THE THERMAL DECOMPOSITION OF PBO FIBER AND HIGH THERMAL MECHANICAL PROPERTIES OF PBO COMPOSITE MATERIALS

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1 Introduction
Poly (p-phenylene benzobisoxazole) (PBO) fibers are known to have good mechanical properties, excellent thermal stability, chemical resistance and high char yield [1-7]. It is an ideal candidate for conversion to carbon fiber [4]. It is also used in many applications under high temperature, even used in ablative materials [7].

The thermal decomposition information is possible to provide a database of safety condition for use in industry practices. It can also provide the basic parameters to the theoretical models for the ablative composite, such as the model to estimate life time or the thermal responses of these materials and so on [4, 8-12]. Thermo gravimetric analysis (TGA) is a simple experimental to investigate the thermal degradation process. And many methods base on the chemical reaction and Arrhenius laws were developed to calculate the main kinetic parameters, the active energy ($E_a$), the pre-exponential factor ($A$) and the reaction order ($n$), according to the TGA data [8-16]. Based on the form of the equation of the decomposition degree, or the extent of reaction, there are integral methods and difference methods. Moreover, the methods also can be classified into multiple-heating-rate methods and single-heating-rate methods. Expect that there are also methods only calculate the kinetic parameters by some special data, such as the maximum value point and half of the maximum value. Based on these methods, one or several sets of kinetic parameters are gained.

Among these results, the active energy is usually in a certain range, while the pre-exponential factor and the reaction order often differ a lot. A thermogravimetric analyzer /differential scanning calorimeter (TGA/DSC) instrument was used to obtain TGA and derivative thermogravimetric (DTG) curves of the PBO fibers at different heating rates. The thermal stability of the PBO fiber was also discussed. The methods of Kissinger, Ozawa and modified Coats-Redfern were employed to calculate the thermal decomposition kinetic parameters. Then the theoretical curves based on these kinetic parameters were compared to the experimental curves. The differences of the methods and the effect of the reaction order were discussed, and then the appropriate kinetic parameters were obtained to describe the thermal decomposition of the PBO fiber. The mechanical properties of PBO fibers reinforced composites materials were always worth to attention because of the weak interface of PBO fiber and resin matrix, especially the mechanical properties of these composites at high temperature or after heat treatment. The flexural properties and interlaminar shear strength of the PBO fibers composites after high thermal treatment at the characteristic temperature base on the TGA results were also investigated in this paper.

2 Experimental
2.1 Materials and processing
The PBO fibers were supplied by Toyobo Co. Ltd., Japan, which trade name is Zylon® HM. The phenolic resin, B30, was supplied by Institute of Chemistry, the Chinese Academy of Science. A combination of winding and compression molding method was used to prepare the composites specimens. The program for curing the matrix was that: 80°C (7h) + 90°C (1h) + 110°C (1h) +130°C (1h) + 150°C (2h). The pressure of 1MPa and 3MPa was added when the temperature was up to 90°C and 130°C, respectively.

2.2 Thermo gravimetric analysis
The thermo gravimetric analysis (TGA) of the fibers was performed with a Mettler TGA/DSC 1 instrument. The experiment was run from 25°C to 1000°C. Four heating rates, 10, 20, 50, 100°C min$^{-1}$, in nitrogen atmosphere and one heating rate of 10°C /min$^{-1}$ in air atmosphere were used for study. The char yield at 1000°C and the temperature corresponding to the mass loss about 2%, $T_{0.02}$ were
2.3 X-ray diffraction

The residues of PBO fibers after the TGA test were determined by X-ray diffraction (XRD) using a Bruker D8 Advance diffractometer equipped with Cu Kα (λ=0.15406 nm) radiation, working in a classical coupled θ-2θ mode. The scanning step is 0.02°.

2.4 Mechanical properties

A three-point bending test and a short beam bending test were used to study the flexural properties and the interlaminar shear strength (ILSS) of the PBO fibers reinforced phenolic resin composites. The specimens were classified into 4 groups. The first one without any treatment was tested. And the other three groups were heated at 550°C, 700°C and 800°C for 5 minutes before testing at room temperature, respectively.

