Composites Part B 94 (2016) 152–159

Contents lists available at ScienceDirect

Composites Part B

journal homepage: www.elsevier.com/locate/compositesb

Investigation of the dynamic mechanical properties of epoxy resins modified with elastomers

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ARTICLE INFO

Article history:
Received 5 December 2015
Received in revised form
26 February 2016
Accepted 11 March 2016
Available online 23 March 2016

Keywords:
A. Resins
A. Rubber toughening
B. Vibration
C. Numerical analysis
D. Non-destructive testing

ABSTRACT

The mechanical and modal properties of epoxy resin reinforced with different content of carboxyl-terminated butadiene acrylonitrile copolymer (CTBN) rubber were investigated in this paper with an analytical-experimental identification method. Mechanical tensile tests were conducted for concentrations between 0 and 25wt% of CTBN rubber. The dynamic responses of the epoxy/CTBN rubber composites were measured by vibrating cantilever beam specimens with an impact force through a modal hammer, while the vibratory response was detected through an acceleration transducer. The analytical-experimental transfer function method is utilized for the deduction and therefore comparison of the elasticity modulus of the epoxy/rubber composites. The procedure for the identification of analytical-experimental transfer functions was carried out using a genetic algorithm (GA) by minimizing the difference between the measured response from tests and the calculated response, which is a function of the modal parameters. Both tensile and modal tests have shown, while it was evident from the results that the CTBN composites could absorb greater amounts of strain energy. The modal test results indicate that CTBN rubber particles can improve the damping capacity of the epoxy-based composites. However, it was observed that the stiffness of the epoxy/CTBN rubber composites was dramatically reduced.

1. Introduction

In response to a transient or dynamic loading, there is a wide set of structural components or assemblies for which vibration is directly related to performance, either by virtue of causing temporary malfunction during excessive motion or by creating disturbance or discomfort, such as stress fatigue failure, premature wear, operator discomfort, unsafe operating condition, high noise levels. For all these potential problems, it is important the vibration levels encountered in service or operation to be anticipated and brought under satisfactory control [1]. Thus, it is important to determine three modal parameters; resonance frequencies of the structure to avoid resonance, damping factors and mode shapes to reinforce the most flexible points or to determine the suitable points to reduce weight or to increase damping. With respect to these dynamic aspects, composite materials represent an excellent possibility designing components requiring for dynamic behavior.

In the past, the damping capacity of conventional engineering materials has not generally provided sufficient energy dissipation to limit resonant or near-resonant amplitudes of vibration [2]. It would therefore be of interest to investigate new materials simultaneously exhibiting high damping capacity with high stiffness and low density which includes polymer matrix nanocomposites. High damping capacity is an important factor for various industrial applications; therefore, it is necessary to develop structural components with a high level of mechanical damping. High loss factor polymers have been used in the past for modern damping applications [3–7]. Nowadays there are plenty of other advanced materials that could be utilised for damping applications. Researchers have, therefore, concentrated their efforts towards the development of polymers in which nanomaterials are embedded in polymer substrates and promising results have been established primarily improving the mechanical properties [8–11]. However, for increasing damping, epoxy resins reinforced with CTBN rubber are promising materials due to their large recoverable strain and high damping response. Adding rubber particulates (reactive liquid rubber CTBN) into polymer resin is an approach to effectively improve the damping behavior of composites [12]. In general,

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http://dx.doi.org/10.1016/j.compositesb.2016.03.024
1359-8368/

embedding such CTBN inclusions into a polymeric matrix system, can effectively improve the ductility as well as the fracture toughness of the polymeric composites [13,14]. The fracture toughness is an important property in fibre polymer composite industry, since it prevents delamination damage, while it is also vital in composite repair procedures [15–18].

The current work aims to investigate the dynamic and mechanical behavior of epoxy resins reinforced with CTBN rubber particles through an optimization algorithm for modal analysis and identification of experimentally defined transfer functions. The proposed modal analysis algorithm derives modal parameters from the transfer functions (TFs) of the composites by a curve-fitting technique. According to the authors' knowledge the influence of the CTBN rubber on the damping response of epoxy based composites is rarely discussed in the literature. Samples of 10–25wt% CTBN have been used to reinforce a DGEBA/F epoxy resin. The dynamic mechanical properties of the rubber modified epoxies were determined by both tensile and vibration tests. An analytical-experimental transfer function method is utilized for the deduction and therefore comparison of the elasticity modulus of the epoxy/rubber composites.

