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Vibration damping properties of gradient polyurethane/vinyl ester resin interpenetrating polymer network

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Abstract

In this paper, the vibration damping properties were measured by cantilever method with steel beams as substrate, gradient PU/VER (BMA) IPN as coatings and when used, polysulfide rubber modified epoxy resin without fillers and with common inorganic fillers and whisker crystals as constrained layer. The effects of the thickness ratio of damping layer and steel beam and the sequence of gradient coating on loss factor (η) of extensional damping structure were studied. The effects of the thickness ratio and the time interval of coating (the time difference between coating a layer and another layer) between constrained layer and damping layer on damping properties of constrained damping structure were detected. Modulus of constrained layer was further increased by adding common fillers and inorganic whisker crystals in order to increase η of overall structure. The results show that damping properties of the extensional damping structure with the thickness ratio of 2:1 and the sequence of 70:30–60:40–50:50 (on the steel beam, the first layer is IPN with the component ratio of 70:30, the second layer is 60:40 IPN and the third layer is 50:50 IPN), are better compared with the others. When the thickness of constrained layer and damping layer is respectively 1 mm and the time interval of coating is 3 h, the η of optimized constrained damping structure with 10% aluminum borate ($Al_{18}B_4O_{33}$) whisker crystal in the constrained layer at 2nd mode are higher than 0.14 from −20 to 55 °C and its η at 2nd mode is 0.32 at −20 °C. The binding condition between constrained layer and damping layer was observed by SEM.

Keywords: Vibration damping; Gradient IPN; Polyurethane; Vinyl ester resin

1. Introduction

The conversion of vibration energy to heat is of special interest in damping unwanted noise because a polymer, at its glass transition conditions and in contact with a vibration surface, rapidly converts the mechanical energy to thermal energy, thereby reducing the emitted noise [1]. The theoretical aspects of resonant vibration attenuation by coatings have been described by Ungar [2], who described two main types of coating configurations: extensional and constrained. An extensional damping treatment is a single layer coating on an elastic substrate (e.g., steel) in which energy dissipation (and consequent damping) evolves primarily from the flexural and extensional motions of the damping layer. A constrained layer treatment consists of a two-layer system on the substrate with a viscoelastic layer under a stiff constraining layer. The addition of the constrained layer produces a shear action within the viscoelastic layer as the composite panel vibrates. The shear action in combination with flexure and extension greatly increases the amount of energy dissipated per cycle over extensional systems.

IPN has been the promising technique of preparing materials with broad T_g ranges and excellent damping performances [3,4]. Gradient IPN, a mixture of crosslinked polymers in which the concentration of one network changes across the section of a sample, may be regarded as a combination of an infinite number of layers of IPN [5], and it was shown that gradient IPN had a maximum of mechanical loss tangent ($\tan\delta$) spanning a broad temperature range [6,7] and more excellent damping properties than IPN.

In recent years, there has been increasing interest in polymers for vibration and damping applications. Most of the research has concentrated on the damping properties of neat polymers [8], polymer foams [9], and IPNs [10,11]. For PU/VER IPN, a great deal of research has been concentrated on their synthesis,

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morphology and mechanical properties, but seldom on their damping properties [12,13] and on the evaluation of the vibration damping efficiency of the IPN-laminated steel beams [14]. In the previous work [6], a series of polyurethane/vinyl ester resin (PU/VER) gradient IPNs having broad, useful temperature ranges of damping were synthesized by casting the mixture of different component ratios in a mold at various times. In this paper, the vibration damping properties were studied with steel beams as substrate, gradient PU/VER(BMA) IPN as coatings and when used, polysulfide rubber modified epoxy resin without fillers and with common inorganic fillers and whisker crystals as constrained layer. The effects of the thickness ratio of damping layer and steel beam and the sequence of gradient coating on loss factors (η) of extensional damping structure were studied. The effects of the thickness ratio, the time interval of coating (the time difference between coating a layer and another layer) between constrained layer and damping layer and Modulus of constrained layer on damping properties of constrained damping structure were detected. Furthermore, the binding condition between constrained layer and damping layer was observed by SEM.

2. Experimental

2.1. Materials

Phosphating agent, surface conditioning agent and phosphating accelerator were chemical pure and supplied by Harbin Huaxing Corporate. Bisphenol A epoxy resin E-51 was supplied by Wuxi Synthetic Resin Plant. Three kinds of polysulfide rubber (JLY-121, JLY-124, JLY155) were supplied by Jinxi Research Institute of Chemical Industry. Aluminum borate ($Al_{18}B_4O_{33}$) whisker crystal, calcium carbonate ($CaCO_3$) borate whisker crystal, calcium sulfate ($CaSO_4$) borate whisker crystal were supplied by Qingha Institute of Salt Lakes. $CaCO_3$ powder, Mica and wollastonite powder were supplied by Beijing Guoli Superfine Powder Company. Active diluents, polyamide curing agents and γ-aminopropyltriethoxysilane (KH550) coupling agent were respectively supplied by Beijing Yili Chemical Company, Tianjin Jindong Chemical Plant and Nianjing Shuguang Chemical Plant. Polyamide curing accelerator was prepared in our laboratory. Steel plates with 1 mm thickness were purchased from Steel & Iron Factory. Other reagents were chemically pure and obtained from various suppliers. Materials of IPN damping layer were listed in the previous paper [6].

