394	0.431 ± 0.027	22.3417	22.3459 ± 0.0109
	10	1.187		0.427		22.3429	
	15	1.159		0.449		22.3618	
	20	1.151		0.454		22.3373	

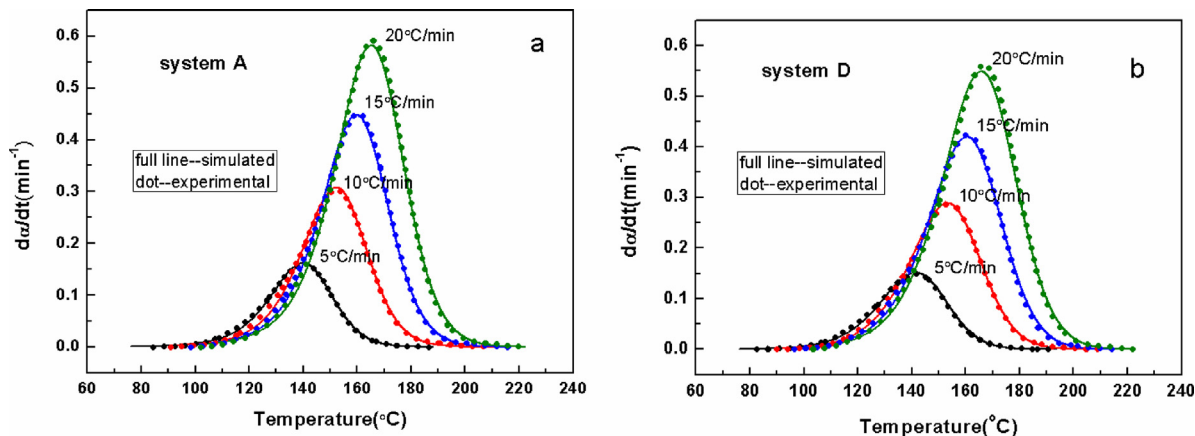
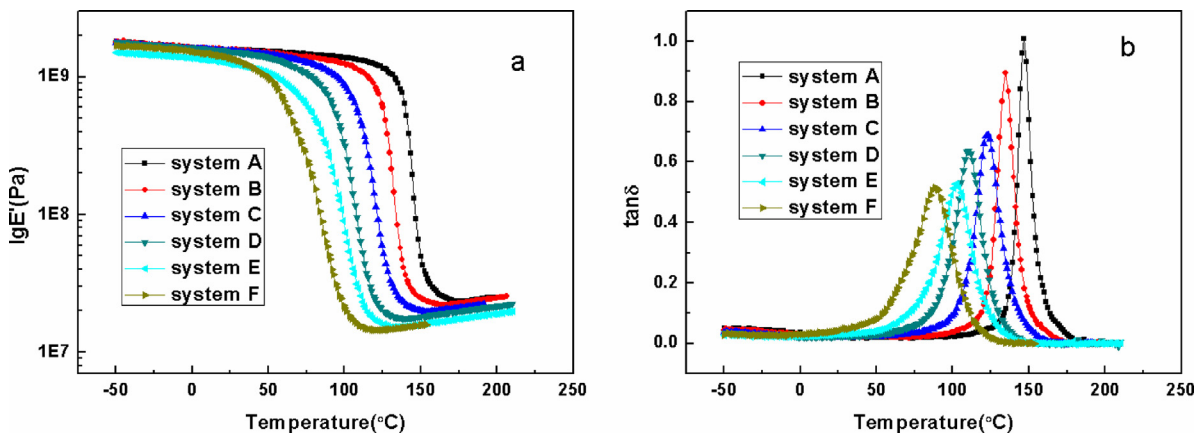
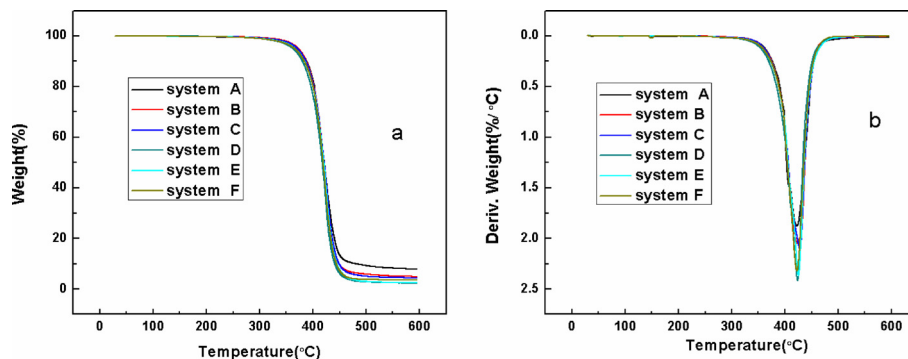
**Fig. 7.** Comparison of experimental rates (dots) and calculated rates (full lines) from SB(m , n) for system A (a) and system D (b). Note: the initial values are set as $\alpha = 0.01$ when $T = 75.93$ $^{\circ}\text{C}$ for system A and $\alpha = 0.005$ when $T = 75.93$ $^{\circ}\text{C}$ for system D.**Fig. 8.** Plots of storage modulus (a) and loss tangent (b) versus temperature of cured DGEBA/DGEDD/HHPA/DMP-30 systems.**Fig. 9.** TG (a) and DTG (b) curves of DGEBA/DGEDD/HHPA/DMP-30 systems with the heating rate of 10 $^{\circ}\text{C}/\text{min}$.

