Supporting Information

Mechanical and Damping Properties of Graphene Modified Polyurethane-epoxy Composites for Structures

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Abstract: Polyurethane has received extensive attention in structural engineering due to its excellent mechanical properties and damping properties. In this research, graphene modified polyurethane-epoxy composites are prepared for the application in structural engineering. The mechanical properties and damping properties of the composites with different contents of graphene are investigated. The damping properties of the composites were also investigated by performing dynamic mechanical analysis (DMA). The results showed that with the increase of graphene content, the tear strength of the composites decreased, from 52 MPa to 39 MPa. Due to the enhancement of appropriate amount of graphene, the tensile strength and elongation at break increase to the maximum value, being 16 MPa and 675% respectively. And DMA tests showed that the damping properties reach the optimal values when the graphene content is 0.2%. The $\Delta T_{0.5}$ is 33 ℃, from -2.9 ℃ to 30.1 ℃. η_{max} is 0.92 and TA reach 36 ℃, much better than the pure PU/EP IPN. In addition, scanning electron microscopy (SEM) results show that agglomeration appears with higher graphene content.

Keywords: polyurethane, graphene, structural engineering, mechanical properties, damping properties.

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1 Performance objectives

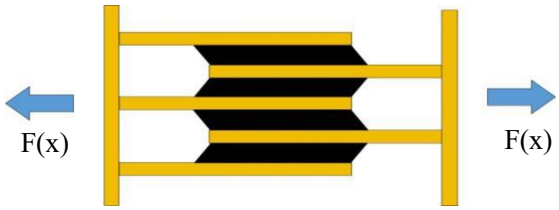
Polyurethane materials can be used in viscoelastic dampers or isolation bearings in building structures to dissipate energy under strong earthquake or wind. As an example, Figure 1(a) is a viscoelastic damper, consisting of constrained steel plates and damping sandwich materials. When both ends of the damper are subjected to external cyclic loads F(x), damping sandwich materials will produce reciprocating shear deformations, as shown in Figure 1(b). And under these motions, the phenomenon which the strain lags behind the stress occurs in these materials, which is called "anelasticity", as shown in Figure 2. The reason is that damping materials can convert mechanical energy into thermal energy by frictions between molecular chains. Thus, internal frictions produce the "anelasticity" of damping materials, which can be used to evaluate its damping performance. The strain still exists, while the stress disappeared. And after the direction of the stress reverses, the strain becomes zero. Moreover, δ represents the phase difference of strain lag behind stress. The larger δ is, the greater the hysteresis of damping sandwich materials is. So do the energy. For convenience, η (η=tanδ) is used to characterize its "anelastic" properties in this study.

Two problems should be solved if polyurethane damping materials are used in structural engineering. The first one is that under strong earthquake or wind, the specifications of the design code should be satisfied for the ability of strength and deformation in the limit state of damping materials. And the other one is that when the structure is subjected to reciprocating vibration, the vibration amplitude should be reduced quickly to ensure the structure safe by taking energy dissipation. That is, the high damping properties is required. The performance indexes of viscoelastic damping materials in various literatures are shown in Table 1. Among them, tensile strength and elongation at break are related to the first problem. The peak value of tanδ (η_{max}), glass transition

temperature (T_g) and temperature range of tanδ > 0.5 ($\Delta T_{0.5}$) are related to the second problem. The energy dissipation capacity of damping materials is related to their chemical structures. Generally, the hysteresis phenomenon of hard segments in the molecules is small, while that of flexible segments is obvious. Hardness can reflect this rule from another perspective. The hardness of different materials is listed in Table 1.

In Rubber Isolation Bearings for Buildings (JG/T 118-2018),[1] the tensile strength and the elongation at break must be greater than 10 MPa and 550%. So the limits of these two indicators are the performance objectives of this study. As is known to all, isolation bearings or dampers for building structures are permanently installed in the indoor environment. So their working temperature is in the range from 0 ℃ to 30 ℃ generally, considering the temperature changes all the year round in China. Therefore, T_g should be in the range of 0 ℃~30 ℃ for more energy dissipation. Performance objectives of different kinds of polymer damping materials are shown in Table. 1. According to the importance of the temperature sensitivity, $\Delta T_{0.3}$ is replaced by $\Delta T_{0.5}$. The target performance requirements of $\Delta T_{0.5}$ and TA should be larger than 20 ℃ and 30 ℃ respectively by reference 12. Considering the cost of material production, η_{max} should be larger than 0.9, which is a suitable value referring to Table 1.

（a）Viscoelastic damper device diagram



（b）Force diagram of viscoelastic damper

Figure.1 Viscoelastic damper

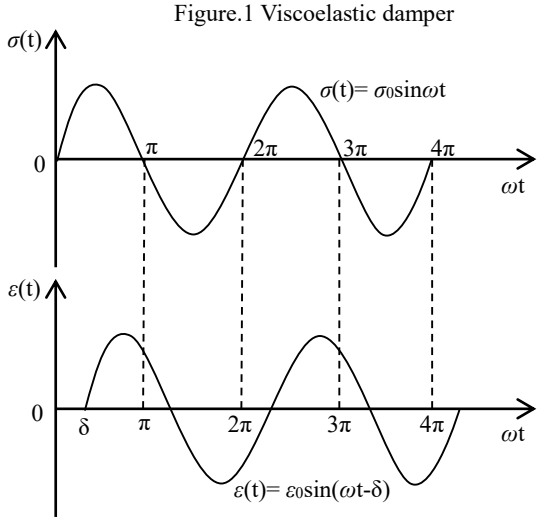


Figure.2 Curves of stress and strain varying with time

Table.1 Performance indexes

Materials	η_{max}	T_g/℃	$\Delta T_{0.3}$/℃	Hardness /HA	Tensile strength /MPa	Elongation at break /%
JG/T 118-2018[1]	-	-	-	-	≥10	≥550
PNS-PU[2]	0.98	29	56 (4~60)	92	12.98	566
PNPS-PU[2]	0.79	13.5	69 (-9~60)	78	11.64	786
PU/EP/PTW[3]	1.26	64.2	46.6 (44.2~90.8)	-	25.5	-
PU/EP/MMT[4]	1.132	73.9	52.7 (51.1~103.8)	-	30	-
TPU-ER[5]	0.47	-9.8	32 (24~8)	82	20.8	1155
TPU/AO-80[6]	1.2	3.3	29.7 (-10.4~19.3)	70	25.6	747
Blocked PU/EP[7]	0.84	99.2	40 (85~125)	75	50	-
PU/EP/CNT[8]	0.984	67.7	38.6 (49.9~88.5)	-	29	-
NR/ENR/MMT[9]	1.1	-39.9	49.8 (-49~0.8)	-	13.3	662
NR/ENR/SiO_2[9]	1.6	-38.9	34.7 (-48.8~-14.1)	-	26.5	673
NR/ENR/CB[9]	1.11	-41.1	48.7 (-50~-1.3)	-	29.48	619

Note: the values of $\Delta T_{0.3}$ column in parentheses refer to the temperature range of tanδ > 0.3.

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