Synthesis of Diphenylphosphine Oxide Derivative and Its Flame Retardant Application in Epoxy Resin

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A type of reactive phosphorus based flame retardant, hydroxy(4-hydroxyphenyl)methyl)diphenylphosphine oxide (DPO-H), was synthesized and characterized by Fourier Transform Infrared (FTIR) and Nuclear Magnetic Resonance (NMR) spectroscopies. 4,4'-Diaminodiphenylsulfone (DDS) was used as the curing agent and DPO-H was used as the reactive flame retardant and co-curing to prepare the flame-retardant epoxy resins with different P contents. It can be observed that the introduction of DPO-H could enhance the transparency of epoxy resin. Flame-retardant epoxy resin samples were investigated by limit oxygen index (LOI) test, vertical burning (UL-94) testing, cone calorimetry test and thermogravimetric analysis (TGA). The results indicated that DPO-H can increase the flame retardation and carbon formation of epoxy resin. The flame-retardant epoxy resin sample with P content of 0.5 wt% can reach UL-94 V-0 rate, and LOI value increased to 29.6%. The flame-retardant mechanism of the DPO-H modified flame-retardant epoxy resin was analyzed by thermogravimetry-infrared combination (TG-IR), pyrolysis gas chromatography mass spectrum (PY/GC-MS) and scanning electron microscope (SEM). The results showed that the introduction of DPO-H can inhibit the pyrolysis of epoxy resin effectively. Epoxy resin modified by DPO-H had evident flame-retardant effect both in gas phase and condensation phase.

Keywords: Flame retardance, Diphenylphosphine oxide, Epoxy resin, Transparency, Pyrolysis

1. Introduction

Epoxy resin was an important thermosetting resin. Due to its excellent mechanical, electrical insulation, corrosion resistance and adhesion properties, epoxy resin were widely used in various fields, such as electronic and electrical industry, adhesives, coating materials and aerospace and so on. [1-4]. However, the inflammability of epoxy resin impedes its wider applications. Therefore, it’s very important to endow the flame-retardancy to epoxy resin. Owing to the good flame retardancy and appropriate price, halogen based flame retardant was widely used in different kinds of materials in the past century [5-7]. However, environmental concerns for halogen flame retardants, which produce smoke and poisonous gases has restricted their application [8,9].

Recently, the high-efficiency retardant, low smoke and low toxicity halogen-free flame retardant is the trend. More and more non-halogen elements (such as P, N and Si) are introduced to the flame-retardant systems [1,10-16]. Organophosphorus flame retardant has been widely studied due to its environmental, nontoxic and smokeless properties. In particular, 9,10-dihydro-9-oxa-10-phosphaphenanthrene-10-oxide (DOPO), which can make addition reactions with unsaturated bonds (e.g. olefins, epoxy groups and carbonyls) [10,17,18]. So, it not only can be used as the flame retardant independently, but also can be used to prepare a series of derivatives [10,17-21]. Although phosphaphenanthrene flame retardants generally have high flame-retardant efficiency, low smoke and toxicity, they can influence the thermostability of epoxy resin significantly.
Recently, Wang et al. applied DPO and its derivatives to flame retardants [23-25]. And Tian et al. also applied DPO derivatives to flame retarded poly(ethylene terephthalate) [26].

In this study, a kind of reactive flame retardant with active hydroxyl, which was synthesized by DPO and \( p \)-hydroxybenzaldehyde and used the method in the literature [25]. DPO-H was used as the flame retardant and curing agent to modify the epoxy resin. The DPO-H modified epoxy resin not only showed excellent flame retardancy, but also enhanced the transparency of epoxy resin.

2. Experimental

2.1. Materials

DGEBA (E-44) was supplied by Zhenjiang Danbao Resin Co., Ltd. Diphenylphosphine oxide (DPO) was obtained from Qingdao Fusilin Chemical Science & Technology Co., Ltd. 4,4’-diaminodiphenylsulfone (DDS), \( p \)-hydroxybenzaldehyde, dichloroethane and ethyl acetate were purchased from Aladdin Industrial Corporation. All chemicals were used as received.

