EVALUATING THE TEMPERATURE AND GLASS FIBRE REINFORCEMENT EFFECTS ON THE DAMPING PROPERTIES OF THE SHAPE MEMORY POLYMERS

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ABSTRACT

Shape memory polymers (SMPs) are novel class of active polymers that have a unique ability to undergo a substantial shape deformation and subsequently recover the original shape when exposed to a particular external stimulus. In the past, more attention has given to the shape memory alloys (SMA) than the SMP because unreinforced SMPs have substantial lower mechanical characteristics. Though when reinforced with continuous fibres their properties dramatically improve. SMPs and their composites (SMPCs) have been used in a vast range of applications from biomedical devices to morphing and deployable structures. However, dynamic mechanical analysis has shown that SMPs have promising damping characteristics that give them significance in the control of structural noise and vibration applications by just control the SMP temperature. In this paper, styrene base SMP and its woven glass fibre SMPCs have been tested to investigate their damping properties. Dynamic mechanical analyzer (DMA Q800) has used to evaluate the loss factor of both neat and composite samples, and LMS SCADAS data acquisition systems has used inside thermal control chamber to examine the damping efficiency at different temperatures where two temperatures (25^{o}C and 65^{o}C) have investigated. DMA results revealed that, near the glass transition temperature, neat SMP has shown loss factor up to (1), however fibre reinforcement has reduced this value in the SMPC samples. Furthermore, glass fibre reinforcement has reduced damping ratio from 0.3 for SMP to 0.07 for SMPC. Results have also shown that temperature increase from room temperature to 65^{o}C has increased the damping ratio by 33% for the SMP sample and 6 times increment for the SMPC sample.

1 INTRODUCTION

Shape memory polymers (SMPs) are novel class of active polymers that have a unique ability to undergo a substantial shape deformation and subsequently recover the original shape when exposed to a particular external stimulus. SMPs are a stimulus responsive materials having a large number of stimuli such as magnetic field [1], electrical field [2], heat [3] and light [4]. However, heat is the more common stimulus, and the others represent different method for heating. SMP thermochemical cycle incorporates, for shape programming, a heating process above the material glass transition temperature (T_g), applying constrain and then cooling below T_g with the present of the external constrain. Though, the shape recovery process incorporates a heating process above the T_g again.

In the past, more attention has given to the shape memory alloys (SMA) than the SMP because unreinforced SMPs have substantial lower mechanical characteristics. Shape memory polymers have characterized by a unique thermomechanical properties and low mechanical properties [5], though when reinforced with continuous fibres their properties dramatically improve [6]. Consequently, SMPs and their composites have been used in a vast range of applications, from smart textile and apparel to complicated biomedical devices and aerospace deployable structures [7-9]. However, dynamic mechanical analysis has shown that SMPs have promising damping characteristics that give them a new significance in the control of structural noise and vibration applications. Butaud, Ouisse [10] designed a sandwich structure of aluminum skins and SMP core, and tested the ability of the SMP core to control the wave propagation in the sandwich by tuning the core temperature, an impressive damping property of the sandwich was reported. Moreover, [11] reported SMP with loss factor of 2.5 which was a promising finding for damping applications using SMPs. This indicates that damping is inherent to SMP material which makes them good option as passive damping material with low cost and robust vibration control [12].

In this paper, styrene base SMP and its woven glass fibre SMPCs have been tested to investigate their damping properties. Two set of samples have produced; first has been used to evaluate the loss factor of the neat SMP and SMPCs samples using dynamic mechanical analyzer (DMA Q800), and the second has been tested in LMS SCADAS data acquisition systems to examine the damping efficiency at different temperatures. Two temperatures have selected (25^{o}C and 65^{o}C) to show the temperature effect on the samples damping ratio. DMA results revealed that, near the glass transition temperature, neat SMP has shown loss factor up to (1), however glass fibre reinforcement has reduced the loss factor because of the increase in stiffness and reduction of the material viscous effect. The effect of glass fibre reinforcement on the amplitude decrement has been tested where the damping ratio has found to be reduced from 0.3 for SMP to 0.07 SMPC. Furthermore, temperature increase from room temperature to 65^{o}C has shown improvement in damping ratio for both samples. For the SMP, the increase in temperature has increased the damping ratio by 33% whereas for the SMPC it has increased 6 times approximately.