3 Results and Discussion

3.1 Thermo gravimetric analysis

PBO fiber is one of the best high-temperature resistant organic fibers. Fig.1 (a) showed the TGA curves of PBO fibers under nitrogen and air atmosphere at the heating rate of 10 K min⁻¹, respectively. It can be see clearly that the PBO fibers began to degrade above 850 K in air and 900 K in nitrogen. TGA curves of PBO fibers at the other three heating rates under nitrogen atmosphere were likely the curve at 10 K min⁻¹. The temperatures corresponding to the mass loss about 2%, T₀.02, were 823 K and 810 K under air and nitrogen atmosphere at the heating rate of 10 K min⁻¹. And T₀.02 for the other three heating rates were 943, 945 and 950 K respectively. There was almost nothing left in the air atmosphere. While in the nitrogen atmosphere the char yield more than 60% up to 1273K, there were 61.6%, 64.3%, 64.7% and 65.3% at the heating rates of 10, 20, 50 and 100 K min⁻¹, respectively.

Fig.1 (b) showed the DTG curves of the PBO fibers. The DTG curves also had little variation and nearly as horizontal lines until about 920K, which temperature was regarded as the onset of the thermal decomposition process, Tᵢ. After the temperature of 920K, the mass of PBO fibers decreased dramatically and the fastest mass loss rate took place at 999 K, 1013 K, 1029 K and 1042 K at the heating rate of 10, 20, 50, 100 K min⁻¹, respectively, and the corresponding temperature, Tᵢ, were summarized in Table.1. After the temperature, Tᵢ, 1040 K, 1066 K, 1141 K and 1210 K for the four heating rates, the change of the DTG curves became horizontal again. The char yield and the temperature T₀.02, Tᵢ, Tᵢ and Tₑ were all summarized into Table.1, for these values characterize the PBO fibers. Because the DTG curves have only one clearly peak, the thermal decomposition process of the PBO fibers can be thought as one stage reaction.

![Fig. 1](image)

**Table.1 Characteristic values for the PBO fibers based on the TGA and DTG curves.**

<table>
<thead>
<tr>
<th>Heating rate (K min⁻¹)</th>
<th>T₀.02</th>
<th>Tᵢ</th>
<th>Tᵢ</th>
<th>Tₑ</th>
<th>Char yield at 1273 K(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10(Air)</td>
<td>823</td>
<td>867</td>
<td>966</td>
<td>1057</td>
<td>1.6</td>
</tr>
<tr>
<td>10(N₂)</td>
<td>810</td>
<td>920</td>
<td>999</td>
<td>1040</td>
<td>61.6</td>
</tr>
<tr>
<td>20(N₂)</td>
<td>943</td>
<td>920</td>
<td>1013</td>
<td>1066</td>
<td>64.3</td>
</tr>
<tr>
<td>50(N₂)</td>
<td>945</td>
<td>920</td>
<td>1029</td>
<td>1141</td>
<td>64.7</td>
</tr>
<tr>
<td>100(N₂)</td>
<td>950</td>
<td>920</td>
<td>1042</td>
<td>1210</td>
<td>65.3</td>
</tr>
</tbody>
</table>
The Fig.2 showed the XRD patterns of residues of PBO fibers. According to the former investigations [17], the broader peak reflected the existence of turbostratic structure.

![XRD pattern](image)

Fig. 2. XRD patterns of PBO fibers after TGA test.

3.2 Methods to calculate the kinetic parameters of the decomposition

The decomposition process can be described by the theory of chemical reaction rate and Arrhenius law. Based on this theory and on the one-stage chemical reaction assumption, the thermal decomposition process can be described by the integral equation of the degree of decomposition, \( \alpha \), as follow:

\[
\frac{d\alpha}{dT} = \frac{A}{\beta} \exp\left(-\frac{E_A}{RT}\right)(1-\alpha)^n \tag{1}
\]

\[
g(\alpha) = \int_{0}^{\alpha} \frac{d\alpha}{(1-\alpha)^n} = \frac{A}{\beta} \int_{0}^{\alpha} \exp\left(-\frac{E_A}{RT}\right) dT
\]

\[
= \frac{AE_A}{\beta R} \int_{0}^{\alpha} \frac{-e^{-x}}{x^{n}} dx = \frac{AE_A}{\beta R} P(x) \tag{2}
\]