2.2. Synthesis of DPO-H

\( p \)-Hydroxybenzaldehyde (12.20 g, 0.1 mol) and 1,2-dichloroethane (EDC, 30 mL) were added into a 250 mL three-necked round-bottom flask equipped with a mechanical stirrer, reflux condenser and thermometer, and stirred until the \( p \)-hydroxybenzaldehyde was completely dissolved. Then DPO (20.22 g, 0.10 mol) was added into the round-bottom flask. The mixture was cooled to room temperature after stirring at 80 °C for 10 h. The precipitate was filtered and washed three times with ethyl acetate to obtain 28.19 g of product (white powder, 87.3% yield). The melting point is 178.7 °C. The synthetic route is shown in Scheme 1.

![Scheme 1. Synthetic route of DPO-H.](image)

Table 1. Formulation of epoxy resin thermosets.

| Sample | P content (wt%) | DGEBA (g) | DPO-H (g) | DDS (g) |
|--------|-----------------|-----------|-----------|---------|
| EP-0   | 0               | 100       | 0         | 28.55   |
| EP-0.3 | 0.3             | 100       | 4.07      | 25.73   |
| EP-0.5 | 0.5             | 100       | 6.88      | 24.66   |
| EP-0.7 | 0.7             | 100       | 9.76      | 23.55   |
| EP-0.9 | 0.9             | 100       | 12.72     | 22.42   |

2.3. Preparation of flame-retarded epoxy resins

Modified epoxy resins were prepared via thermal curing of epoxy resin with DDS, and DPO-H. DGEBA and a defined amount of DPO-H were heated to 180 °C and stirred until DPO-H dissolved in DGEBA completely. DDS (the sum of reactive hydrogen of DDS and DPO-H were equal to the epoxy groups of DGEBA) was then added into the mixture and mixed adequately to form a uniform mixed system. After that, the mixture was poured into the preheated molds and pre-cured at 120 °C for 2 h, cured at 140 °C for 3 h and further cured at 170 °C for 1 h. The obtained samples were labeled with the mass content of the P element. For example, EP-0.3 means the mass content of P element in EP thermosets was 0.3 wt%. Control sample (EP/P-0) was also prepared in the same manner but without the addition of DPO-H. The formulas of the EP thermosets were listed in Table 1.

2.4. Characterization

Fourier transform infrared (FTIR) spectra were recorded on Nicolet 380 (Thermo Fisher, United States) with KBr pellets. Spectra in the optical range of 400-4000 cm\(^{-1}\) were obtained by averaging 32 scans at a resolution of 4 cm\(^{-1}\).

\(^1\)H and \(^31\)P NMR spectra were recorded on Bruker Avance III HD spectrometer (500 MHz, Bruker, Germany) and using DMSO-\(d_6\) as solvent.

Thermogravimetric analysis (TGA) was obtained using Mettler Toledo TGA/DSC1 (Mettler-Toledo, Switzerland) with a heating rate of 10 °C/min under nitrogen atmosphere from 100 °C to 700 °C.

Dynamic mechanical analysis (DMA) was performed by using Mettler Toledo DMA1 (Mettler-Toledo, Switzerland). The tan \( \delta \) were determined as the sample was subjected to the temperature scan mode at a programmed heating rate of 10 °C min with a frequency of 1 Hz.
The limited oxygen index (LOI) values were measured on a BG-5207 oxygen index meter (BinGo, China), according to ISO4589-1984 standard and samples were 130 mm × 6.5 mm × 3 mm. Vertical burning test was carried out on BG5210 instrument (BinGo, China) with dimension of 130 mm × 13 mm × 3 mm according to UL94 test standard. Cone calorimeter measurements were performed on an FTT cone calorimeter (UK) according to ISO 5660 under an external heat flux of 50 kW/m² with the samples size of 100 mm × 100 mm × 3 mm.

Thermogravimetric analysis/infrared spectrometry (TGA-FTIR) of the samples was performed using the NETZSCH TG 209 F1 thermogravimetric analyzer that was interfaced to the Bruker Vertex FTIR. About 10 mg samples were put in an alumina crucible and heated from 100 to 600 °C at a heating rate of 10 °C/min.

Pyrolysis-gas chromatography-mass spectrometry (Py-GC/MS) was conducted using PY-3030D/7890B-5977A (Agilent, United States). The sample weighed about 2.0 mg, the injector temperature was 250 °C, and the temperature of GC/MS interface was 280 °C, and the cracker temperature was 500 °C.

A morphological study on char residues was conducted using a Nova Nano SEM450 scanning electron microscope (SEM) (FEI, America) at an acceleration voltage of 10 kV.

