

Supplementary material

A new strategy to improve the toughness of epoxy thermosets—by introducing poly(phthalazinone ether nitrile ketone)s containing phthalazinone structure

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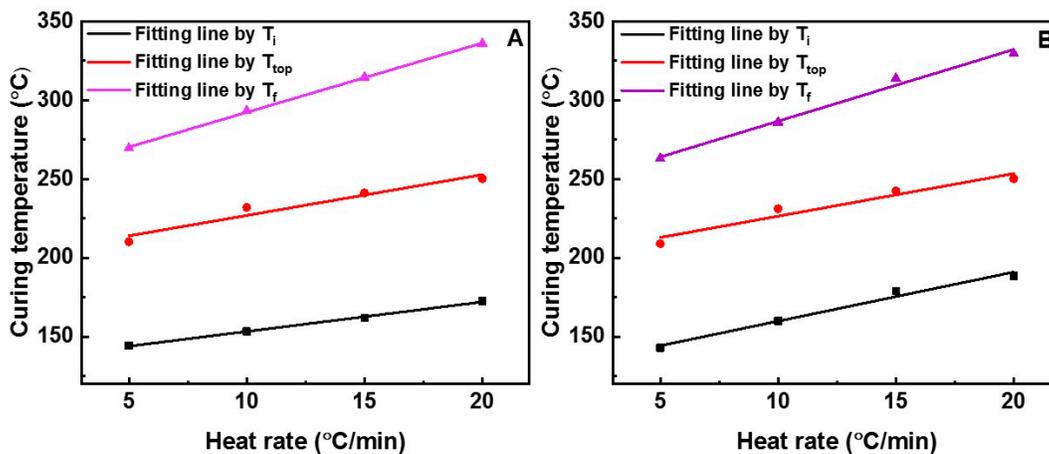


Figure S1 Curves of PPENK/E51 blends curing exothermic peak temperature and heating rate: A E51, B 10 phr-PPENK/E51.

Table S1 Curing exothermic peak temperature of E51 at different heating rates.

Heat rate (°C/min)	T_i (°C)	T_{top} (°C)	T_f (°C)
5	144	210	270
10	153	232	293
15	162	241	315
20	173	250	336

Table S2 Curing exothermic peak temperature of PPENK/E51 at different heating rates.

Heat rate (°C/min)	T_i (°C)	T_{top} (°C)	T_f (°C)
5	143	209	263
10	160	231	286
15	179	242	314
20	189	250	330

Table S3 The crosslinking density of different blend systems.

Blend systems	T_g (°C)	E_r (MPa)	crosslinking density(mol/m ³)
E51/DDS	166	32.7	2.80×10^3
3%-PPENK/E51/DDS	186	30.6	2.51×10^3
5%-PPENK/E51/DDS	188	27.6	2.21×10^3
10%-PPENK/E51/DDS	206	23.61	1.86×10^3
15%-PPENK/E51/DDS	201	11.8	0.94×10^3
20%-PPENK/E51/DDS	198	8.8	0.89×10^3

Calculation of crosslinking density of blends

The crosslinking density of E51 and 10%-PPENK/E51 were calculated jointly by theoretical formula of rubber elasticity:

$$E_r = 3\Phi RT$$

where E_r is the storage modulus (MPa), Φ is the crosslinking density(mol/m³), R is the gas constant (8.314 J/mol·K), $T = T_g + 30^\circ\text{C}$.