Where, \( \alpha \) is the degree of decomposition, \( \alpha=(M_f-M)/(M_f-M_0) \), \( M_f \), \( M \) and \( M_0 \) are the initial mass, the mass at the reaction time \( t \) and the final mass after decomposition. \( E_A \) is the activation energy, \( A \) is the pre-exponential factor, \( n \) is the reaction order, \( \beta \) is the heating rate, \( T \) is the temperature, and \( R \) is the universal gas constant.

\[
\int_{0}^{\alpha} 1/(1-\alpha)^n d\alpha \text{ is the integrated function of the decomposition degree, } \int_{0}^{\alpha} \exp(-E_A/RT) dT \text{ is the integrated function of temperature and this part cannot be solved analytically. } P(x) (x = E_A /RT) \text{ is the approximination function to solve the temperature part by using TGA and DTG data. The kinetic parameters are somewhat different from each other by using different } P(x). \text{ Kissinger method [7, 9] was developed by Eq. (1) and Ozawa method and Coats-Redfern method were developed by Eq. (2).}

3.2.1 Kissinger method

The derivative of \( T \) of Eq. (1) gives:

\[
\frac{d^2\alpha}{dT^2} = \frac{AE_A}{\beta RT^2} \exp\left(-\frac{E_A}{RT}\right) \cdot (1-\alpha)^n \cdot \frac{A}{\beta} \exp\left(-\frac{E_A}{RT}\right) \cdot n(1-\alpha)^{n-1} \frac{d\alpha}{dT} \tag{3}
\]

When the maximum reaction rate occurs at temperature, \( T_p \), the Eq. (3) is equal to zero. The subscript \( p \) means the value at the point of the peak in the curve of \( d\alpha/dT \). That is, when \( T=T_p, \frac{d^2\alpha}{dT^2} =0 \), then Eq. (4) is obtained:

\[
\frac{E_A\beta}{RT_p^2} = An(1-\alpha_p)^{n-1} \exp\left(-\frac{E_A}{RT_p}\right) \tag{4}
\]

In the Kissinger method, it assumes that the product \( n(1-\alpha_p)^{n-1} \) is independent of \( \beta \). According to Eq. (4), the activation energy, \( E_A \), can be determined by plotting \( \ln(\beta/\alpha d\alpha/dT) \) against \( 1/T_p \), as shown in Fig.3. When the reaction order, \( n \) is assumed as 1, the pre-exponential factor \( A \) can be calculated from the intercept of the line \( \ln(\beta/\alpha d\alpha/dT) \) against \( 1/T_p \). If \( n \neq 1 \), it can be calculated by Eq. (5). Then \( A \) can be determined by substituting \( n \) and \( E_A \) into Eq. (4).

\[
-n(1-\alpha_p)^{n-1} = 1 + (n-1) \frac{RT}{E_A} \tag{5}
\]

The results were listed in Table.2. In Kissinger method, only one group of kinetic parameters was obtained and \( E_A \) was 448kJ/mol. The reaction order \( n \) was assumed as 1, because a negative value was gained by Eq. (5).

![Graph](image)

Fig. 3 Determination of EA from Kissinger method (experimental data and fitted straight line).

3.2.2 Ozawa method

The Ozawa method [7-9,14] essentially assumes that \( A, (1-\alpha) \) and \( E_A \) are independent of \( T \), whereas \( A \) and \( E_A \) are independent of \( \alpha \). Using Doyle’s approximation Eq. (6) for \( P(x) \) at 20<x <60, that is 20<E_A /RT<60.

\[
P(x) = 0.0048e^{-1.0516x} \tag{6}
\]

By substituting Eq. (6) into Eq. (2) and taking the logarithm of each side of the equation, \( EA \) and \( A \) can be calculated by the Eq. (7):
\[ E_A = -\frac{R}{0.4567} \frac{d \log \beta}{d(1/T)} \quad (7.1) \]
\[ \log A = \log \beta + \log E_A + \frac{0.434E_A}{RT} - 2 \log T \quad (7.2) \]

As shown in Fig.4, the activation energy \( E_A \) in a special \( \alpha \) was calculated by the slope of the line \( \log \beta \) against \( 1/T \). When \( n \neq 1 \), by substituting Eq. (8) into Eq. (9), \( n \) can be calculated, where the y-intercept of the line \( \log \beta \) versus \( 1/T \).

\[ g(\alpha) \approx \frac{1-(1-\alpha)^{1-n}}{1-n} \quad (8) \]
\[ \log g(\alpha) = \log(AE_A/R) - \log \beta^* - 2.315 \quad (9) \]

In this paper, the values of pre-exponential factor \( A \) and the reaction order \( n \) were calculated by the data at the heating rate of 100K/min. And for each \( \alpha \) from 0.2 to 0.6, \( n \) has two values. One is 1 for all \( \alpha \), and the other value decreased and closed to 1 with \( \alpha \) increased. All the results were summarized in Table.2.