2. Materials and test methods

2.1. Preparation of the rubber-modified epoxy composites

The epoxy resin that has been used to form the rubber reinforced composites was a standard diglycidyl ether of bisphenol A/F (DGEBA/F) with an epoxide equivalent weight (EEW) of 1697 g/eq. supplied by Gurit, UK. The reactive liquid rubber, which generates the micrometer-sized spherical rubber particles upon curing of the formulation, was a carboxyl-terminated butadiene-acrylonitrile (CTBN) rubber. It was supplied as 40wt% CTBN-epoxy adduct, 'Albipox 1000' (EEW = 330 g/eq.), from Evonik, Germany. The curing agent was a 3-aminomethyl-3,5,5-trimethylcyclohexylamine (SP115 hardener with an amine-hydrogen equivalent weight of 42,3 g/eq.), also supplied by Gurit, UK. In order to prepare a series of composites with 10–25wt% rubber content, the SP115 epoxy resin was mechanically mixed with Albipox 1000 – DGEBA/F masterbatch for 30 min. The mixture was degassed for 15 min in a vacuum oven and then was blended in a stoichiometric amount of SP115 hardener (based on the amount of DGEBA and the masterbatch) for 10 min. The rubber-modified resin was afterwards degassed in the vacuum oven before curing to remove any air entrapped in the mixture and then poured into a silicon mould. Finally, the resin system was cured at room temperature for 24 h following 16 h at 50 °C with a ramp rate of 1 °C/min followed by a cooling step to room temperature to room temperature at 1 °C/min. Subsequently, rectangular specimens with the dimension of $160 \times 20 \times 4$ mm^3 were utilized for the vibration tests were fabricated. For each particulate epoxy/rubber composite at least three specimens were prepared.

2.2. Tensile tests

Tensile tests were performed at room temperature (23 °C) on a Zwick Z010 (Zwick, Germany) universal testing machine at a constant crosshead speed of 1 mm/min. The measurements followed the ISO 527 testing standard using dumbbell shaped specimens. The specimens with 4 mm thickness were fabricated using a silicone mold. The overall length of dumbbell specimens was 150 mm. The length and width of the narrowed section were 10 and 4 mm, respectively. E-moduli were calculated within the linear section of the tensile stress–strain curves. All presented data corresponds to the average of at least five measurements.

2.3. Fractographic analysis

The local microstructure of the specimens was qualitatively examined using a JEOL JSM-840A scanning electron microscope (SEM). Prior to the test, the fractured surfaces of the samples were gold coated in an ion sputtering unit for over 6 min. The fractured surfaces were observed at suitable magnifications. The fractographs revealing the respective characteristic details of each sample were taken after suitable adjustments in probe current, voltage, image contrast and brightness as well as working distance. In this manner, images were taken on tension-failed, unmodified and rubber modified epoxy samples.

2.4. Modal tests and signal processing

The experimental apparatus for the forced vibration tests is shown in Fig. 1, where the specimen is clamped on rigid support as a cantilever beam and vibrated by the impact hammer with a high-quality piezoelectric force transducer (Endevco Model 2302-10). The force-hammer was used to apply an initial vibration (input signal) on the free boundary where the specimen was subjected to free damped vibration. In addition, the vibratory response at the specimen tip (output signal) was detected through an acceleration transducer with a sensitivity of 100 mV/g (Brüel & Kjaer 4507B), mounted on the free boundary, while the sensing cables were kept in a free state, thereby having a little influence on the vibration test. For impact excitation, an acquisition and realtime-analysis routine provided digital filtering for two-channel acquisition.

So both the force and acceleration analog signals are acquired by an analog-to-digital converter (FFT analyzer PULSE Brüel & Kjaer), while the corresponding results were recorded in a computer. The frequency range of acceleration signals was up to 3200 Hz, the sampling time interval was 0.12207 μs and the sampling frequency was 8192 samples per second (Hz). The modal hammer was calibrated by adjusting the level of the signal trigger force. Each specimen was tested 10 times and linear averaging was performed.

In order to obtain the specimen's modal properties from the transient vibration, the Fourier Transforms of both the excitation and the response signals were calculated. The ratio of response to excitation functions is computed to obtain an expression from the corresponding transfer function. The response can be calculated in terms of displacement, velocity or acceleration and as a result different terms have been used for the ratios of response to force. This study is focused on displacement responses and any reference to the TF expresses the receptance (dynamic compliance) of the system. The displacement is determined through a double integration process of the experimental data of the accelerometer

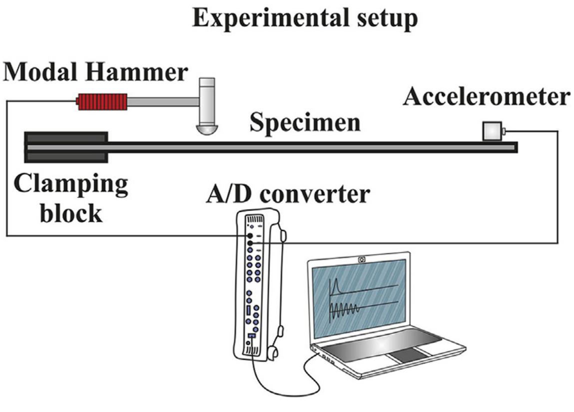

Fig. 1. Experimental setup of vibration tests.