SI

1. Volume resistivity of DETA/EP and DETA-Si /EP

Table 1. Volume resistivity of DETA/EP and DETA-Si /EP

sample	Volume resistivity
DETA/EP	>35.3×10^{13}
DETA-Si/EP	>35.3×10^{13}

2. Solubility Analysis of NBO_n Series

Table 2 Solubility test of epoxy curing agent NBO_n in different solvents

Solvent	Room temperature	Heating (60℃)
water	insoluble	insoluble
DMSO	soluble	dissolve
THF	soluble	dissolve
dichloromethane	soluble	dissolve
acetone	Lightly soluble	thermosol
acetonitrile	insoluble	thermosol
carbinol	insoluble	thermosol
Ethyl alcohol	insoluble	thermosol
Isopropyl alcohol	insoluble	thermosol
toluene	insoluble	thermosol
Ethyl ether	insoluble	Lightly soluble
cyclohexane	insoluble	insoluble
Petroleum ether	insoluble	insoluble

As shown in **Table 1**, the solubility test results for different solvents indicate that the series of epoxy resin curing agents NBO_n with varying flexible chain lengths, exhibit excellent solubility in strongly polar solvents such as acetone, tetrahydrofuran (THF), and dimethyl sulfoxide (DMSO). This favorable solubility profile suggests promising application potential for these materials. In contrast, NBO_n demonstrates thermal solubility in weakly polar solvents, followed by crystallization at room temperature. This property was utilized to purify NBO_n using ethanol. Notably, NBO_n is insoluble in non-polar solvents such as cyclohexane and petroleum ether, a characteristic that can be exploited for separation processes in practical applications. These distinct solubility behaviors highlight the versatility and potential utility of these materials in various industrial contexts

3. **Volume Resistivity of EP/NBO_n Composites**

Table 3 Volume resistivity test of EP/NBO_n

Sample	**Volume resistivity (Ω.m)**
EP/NBO_4	>$35.3*10^{13}$
EP/NBO_6	>$35.3*10^{13}$
EP/NBO_8	>$35.3*10^{13}$
EP/NBO_{10}	>$35.3*10^{13}$

As shown in **Table 3**, all EP/NBOnOBN composites exhibit volume resistivities exceeding 35.3×10^{13} **Ω·m**, indicating excellent electrical insulation properties. This makes them suitable for use in electronic devices where high insulation performance is required.

4. WLF equation

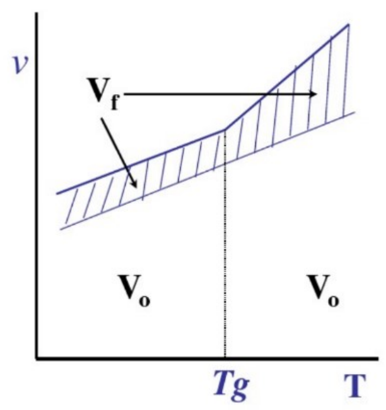

Fig. 1 Diagram of free volume

According to He [16], the glass transition temperature (Tg) can be analyzed using the Williams-Landel-Ferry (WLF) equation:

$$lga_T = \frac{-17.44(T - Tg)}{51.6 + T - Tg}$$

Additionally, the WLF equation derived from the concept of equal free volume is expressed as:

$$lga_T = -\frac{B}{2.303}\left[\frac{T - Tg}{(f_g/\alpha_f) + T - Tg}\right]$$

The glass transition temperature, measured by differential scanning calorimetry (DSC), reveals that a decrease in Tg corresponds to an increase in free volume. This relationship explains the enhanced low-temperature resistance of the materials, as the increased free volume facilitates molecular mobility and flexibility under low-temperature conditions.