2.2. Preparation of extensional and constrained IPN beams

2.2.1. Preparation of extensional IPN beams

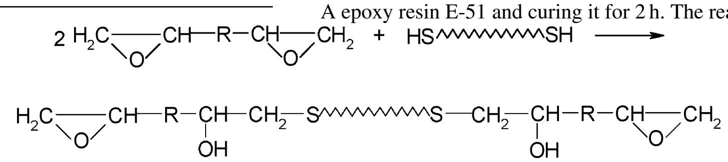
Before the preparation of IPN beams, steel beams (20.0 cm × 1.0 cm × 0.1 cm) were pretreated in order to improve the adhesive attraction between IPN materials and steel beams. First, the phosphating process was adopted as follows. 25 ml Phosphating agent, 1–1.2 g $NaCO_3$ and 1–1.5 ml phosphating accelerator were dissolved in 1000 ml water and the free acidity of the solution was remained at 0.5–0.8, total acidity was remained at 18–22. If the free acidity was lower than 0.5, phosphating solution was added and if the free acidity was higher than 0.8, $NaCO_3$ was added. Second, the steel beam was coated with KH550 and dried at low temperature.

The structure of extensional IPN beams is illustrated in Fig. 1. The preparation of the gradient IPN mixture was presented in the previous paper [6].

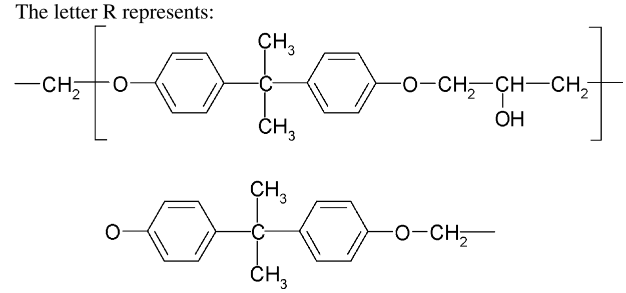
The steel beam was coated with gradient IPN mixture with different component ratios at the time interval of 3 h which indicates that another layer is coated when a layer has cured for 3 h. And the extensional beams were obtained by curing the samples at room temperature.

2.2.2. Preparation of polysulfide rubber modified epoxy resin materials as constrained layer

The prepolymer was prepared by mixing polysulfide rubber and Bisphenol A epoxy resin E-51 and curing it for 2 h. The reaction equation is as follows:



The letter R represents:



A component was the mixture of the prepolymer and active diluents and B component was the mixture of polyamide curing agents and curing accelerator. Both A and B component were preheated to 60 °C in order to lower their viscosity and then they were mixed and cured at room temperature to form the product. In order to improve its mechanical properties, common inorganic fillers and whisker crystals were added. First, the common inorganic fillers and whisker crystals were dried for several hours at certain temperature and then were stirred for an hour in the solution of KH550 and alcohol. Last the mixture was separated by the method of filtering and drying. In the other method, the inorganic fillers and whisker crystals were mixed with active diluents and polysulfide rubber modified epoxy resin to form A component and the other process was the same as that of polysulfide rubber modified epoxy resin.

2.2.3. Preparation of constrained IPN beams

First the gradient IPN coating was prepared on the surface of pretreated steel beam. Then the mixture of polysulfide rubber modified epoxy resin was added on the IPN coating after the last layer of gradient IPN polymerized for a period of time. Last the whole material cured to form the constrained IPN beam at room temperature and normal pressure. The structure is also shown in the Fig. 1.

2.3. Measurements

Mechanical properties were measured on a INSTRON 4467 tensile tester with extension rate of 100 mm/min. The samples were the dumbbell shape in accordance with GB1040-79.

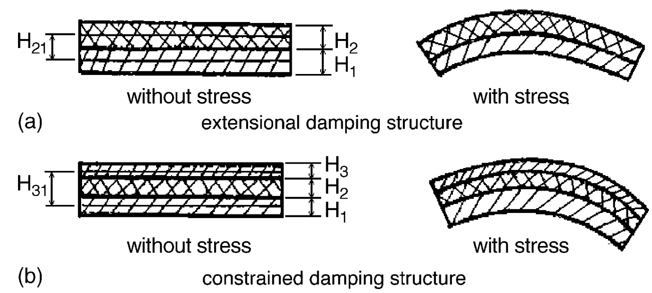


Fig. 1. The diagram of extensional and constrained damping structures. H_1: the thickness of substrate, H_2: the thickness of damping layer, H_3: the thickness of constrained layer, H_{21}: the distance between the center lines of damping layer and substrate, H_{31}: the distance between the center lines of constrained layer and substrate.