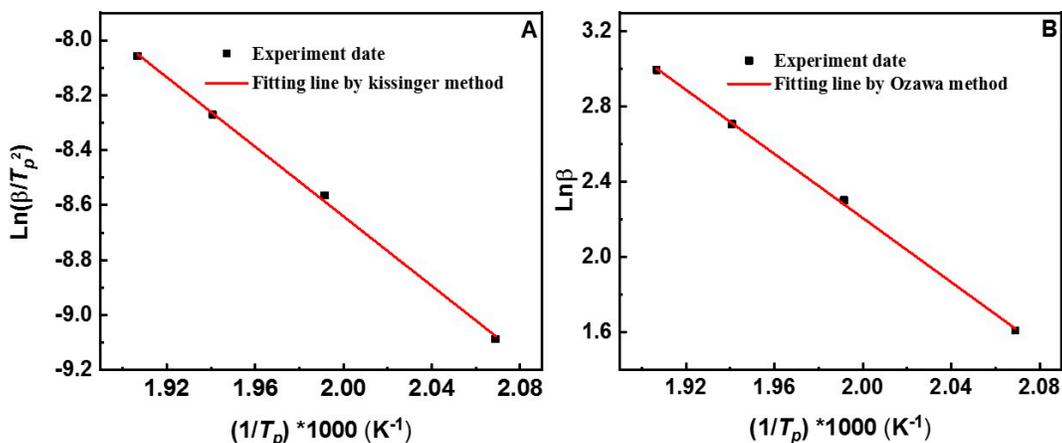


Figure S2 Fitting line of E51/DDS: A Kissinger method, B Ozawa method

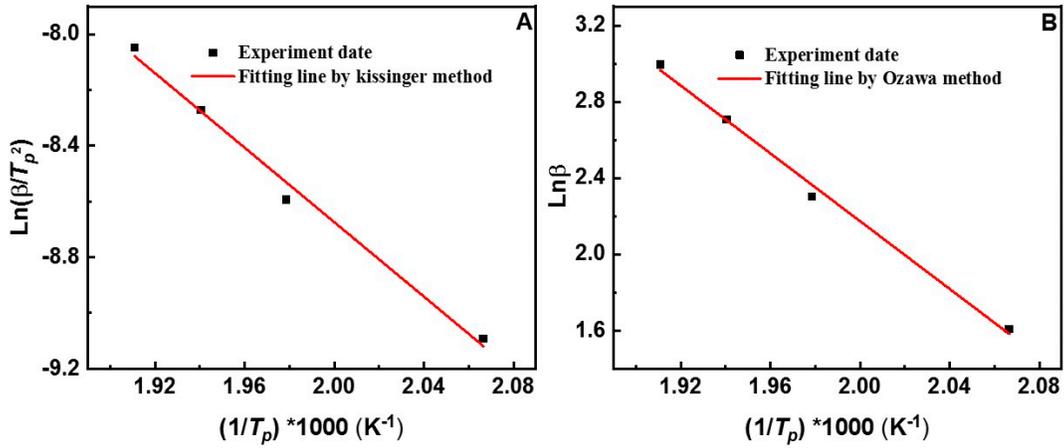


Figure S3 Fitting line of 10%-PPENK/ E51/DDS: A Kissinger method, B Ozawa method

Calculation of activation energy of blends

The apparent reaction activation energy of E51 and 10%-PPENK/E51 were calculated jointly by Kissinger method and Ozawa method, Kissinger equation is as follows:

$$\frac{d \ln(\beta/T_p^2)}{d(1/T_p)} = -\frac{\Delta E_a}{R} + \ln\left(\frac{AR}{E_a}\right) \quad (S1)$$

where β is the heating rate (K/min), T_p is the peak top temperature on the DSC curves (K), R is the gas constant (8.314 J/mol·K), and E_a is the reaction activation energy (KJ/mol).

Ozawa equation is as follows:

$$\frac{d \ln \beta}{d(1/T_p)} = -1.052 \frac{\Delta E_a}{R} \quad (S2)$$

where β is the heating rate (K/min), T_p is the peak top temperature on the DSC curves (K), R is the gas constant (8.314 J/mol·K), and E_a is the reaction activation energy (KJ/mol).

As shown in Figure S2-S3, the linear fitting is carried out by $\ln(\beta/T_p^2) - (1/T_p) \times 10^3$ and $\ln(\beta) - (1/T_p) \times 10^3$ data, respectively. The average activation energy was calculated based on slopes of the straight lines, as shown in table 1.