3.2.3 Modified Coats-Redfern method

In the modified Coats-Redfern method [7], Using Coats-Redfern’s approximation Eq. (10) for \( P(x) \),

\[ P(x) = \frac{1}{x^2} \left(1 - \frac{2}{x} \right) e^{-x} \quad (10) \]

And the \( g(\alpha) \) can be expanded to Eq. (11).

\[ g(\alpha) = \int_0^\alpha \frac{d\alpha}{(1-\alpha)^n} = \alpha + \frac{n\alpha^2}{2} + n(n+1)\frac{\alpha^3}{6} + \ldots \quad (11) \]

In the case of low value of \( \alpha \), terms of \( \alpha^2 \) and higher can be neglected giving

\[ \alpha \approx \frac{ART^2}{\beta E_A} (1 - \frac{2RT}{E_A}) \exp(\frac{-E_A}{RT}) \quad (12) \]

By logarithm transform, Eq. (13) results in

\[ \ln(\frac{\alpha}{T^2}) = \ln(\frac{AR}{\beta E_A}) + \ln(1 - \frac{2RT}{E_A}) - \frac{E_A}{RT} \quad (13) \]

Thus a plot of \( \ln(\alpha/T^2) \) versus \( 1/T \) should give a straight line with a slope of \( -E_A/R \) since \( \ln(AR/\beta E_A) + \ln(1 - 2RT/E_A) \) is nearly constant [7], as shown in Fig.5. Substituting \( E_A \) into Eq. (13) the value of \( A \) is obtained. But the value of \( n \) cannot be directly calculated based on this method. Eq. (4) can be used to get the value of \( n \). The results were also summarized into Table.2.

Fig.5 Determination of \( E_A \) from Coats-Redfern method (experimental data and fitted straight lines at different heating rates).

Table.2 Kinetic parameters by Ozawa, and Coats-Redfern methods.

<table>
<thead>
<tr>
<th>Method</th>
<th>( E_A ) (kJ mol(^{-1}))</th>
<th>( A ) (min(^{-1}))</th>
<th>( n )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kissinger</td>
<td>448</td>
<td>1.41E23</td>
<td>1</td>
</tr>
<tr>
<td>Ozawa(^1)</td>
<td>( \alpha=0.2 )</td>
<td>394</td>
<td>9.94E20 12.5,1</td>
</tr>
<tr>
<td></td>
<td>( \alpha=0.3 )</td>
<td>432</td>
<td>5.85E22 5.9,1</td>
</tr>
<tr>
<td></td>
<td>( \alpha=0.4 )</td>
<td>389</td>
<td>1.67E20 3.3,1</td>
</tr>
<tr>
<td></td>
<td>( \alpha=0.5 )</td>
<td>410</td>
<td>1.62E21 1.9,1</td>
</tr>
<tr>
<td></td>
<td>( \alpha=0.6 )</td>
<td>383</td>
<td>4.31E19 1.1,1</td>
</tr>
<tr>
<td></td>
<td>( \alpha=0.7 )</td>
<td>361</td>
<td>2.21E18 1</td>
</tr>
<tr>
<td></td>
<td>( \alpha=0.8 )</td>
<td>401</td>
<td>1.30E20 1</td>
</tr>
<tr>
<td>Coats-Redfern(^2)</td>
<td>( \beta=10K ) min(^{-1})</td>
<td>242</td>
<td>1.26E12 1</td>
</tr>
<tr>
<td></td>
<td>( \beta=20K ) min(^{-1})</td>
<td>293</td>
<td>5.45E14 1</td>
</tr>
<tr>
<td></td>
<td>( \beta=50K ) min(^{-1})</td>
<td>253</td>
<td>6.35E12 1</td>
</tr>
<tr>
<td></td>
<td>( \beta=100K ) min(^{-1})</td>
<td>227</td>
<td>3.35E11 1</td>
</tr>
</tbody>
</table>

1: \( A \) and \( n \) was calculated based on the experimental data at the heating rate of 100K min\(^{-1}\).
2: \( n \) was calculated by Eq. (4).