5.^{13}C NMR of NBO_n

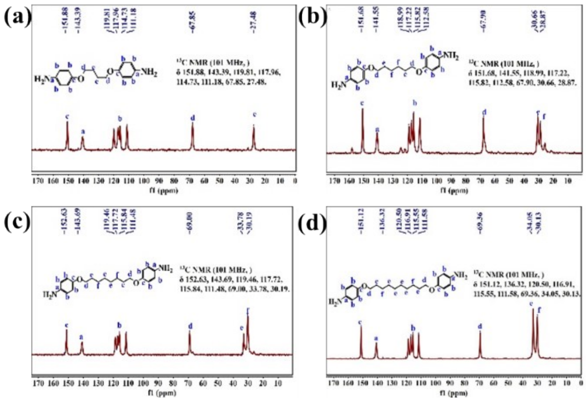

Fig. 2 (a) ^{13}C NMR of $NBO_{4,}$ (b) ^{13}C NMR of $NBO_{6,}$ (c) ^{13}C NMR of $NBO_{8,}$ (d) ^{13}C NMR of $NBO_{10,}$

The carbon peak of oxymethylene is around f_1=68ppm, and the carbon peak of methylene is between f_1=28 ppm and 34 ppm. The carbon peak on the benzene ring is when f_1=110-120 ppm. At f_1=152 ppm, it is the carbon peak at the oxygen link of the benzene ring. The carbon peak at f_1=143 ppm is at the benzene ring where the primary amine is linked. Moreover, it can be seen from f_1=28-34 ppm that as the chain length of the flexible chains contained in a series of epoxy curing agents increases, the electron-withdrawing ability of the electron-withdrawing groups enhances, and the chemical shift of the carbon peak of the methylene group gradually increases.

6. The stretching curve of NBO_n

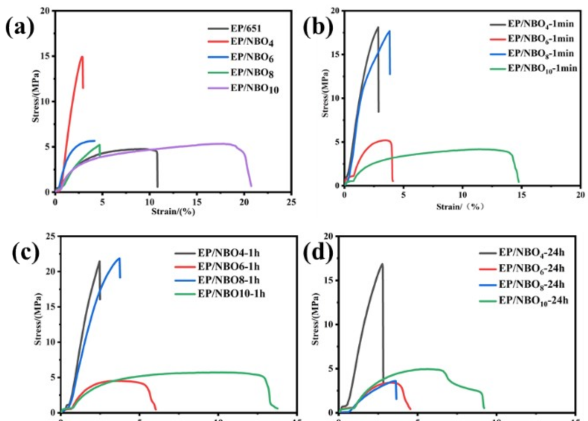

Fig. 3 (a)Tensile test of EP/651 and EP/NBO_n at room temperature, (b)Tensile test of EP/NBO_n after soaking in liquid nitrogen for 1min, (c)Tensile test of EP/NBO_n after soaking in liquid nitrogen for 1h, (d)Tensile test of EP/NBO_n after soaking in liquid nitrogen for 24h.

7. Performance comparison of NBO_n

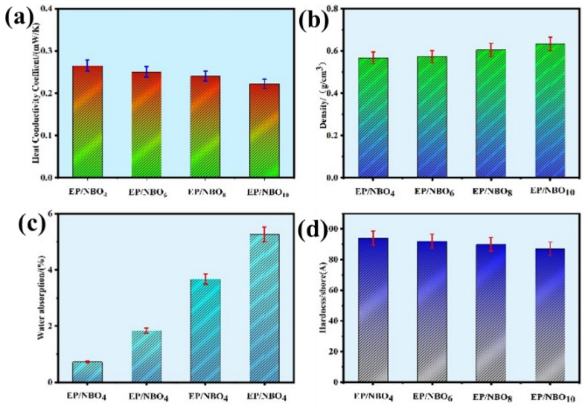

Fig. 4 (a)Thermal conductivity of EP/NBO_n,(b)Density of EP/NBO_n,(c)Water absorption of EP/NBO_n,(d)Hardness of EP/NBO_n.

8. The modulus and rate of immersion in liquid nitrogen for different durations

Table 4 The modulus and rate of immersion in liquid nitrogen for different durations

Modulus（KJ /m^3）	**EP/NBO_4**	**EP/NBO_6**	**EP/NBO_8**	**EP/NBO_{10}**	**EP/651**
0	207.726	168.2355	134.4784	867.7201	403.7785
1min	295.9771	145.7678	102.7496	483.5948	---
1h	240.8226	110.8524	198.0853	624.1247	---
24h	228.4437	93.1825	67.9492	304.5703	---
24h Rate of change（%）	10	-45	-49	-65	---