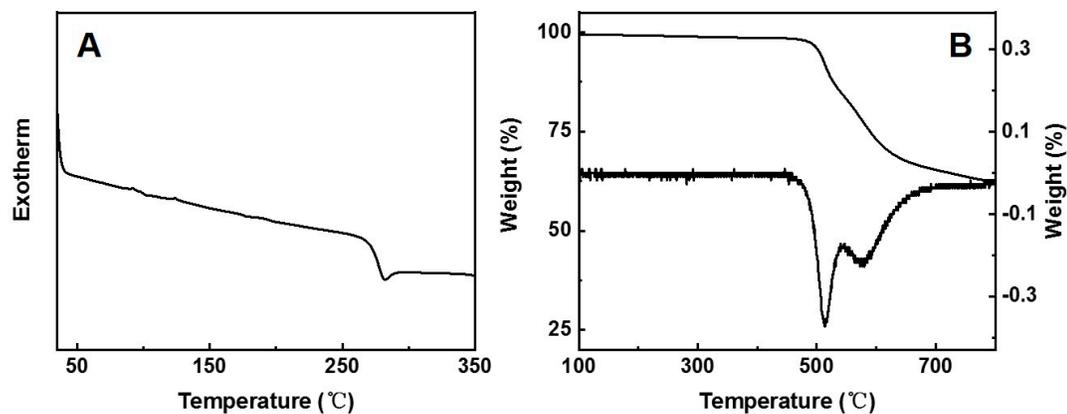


Figure S4 A DSC curves and B TGA curves of PPENK.

Table S4 DSC data and TGA data of PPENK

Polymer	T_g (°C)	$T_{d5\%}$ (°C)	T_{dmax} (°C)	Char yield (%)
PPENK	276	505	515	62

Table S5 The mechanical properties of blends at room temperature and ultra-low temperature

Blend systems	Impact strength (kJ/m ²)		Flexural strength (MPa)		Tensile strength (MPa)	
	RT	ULT	RT	ULT	RT	ULT
0%	16.0 ± 2.3	11.6 ± 1.4	121 ± 2	157 ± 9	70 ± 5	86 ± 5
3%	22.4 ± 2.8	21.2 ± 3.5	127 ± 1	171 ± 6	75 ± 6	---
5%	29.9 ± 2.4	26.5 ± 3.1	133 ± 2	174 ± 3	75 ± 4	---
10%	37.0 ± 1.0	27.8 ± 4.1	133 ± 3	202 ± 6	80 ± 5	110 ± 5
15%	30.3 ± 2.0	23.6 ± 0.6	132 ± 3	230 ± 3	74 ± 6	---
20%	22.5 ± 1.5	20.1 ± 1.7	125 ± 2	204 ± 11	65 ± 3	---

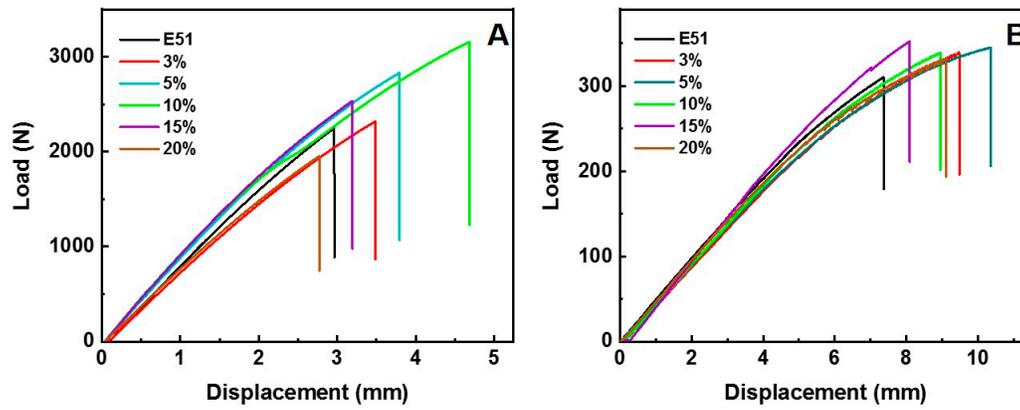


Figure S5 **A** Typical tensile load–displacement curves, **B** Typical flexural load–displacement curves.



Figure S6 Curing molds for PPENK/E51 blends