3. Results and discussion

3.1. Synthesis and characterization of DPO-H

The chemical structure of DPO-H was characterized by FTIR, ¹H NMR and ³¹P NMR. The results are depicted in Figs. 1-3. Figure 1 shows the FTIR spectrum of DPO-H. The peaks at 1136 cm⁻¹ belonged to the stretching vibration of P=O. The peaks at 1612 cm⁻¹ was ascribed to the vibration absorption of P-Ph. The characteristic peak (P-H) of DPO at 2367 cm⁻¹ disappeared, this indicated that DPO was reacted completely with p-hydroxy benzaldehyde and the desired target products of DPO-H was gained.

The chemical structure of DPO-H was further characterized by NMR. As shown in Fig. 2, the single peak at 9.29 ppm was assigned to proton peaks on the Ph-OH benzene ring. The peaks at 7.83-7.43 ppm were attributed to aromatic hydrogen. The peak at 5.49 ppm was attributed to aliphatic hydrogen. The peaks at 6.57-6.55 ppm were assigned to proton peaks on the Ph-OH benzene ring. The peaks at 6.31-6.25 ppm was attributed to the -OH on the tertiary carbon. As illustrated in Fig. 3, the ³¹P NMR spectrum of DPO-H showed a single peak at 27.51 ppm. In conclusion, DPO-H has been successfully synthesized.
3.2. The images of the epoxy resin thermosets

Figure 4 displays the photographs of epoxy thermosets, it can be seen from these photographs that the epoxy resin modified by DPO-H were almost colourless, while the EP-0 was slightly yellow. In addition, the flame-retardant epoxy resin samples were more transparent than pure epoxy resin. EP-0.7 sample showed the highest transparency, while the transparency of EP-0.9 decreases to some extent. This can be attributed to the incomplete reaction between excessive DPO-H content and epoxy resin. However, the transparency of EP-0.9 sample is still higher than that of EP-0. This suggested that DPO-H can improve the transparency of epoxy resin. Moreover the epoxy resin modified by DPO-H was colourless and can be used in some fields which has special requirements on color and transparency of epoxy resins.

3.3. Thermal stability of flame retardant epoxy resins

Figure 5 presents the TG and DTG curves of the epoxy thermosets under nitrogen atmosphere. The corresponding characteristic data including temperature at 5% weight loss ($T_{5\%}$), temperature at 10% weight loss ($T_{10\%}$), temperature at maximum weight loss rate ($T_{\text{max}}$) and char yields at 600 °C were listed in Table 2.

![Fig. 4. The photographs of the epoxy thermosets. (a)EP-0, (b) EP-0.3, (c) EP-0.5, (d) EP-0.7 and (e) EP-0.9.](image)

| Sample | $T_{5\%}$ (°C) | $T_{10\%}$ (°C) | $T_{\text{max}}$ (°C) | Char yield at 600 °C (wt%) | $T_g$ (°C) |
|--------|----------------|----------------|----------------------|-----------------------------|-----------|
| EP-0   | 392.0          | 400.3          | 423.9                | 20.60                       | 174.2     |
| EP-0.3 | 380.3          | 393.3          | 417.1                | 21.23                       | 160.0     |
| EP-0.5 | 378.3          | 387.3          | 407.9                | 24.76                       | 143.2     |
| EP-0.7 | 367.0          | 383.3          | 407.8                | 25.23                       | 141.6     |
| EP-0.9 | 365.7          | 392.0          | 406.5                | 26.66                       | 131.6     |

![Fig. 5. (a) TG and (b) DTG curves of EP thermosets under nitrogen atmosphere.](image)
As shown in Fig 5, all the epoxy thermosets showed a similar single decomposition process with a shoulder in the mass loss rate after main decomposition. The $T_{5\%}$ of EP-0.3 and EP-0.9 were reduced by 11.7 °C and 26.3 °C respectively. So the $T_{5\%}$ of flame-retardant epoxy resin was slight lower than that of EP-0. This phenomenon was attributed to the earlier decomposition of phosphorus-containing structures which also induced the decomposition of epoxy resin. And this also been observed in other literatures. In addition, the $T_{\text{max}}$ of flame-retardant epoxy resin samples were similar with that of EP-0. Compared with EP-0, $T_{\text{max}}$ of EP-0.3 and EP-0.9 reduced from 423.9 °C (EP-0) to 417.1 °C and 406.5 °C respectively. As the temperature increases, the weight loss rate of the flame-retardant epoxy resin began to slow down. And in the high temperature range (over 430 °C), the weight loss rate of the flame-retardant epoxy resin were lower than that of EP-0. This can be related with the decomposition products of P and N containing in flame retardants under high temperature which could absorb heats and isolate heat exchange. Moreover, char yield at 600 °C of flame-retardant epoxy resin samples were higher than that of EP-0, and the char residue of EP-0.3 and EP-0.9 at 600 °C increased by 3.1% and 29.4%. This indicated that the introduction of DPO-H can promote the formation of char layer.

