NONLINEAR DYNAMIC BEHAVIOUR OF A NANOCOMPOSITE: EPOXY REINFORCED WITH FUMED SILICA NANOPARTICLES

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Summary This study focuses on identification and modelling of vibration characteristics of a nanocomposite; an epoxy resin as the matrix and fumed silica as the reinforcement. The resin alone is manufactured and characterised. Using the same methodology, the manufacturing and characterisation of the silica-reinforced nanocomposite are performed. Following the manufacturing and the experimental characterisation process, a nonlinear model is built to represent characterised behaviour. The model is validated by a separate test case which is also an experimental technique to extract the damping characteristics of a structure.

INTRODUCTION

In comparison to the mechanical properties of their individual components, the nanocomposites display dramatically different characteristics [1]. A significant improvement in strength and dynamic behaviour can be achieved by tailoring the right nanocomposite. Tailoring can be done by controlling the manufacturing process as well as the matrix-reinforcement combinations [2]. This study investigates the effects of addition of a small mass fraction of nano-silica particles on the damped vibration characteristics of epoxy. Using the gathered knowledge, a model is built to predict the behaviour of the structures made of that nanocomposite [3].

MATERIAL PREPARATION, CHARACTERISATION AND MODELLING

Material Preparation and Manufacturing

First, epoxy samples without any nanoparticle addition are manufactured. Therefore, laminating resin MGS® L 285 Hardener MGS® 285 from Hexion are used. Both components are mixed slowly and moulded in vacuum. After an hour in vacuum, the samples are taken to ambient pressure and temperature for 24 hours. Then, post-curing is done at 70°C for 15 hours. Next, the silica particulate reinforced epoxy samples are manufactured with a similar process to eliminate the effects of manufacturing steps on the mechanics of the materials. As nanoparticles, fumed nano-silica (HDK® N20 Pyrogenic Silica - Fumed Silica from Wacker Silicones) is used. Also, the same epoxy resin, (Laminating resin MGS® L 285 Hardener MGS® 285 from Hexion) is used. Before starting, 0.49 g silica which was held in the furnace at 60°C for 8 hours to minimise the humidity, is dispersed in 66.79 g of epoxy resin without adding the hardener with at a high speed of 2000 rpm for 3 hours. Following mixing the silica resin mixture is put into a vacuum chamber for degassing 3 hours. Later on, 26.52 g hardener is added and mixed slowly for 10 minutes. Then the blend is cast into the mould for curing at room temperature in vacuum. The same post-curing process is followed [4].

Experimental Characterisation: Dynamic Mechanical Analysis (DMA) and Vibration Test

As one of the most widely used methods, Dynamic Mechanical Analysis (DMA) is employed to characterise the dynamic behaviour of the epoxy and epoxy-silica nanocomposites [1]. For this purpose, DMA Q800 of TA Instruments is utilised to perform the necessary tests. The epoxy samples and the nanocomposite samples with the mass fraction of 0.5% silica inclusion are put through the DMA with the dual cantilever fixture. The samples are rectangular prisms. The sizes of the samples are approximately 60 mm by 14 mm by 3.5 mm. The excitation is chosen as harmonic with frequencies 1, 2, 3, 4, 5, 10, 15, 20 and 25 Hz, while the vibration amplitudes are picked so that the maximum strain values are between 0.0002 and 0.0008 with 0.0001 incrementations. The temperature is kept constant at 20°C for this first step to avoid the effect of any temperature change on mechanical properties.

A vibration test is also conducted to understand the behaviour of a beam made of the nanocomposite material. The specimen used has the dimensions of 280 mm by 24 mm by 4 mm. The experimental setup consists of the specimen with two tip masses attached and suspended from a light steel cable at the tip masses. It is crucial that only the energy dissipation contribution of the material is measured. The masses are held in place via a frictional contact, enforced by a rounded profile to reduce specimen damage whilst minimising extraneous frictional dissipation. The tip masses ensure that the system demonstrates a 'simply-supported' mode shape for the first flexural mode, placing the nodal locations of this mode at the tips of the specimen, and ensuring that the cable moves only in rotation, minimising energy dissipation of interactions between the suspension and specimen. The specimen is excited mono-harmonically to its first flexural resonance (in this case 26.9 Hz) with a shaker which attaches to the specimen using a c-bracket and contacting surface on a single side. This allows the shaker arm to be displaced from the specimen using an input signal offset initiating a free decay, allowing the calculation of the loss factor using a curve fitting method. The vibration of the specimen is measured using a Polytech LDV system.

Both, DMA and the vibration test setups are displayed in Figure 1.

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Figure 1: DMA and the vibration experiment setups

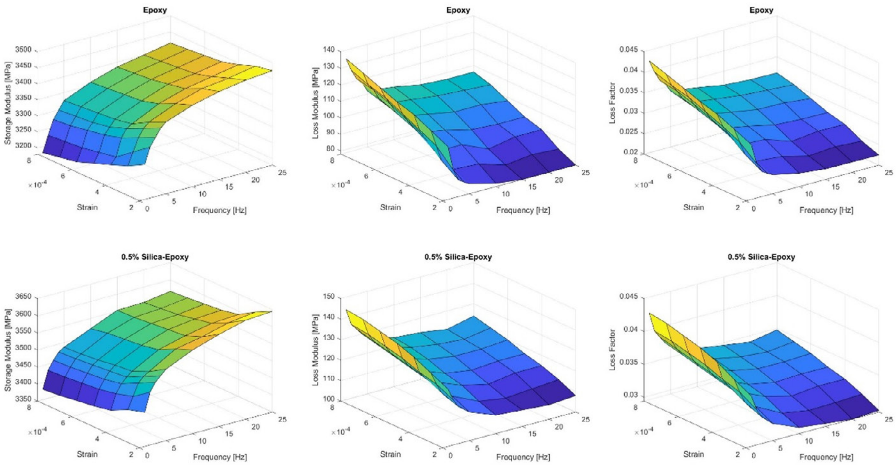

Figure 2: DMA results of epoxy and nanocomposite samples

Modelling of a Single Degree of Freedom (SDOF) System

The system, on which the vibration test is performed, is here considered as a single degree of freedom (SDOF) system. For a simply supported beam the equivalent stiffness is known as $k_{eq} = 48EI/L^3$ whereas the equivalent mass is $m_{eq} = m_{beam}/2$. The Young's modulus E is assumed to be complex. The storage and loss moduli, that are defined as functions of strain and strain rate by curve-fitting the results of DMA, are used as the real and imaginary parts respectively.

RESULTS AND CONCLUSIONS

The results of DMA are plotted in Figure 2 which display a considerable nonlinear behaviour from both materials. The variation of storage modulus of epoxy is found to be around 10% within the investigated range of amplitude and frequency. However, the damping is affected more dramatically. The change is found to be around 65%. For the nanocomposite, the storage modulus shows a similar trend by changing approximately 10%, whereas the damping is affected by around 45%. The addition of 0.5% mass of silica stiffened the material approximately by 5% whereas it increased the damping capabilities by up to 20%. This increase in damping is related to the effect of the interfaces created between the matrix and the nanoparticles. Meanwhile, in loss factor, both materials have almost the same trends as well as values. The vibration test with 0.0003 maximum strain and 26.9 Hz frequency, the loss factor is calculated as 2% whereas the SDOF model predicts the loss factor around 2.25% with an error around 12.5%. It is also important to note that the frequency of the vibration test is out of range of the DMA tests. Therefore, a direct comparison between those two tests are not done, instead, the vibration test results are compared to the results of the model which is built by using the results of the DMA.

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