3.2.4 Comparison of methods

All the kinetic parameters of the PBO fibers calculated by the three methods were summarized in
Table 2. The Kissinger method analysis considers only the points of maximum rate of the decomposition degree, so only one set kinetic parameters was gained for all decomposition degrees and heating rates. For Ozawa methods, there was one set of kinetic parameters obtained at different decomposition degrees by assuming that the kinetic parameters do not depend on the heating rate. Also for the modified Coats-Redfern method one set of kinetic parameters was obtained for a specified heating rate by assuming that the kinetic parameters do not depend on the decomposition degree. Since the kinetic parameters can be obtained at different decomposition degrees in Friedman and Ozawa method, the range $\alpha$ from 0.2 to 0.8 was considered, for the difference was obvious in this range, as showed in Fig.4.

As shown the in Table 2, the values of kinetic parameters, $E_A$, $A$ and $n$ are 448 kJ mol$^{-1}$, 1.41E23min$^{-1}$ and 1, respectively based on the Kissinger method, and the activation energy a little higher than the other method. The activation energy, $E_A$, from Ozawa method was in the range of 361-432kJ mol$^{-1}$, the pre-exponential factor, $A$, varied from $10^{16}$ to $10^{22}$. There were two value for the reaction order, $n$, when the decomposition degree at the range of 0.2 to 0.6: one serial decreased from 12.5 to 1.1 with the decomposition degree increased, which similar variance was found in the estimation of thermal decomposition kinetic parameters by Yu [7] and the other value is 1 for all the decomposition degree. For the modified Coats-Redfern methods, the activation energies were 242, 293, 253 and 227 kJ mol$^{-1}$ for the different heating rates at 10, 10, 20, 50 and 100K/min, respectively, which a little lower than the other method. The corresponding pre-exponential factor was in the range of $10^1$-$10^4$, while the reaction order was same and the value was 1.

Four sets of the kinetic parameters of Kissinger method, Ozawa method at $\alpha=0.4$ and modified Coats-Redfern method at the heating rate of 100 K min$^{-1}$ and were selected to obtain the theoretical curves based on Eq. (1) at the heating rate of 100 K min$^{-1}$. Then the theoretical curves were compared with the experimental data, as shown in Fig.6. Although the kinetic parameters differed significantly in these methods, all calculated curves showed tendencies similar to the experimental curve, especially at the range of 950-1100K, in which the PBO fibers have dramatically mass loss and the main reaction was carbonization of the PBO fiber [1-3]. The activation energy of this carbonization process was $319 \pm 25$ kJ mol$^{-1}$ $(76 \pm 6$ kcal mol$^{-1}$) calculated by different isothermal curves by Newell [3]. Although the activation energy in some sets of the result a little higher than that gained by Newell, all the results can be thought at the same level.

3.2.5 Effect of the reaction order on the fitting

The results of Ozawa method, which had two values of $n$ at same value of $E_A$ and $A$ were used to simulate the experimental data, as Fig.7 shown. Fig.7 (a) shows the theoretical curves based on results of the different decomposition degree, when $n=1$, while Fig.7 (b) shows the theoretical curves based on results of the different decomposition degree, when another value of $n$ was selected. Compared with the experiment curves, it is obvious that when $n=1$, the simulated curves increase fast to the decomposition degree 1 after the decomposition degree to 0.8, but in fact, after that degree, the decomposition degree various slowly. That is, the thermal decomposition process described by the calculated data is faster than that of actual situation. As Fig.7 (b) shown, the difference between the theoretical and experimental curves became more obviously as $n$ increased. And Fig.9 also shows that in the certain range of $E_A$, the value of $n$ affected a lot. Furthermore, the reaction order is also in a certain range or value for a special reaction, and it is not a random value without physical meaning.
In order to calculate a more appropriate value of the reaction order, the following procedure was adopted. From the Fig. 7, the range of \( n \) was primary gained (at the range of 1.9-3.0), then at every 0.1 interval, a value of \( n \) was chosen to calculate a theoretical curve at a certain \( \alpha \) (\( \alpha=0.4 \)). A set of unbiased estimator of these theoretical curves compared with the experimental data was gain. The value of \( n \) was confirmed based on the minimal unbiased estimator. As shown in Fig.8, the reaction order for the decomposition process of PBO fibers was 2.1. And Fig.8 (b) showed the unbiased estimator of all the simulated data based on Ozawa method.