$T_g$ of the epoxy thermosets were obtained by DMA under air atmosphere, and the temperature at maximum of tan $\delta$ was regard as $T_g$. The DMA curves of the EP thermosets were shown in Fig. 6. As shown in Table 2, $T_g$ of EP-0, EP-0.3 and EP-0.9 samples were 174.2 °C, 160.0 °C and 131.6 °C, respectively. This phenomenon can be attributed to that the large steric effect of DPO units may influence the curing reaction between curing agents and epoxy, which reduces the cross-linking density of epoxy thermosets.

### 3.4. Flame retardancy

The flame-retardant properties of all the thermosets were determined by LOI and UL-94 vertical burning tests. The corresponding results were listed in Table 3. Due to the results, pure epoxy resin belonged to combustible materials, and the LOI value of EP-0 was 25.4%. Compared to the pure epoxy resin, the flame-retardant epoxy resin samples achieved higher LOI value. The LOI value of EP-0.3 can reach 28.5%, which belonged to the nonflammable material. As shown in Table 3, the LOI value increased with the increasing of P content. When the P content was 0.9%, the LOI value of epoxy thermosets increased to 32.1%.

In terms of UL-94 test, the EP-0 sample sustained burning until the whole sample was burned out. Whereas most DPO-H modified epoxy were quenched after the removal of the ignition source. EP-0.3 sample reached the V-1 rate. While the P content increased to 0.5 wt%, EP-0.5 sample was quenched at 6.85 s after removing the ignition source and reached UL-94 V-0 rate. These results manifested that the introduction of DPO-H could efficiently improve the flame retardancy of epoxy thermosets. And with the increasing of P content, the extinguishing time of epoxy thermosets decreased. Meanwhile, all the DPO-H modified epoxy resins had a short extinguishing time after the second ignition. For example, the second extinguishing time of EP-0.7 and EP-0.9 samples were about only 1 s, it could be deemed that them extinguished immediately after the ignition source leaving.

| Sample  | LOI Value (%) | Ul-94 tests results |
|---------|---------------|---------------------|
| EP-0    | 25.4          | -                   | -                   | No rate |
| EP-0.3  | 28.5          | 10.11               | 4.68                | V-1      |
| EP-0.5  | 29.6          | 6.85                | 3.24                | V-0      |
| EP-0.7  | 30.7          | 3.05                | 1.29                | V-0      |
| EP-0.9  | 32.1          | 1.56                | 1.00                | V-0      |

| Sample  | LOI Value (%) | Ul-94 tests results |
|---------|---------------|---------------------|
| EP-0    | 25.4          | -                   | -                   | No rate |
| EP-0.3  | 28.5          | 10.11               | 4.68                | V-1      |
| EP-0.5  | 29.6          | 6.85                | 3.24                | V-0      |
| EP-0.7  | 30.7          | 3.05                | 1.29                | V-0      |
| EP-0.9  | 32.1          | 1.56                | 1.00                | V-0      |

$^{a}$ The after-flame time of the first flame test.  
$^{b}$ The after-flame time of the second flame test.

![Fig. 6. DMA curves of EP thermosets under air atmosphere.](image)

![Fig. 7. Video screenshots of EP-0.3 during UL-94 test.](image)
To visibly observe the flammability characteristics, a digital camera was employed to record the burning behaviors of EP-0.3 during vertical burning test. The video screenshots of EP-0.3 during combustion were presented in Fig. 7. It can be shown that airflows were emitted during the combustion process, and the left side of the sample with gas emission was earlier extinguished than the right side. So these airflows can extinguish the epoxy resin. This interesting phenomenon, reported by Zhang et al., was named blowing-out effect [27]. This phenomenon indicated that DPO-H possesses the flame retardant effect in the gaseous phase.