Table 4

Thermal stability parameters for DGEBA/DGEDD/HHPA/DMP-30 systems.

Epoxy resin system	Temperature (°C) at varied weight loss fractions				Temperature (°C) for maximum thermal decomposition rate	Carbon residue rate (%) at 600 °C
	5%	10%	20%	50%		
A	372.4	388.3	403.2	421.4	422.2	7.8
B	372.5	387.8	402.2	421.0	422.8	4.9
C	371.1	386.9	401.7	421.1	427.3	4.4
D	362.6	380.4	396.7	417.6	423.9	2.4
E	366.7	384.4	400.6	420.7	425.1	2.5
F	365.8	384.1	400.6	419.3	422.2	3.5

the thermal decomposition temperature and all these systems possess good thermal stabilities with the decomposition temperatures of 360 °C above. The temperature at which 5% weight loss ($T_{5\%}$) was incurred was set as the index of thermal stability here. The $T_{5\%}$ values of DGEBA/HHPA/DMP-30 system with a small amount of DGEDD show negligible changes. When the content of DGEDD added is more than 30 parts by weight, the $T_{5\%}$ values of the cured epoxy blend systems decrease by 6–10 °C. The reason for this phenomenon is possibly that incorporation of DGEDD lowers the crosslinking density of networks because of its long aliphatic chain. In addition, the introduction of multiple methylene units in DGEDD also leads to a decrease in thermal stability. The carbon residue rate at 600 °C almost decreases gradually with increasing DGEDD content.

4. Conclusion

A novel renewable fatty acid derivative based epoxy (DGEDD) was synthesized and showed satisfactory dilution capability to DGEBA. The addition of diluent DGEDD lowered the total enthalpy and increased peak maximum temperature of DGEBA/HHPA/DMP-30 system. The E_a values calculated by the advanced isoconversional method of DGEBA/HHPA/DMP-30 system without DGEDD were higher than those of the epoxy system with DGEDD (30 parts by weight). The apparent activation energies of the former pure epoxy and the latter blend system were 76.0 kJ/mol and 79.4 kJ/mol respectively and incorporation of DGEDD did not increase largely the reaction energy barrier of DGEBA/HHPA/DMP-30 system. The further analysis with Málek method confirmed that the SB(m , n) model can predict the reaction rate well for both DGEBA/HHPA/DMP-30 system without and with DGEDD and the addition of DGEDD had no significant impact on the overall curing kinetic of DGEBA/HHPA/DMP-30 system. Besides, according to the DMTA analysis, the increasing DGEDD load did not cause a significant drop in storage moduli of the cured epoxy systems. The T_g and $\tan \delta$ values of the mixed DGEBA/DGEDD/HHPA/DMP-30 systems were falling with the increasing DGEDD load and nevertheless the effective damping temperature ranges were widening. TGA showed addition of DGEDD had little impact on the thermal stabilities of the epoxy systems.

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