Five sets of kinetic parameters were gained whose the unbiased estimators were smaller relatively. And the kinetic parameters at decomposition degree \( \alpha=0.5 \) corresponded to the minimal unbiased estimator, at which the active energy, \( E_A \), is 410 kJ mol\(^{-1}\), the reaction order, \( n \), is 2.1 and the pre-exponential, \( A \), is 1.62E21. After renew the value of \( n \) (\( n=2.1 \)), Kissinger method fitted the experimental data better, however for the Coats-Redfern method, the new value of \( n \) leaded to a worse fitting.

The two best sets of kinetic parameters (\( E_A=410 \) kJ/mol, \( A=1.62E21 \), \( n=2.1 \) based on Ozawa method, and \( E_A=448 \) kJ/mol, \( A=1.41E23 \), \( n=2.1 \) based on Kissinger method) were used to calculate the theoretical curves for the other three heating rates. The results are shown in the Fig.9.
3.3 Mechanical properties

Both the flexural strength, module and ILSS of PBO fibers composites at room temperature and after high thermal treatment were listed in Table 2. For the bad interface adhesive, the ILSS was only about 23MPa. After heating at 550°C for 5 minutes, the flexural strength, flexural module and ILSS of the PBO composites dropped by 37%, 14% and 46%, respectively. Because the high thermal stability of the fibers the flexural module decreased not so much, while at 550°C the resin matrix pyrolysed mostly which led to the interface broken and then the ILSS dropped dramatically. After 700°C thermal treatment for 5min, the flexural strength, flexural module and ILSS of the PBO composites dropped by 80%, 48% and 80%, respectively. And after 800°C thermal treatment for 5min, the composites completely broke up. According to the S. Bourbigot et al research [3], amounts of CO, CO₂ and H₂O gases were detected as major products after 19min at 600°C and at 800°C, beside CO, CO₂ and H₂O were detected as major production and nitric oxides NOx were also detected as minor products in gas phase. So the decomposition of PBO fibers at 700°C and 800°C resulted to the mechanical properties decreased.

Table 3 Mechanical properties of PBO/B30 composite materials

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Flexural strength (MPa)</th>
<th>Flexural module (GPa)</th>
<th>ILSS(MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25°C</td>
<td>421±6.5%</td>
<td>62±7.5%</td>
<td>23±3.6%</td>
</tr>
<tr>
<td>550°C</td>
<td>266±14.8%</td>
<td>53±15.2%</td>
<td>13±7.0%</td>
</tr>
<tr>
<td>700°C</td>
<td>86±16.7%</td>
<td>32±10.3%</td>
<td>5±11.3%</td>
</tr>
<tr>
<td>800°C</td>
<td>≈2</td>
<td>-</td>
<td>≤1</td>
</tr>
</tbody>
</table>

Fig.10 and Fig.11 gave the load vs. displacement of the three point bending test and short beam bending test at different treatment, respectively. The curves showed typical characters of the composite materials. When the specimen was broken at the max load, there were some stable load-displacement steps to drop instead of dramatic broken. And both the original and thermal treatment specimens had the quality.

Fig.10 The load vs displacement curves of the composites specimens under bending.

Fig.11 The load vs displacement curves of the composites specimens under short beam bending.

4 Conclusions

The initial and the fastest mass loss temperature of PBO fiber were nearly 600°C and 700°C in air atmosphere, and nearly 650°C and 750°C in nitrogen atmosphere, respectively. The two best sets of kinetic parameters (Eₐ=410 kJ/mol, Aₐ=1.62E21, n=2.1 based on Ozawa method, and Eₐ=448 kJ/mol, Aₐ=1.41E23, n=2.1 based on Kissinger method) were gained.

The flexural strength, flexural module and ILSS of PBO reinforced phenolic resin composite materials were 421MPa, 62GPa and 23MPa at room temperature, respectively. After heating at 550°C for 5 minutes, the values were 265MPa, 52GPa and
13MPa, respectively. After heating 700°C and 800°C for 5 minutes, the mechanical properties decreased dramatically.

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References