Cone calorimeter test provided a useful method to study the fire behavior of flame-retarded epoxy materials. The curves of heat release rate (HRR), total heat release (THR) and mass loss rate curve were shown in Fig. 8. The time to ignition (TTI), time of flameout (TOF), peak of heat release rate (pk-HRR), average CO yield (av-CO), average CO$_2$ yield (av-CO$_2$), total smoke produce (TSP), total heat release (THR) and mass loss rate, were summarized in Table 4.

As shown in Table 4, compared with EP-0, the TTI of EP-0.9 was shorter. It can be attributed to the earlier decomposition of DPO-H which was according to the results from TGA [28]. Meanwhile, compared with EP-0, the TOF of EP-0.9 was earlier more than 150 s, and the char residue increased from 1.75% to 10.95%. This result indicated that DPO-H can endow epoxy resin excellent flame-retardancy, and promote the formation of char layer. As illustrated in Figs. 8 (a) and (b), the pk-HRR and THR of EP-0 reached 1028.29 kW/m$^2$ and 62.06 MJ/m$^2$ respectively. However, with the addition of DPO-H, the pk-HRR and THR of EP-0.9 decreased by 58.0% and 20.1%, respectively. This indicated that the presence of DPO-H was favorable to suppress the intensity of heat release during combustion of epoxy resins. As shown in Table 4, the CO of EP-0.9 thermosets increased from 0.026 kg/kg for EP-0 to 0.041 kg/kg and the CO$_2$ of EP-0.9 thermosets was lower than EP-0. This revealed that EP-0.9 likely had incomplete combustion.

![Fig. 8.](image)

**Fig. 8.** (a) Heat release rate curves, (b) total heat release curves, and (c) mass loss rate curves of EP thermosets.

| Sample | TTI (s) | TOF (s) | THR (MJ/m$^2$) | pk-HRR (kW/m$^2$) | av-CO (kg/kg) | av-CO$_2$ (kg/kg) | TSP (m$^2$/kg) | Mass loss (%) |
|--------|--------|---------|----------------|-------------------|--------------|------------------|---------------|--------------|
| EP-0   | 45     | 524     | 62.06          | 1028.29           | 0.026        | 0.132            | 605.037       | 98.25        |
| EP-0.9 | 40     | 374     | 49.62          | 432.19            | 0.041        | 0.086            | 818.872       | 89.05        |
3.5. The mechanism of flame retardant epoxy resins

TG-IR was usually used to analyze the gaseous products during the thermal degradation process. In order to obtain a deeper understanding of the flame retardant effect of DPO-H modified epoxy resins, the TG-IR spectra of EP-0 and EP-0.9 thermosets were detected. Figure 9 shows the Gram-Schmidt (GS) curves of EP-0 and EP-0.9. The GS curves showed the total amount of evolved gases detected by the spectrometer. The GS curves (Fig. 9) showed that the absorbance intensity of the total decomposition products from EP-0.9 were much lower than those from EP-0. The reason can be attributed to the protective char layer on the surface of the sample which could prevent the further combustion and increase the char residue. In addition, EP-0.9 sample began to decompose around 1000 s and reach the first small peak at 1300 s while EP-0 sample began to decompose around 1500 s. This phenomenon was also displayed in the 3D TG-FTIR spectra (Fig. 10).

Figure 11 shows the FTIR spectra of the gas products obtained from the EP-0 and EP-0.9 at different temperature. Although the peak intensity of the EP-0 and EP-0.9 were different, but the peak position were basically same. At 330 °C, EP-0 epoxy resin only appeared the characteristic peak of CO₂ (2352 cm⁻¹) while EP-0.9 showed obvious characteristic peaks such as NH₃ (1175 cm⁻¹), phenol (1255 cm⁻¹), aromatic nucleus (1508 cm⁻¹ and 3040 cm⁻¹) and water (3648 cm⁻¹). But EP-0 appeared these characteristic peaks until 375 °C. Meanwhile, the characteristic peak intensity of EP-0.9 increased gradually at 330-375 °C. As shown in Fig. 11 (b), when the temperature increased to 400 °C, the absorption intensity of EP-0 was higher than EP-0.9.

![Fig. 9. Gram-Schmidt curves of EP-0 and EP-0.9.](image)

![Fig. 10. 3D TG-FTIR spectra for the pyrolysis products obtained for (a) EP-0 and (b) EP-0.9.](image)

![Fig. 11. FTIR spectra of the gas products obtained from the EP-0 and EP-0.9 at different temperature.](image)
Table 5. Pyrolysis products identified in the pyrograms of EP-0 and EP-0.9.

| No. | m/z   | Area % EP-0 | Area % EP-0.9 | Compound | No. | m/z   | Area % EP-0 | Area % EP-0.9 | Compound |
|-----|-------|-------------|---------------|----------|-----|-------|-------------|---------------|----------|
| 1   | 41    | 44.49       | 29.06         | N        | 10  | 118   | 1.14        | 1.53          | OH       |
| 2   | 58    | 21.23       | 18.34         | O        | 11  | 118   | 1.11        | 2.00          |          |
| 3   | 73    | 2.89        | 1.64          |          | 12  | 120   | 0.33        | 0.81          |          |
| 4   | 78    | 3.42        | 15.3          |          | 13  | 122   | 0.34        | 0.29          | 10-10    |
| 5   | 82    | 1.22        | 1.05          |          | 14  | 132   | 1.38        | 1.50          | 10-10    |
| 6   | 92    | 8.16        | 14.65         |          | 15  | 154   | 0.91        | 1.12          | H3-10    |
| 7   | 94    | 8.06        | 7.53          |          | 16  | 156   | 0.77        | 0.38          | H3-10    |
| 8   | 134   | 0.05        | 0.43          |          | 17  | 148   | 0.05        | 0.11          |          |
| 9   | 156   | 0.44        | 2.23          |          | 18  | 158   | 0.1         | 0.06          |          |

Fig. 12. Pyrograms of EP-0 and EP-0.9.

In order to verify the flame retardant mechanism of DPO-H, the Py-GC/MS test was performed. The results are shown in Fig. 12 and Table 5. As shown in Fig. 12, the main peak of EP-0 and EP-0.9 have the similar retention time, in other word, the main pyrolysis products of them were almost same. But the relative areas of the pyrolytic products were different. As shown in Table 5, compared with EP-0 (68.61%), the m/z of pyrolytic products for EP-0.9 less than 70 decreased to 49.04%. This indicated that under the same condition, the pyrolysis degree of EP-0.9 sample was much lower than that of EP-0 sample. In other word, the addition of DPO-H can effectively inhibit the pyrolysis of epoxy and make it produce more macromolecular structures which were easy to extinguish.

Morphological study of the char residues was conducted by visual observation and SEM. The digital and SEM images of the char residues after cone calorimeter test are shown in Figs. 13 and 14. As shown in Fig. 13, the char of EP-0 system showed a small amount of residue with fragmentary structure which was unable to serve as a protective layer. From the top view of the char layer, it was evident that EP-0.9 sample exhibited a more continuous and compact surface compared with that of EP-0 system. From the side views of the char residues, EP-0.9 sample formed an expanded carbon layer. which might be attributed to the synergistic effect of P and N in DPO-H. The char
residues were further investigated by SEM. As shown in Fig. 14, the surface of EP-0 sample had very obvious holes, while the surface of EP-0.9 sample was continuous and closed. During combustion, the compact surface could prevent the transfer of oxygen and heat. According to many studies, this compact and continuous char layer was formed by phosphoric acids, polyphosphoric acids and other decomposition products of P-containing flame retardant. These research results indicated that DPO-H played a role of flame retardant in condensed phase.

4. Conclusion

A kind of phosphorus based reactive flame retardant DPO-H was synthesized and applied in epoxy resins. The addition of DPO-H reduced the $T_g$ and $T_{5\%}$ of modified epoxy resin samples. While it played a role to promoted the char residue, for example, compared with EP-0 the char residue of EP-0.9 sample at 600 °C increased by 29.4%. Moreover, DPO-H can efficiently improve the flame retardancy of epoxy resin. The flame-retardant epoxy resin sample with P content of 0.5 wt% can reach UL-94 V-0 rate. And its LOI value increased to 29.6%, and the cone calorimeter test showed that the introduction of DPO-H can reduce the heat released and the burning time during the combustion. The results of TG-IR, Py-GC/MS and SEM tests showed that DPO-H modified epoxy resin had evident flame-retardant effect both in gas phase and condensation phase.

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