2 MATERIALS AND EXPERIMENTAL METHODS

Styrene-based SMP type C, which was supplied by *Harbin Institute of Technology*, *China*, has been used to prepare two different types of samples; neat SMP and SMPCs reinforced with woven glass fibre AR177100 W/C 450 0/90 (supplied by COLAN Australia). A rectangular glass mould coated with thin film of Teflon has used to cast the specimens, and the curing process has been done in a temperature controlled oven, at 85^{o}C for 24 hours. Then, two kinds of specimens were cut from the cured samples; for the DMA test and the damping test. The DMA specimens were smaller with dimensions 35×14×1.5 mm^3 which were used as a cantilever beam in the DMA equipment. The second set of specimens was bigger with dimensions 100×20×2.5 mm^3 which were used in cantilever beam arrangement to measure the damping behaviour at two temperatures; 25^{o}C and 65^{o}C. One end of the beam was fixed, and accelerometer was fixed to the free end of the beam, an initial excitement was given to the free end by hummer hit, and the response was recorded with time.

TA instrument Dynamic Mechanical Analyser (DMA Q800) shown in Fig.1 has been used to investigate the loss factor and the glass transition temperatures of the samples. Besides, LMS SCADAS data acquisition systems shown in Fig.2 has been used to investigate the damping properties of the samples at different temperatures which were provided by a controlled temperature thermal chamber.

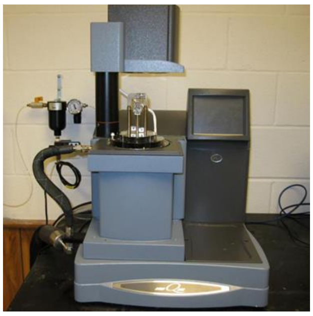

Figure 1: DMA Q800 utilized for dynamic mechanical analysis to investigate the loss factor

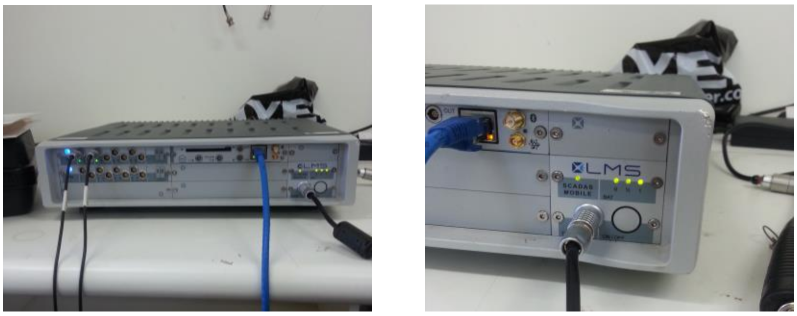

Figure 2: LMS SCADAS data acquisition systems used in the investigation of the damping properties

3 RESULTS AND DISCUSSIONS

3.1 DYNAMIC MECHANICAL ANALYSIS

To characterize the thermomechanical properties of the samples, DMA equipment has used in multi frequency mode with single cantilever beam clamp arrangement. The frequency mode has been used to identify the materials' glass transition temperatures and to characterize the loss factor. A frequency of 1 Hz and temperature ramp of 10^{o}C/min has been selected to scan the material over a temperature span from 30^{o}C to 120^{o}C. Figure 3 depicts the results of the thermal analyses of both neat SMP and 2-layers glass fibre reinforced SMPC. Results showed that glass transition temperature of the samples was around 75^{o}C. Moreover, loss factor of (1) which can be recognised in the neat SMP sample highlights that SMP has a promising inherent damping capacity. Though, glass fibre reinforcement has shown a reduction in the loss factor due to the higher stiffness of the fibres. Generally, it was found that loss factor is a temperature dependent. At room temperature, the SMP is in the glassy state with very high storage modulus; therefore it has low loss factor and consequently low damping. However, as the temperature increase to 65^{o}C which is around 85% of the SMP glass transition temperature a significant improvement in loss factor was achieved.

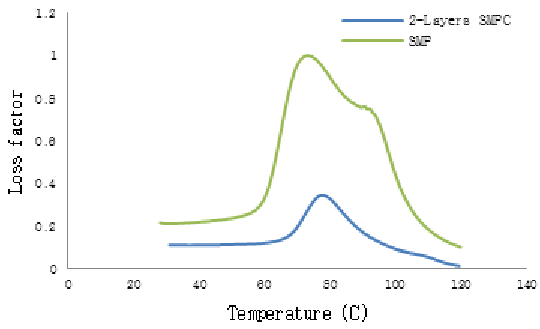

Figure 3: Dynamic mechanical analysis show the loss factor temperature relation

3.2 DAMPING PROPERTIES CHARACTERIZATIONS

LMS SCADAS results data report the amplitude decrements of SMP and SMPC beam specimen obtained for two different temperatures; room temperature which is below the glass transition temperature, and 65^{o}C which is 85% of the transition temperature. The two different samples have shown two different damping behaviours at each temperature.

Damping ratio is calculated using the free vibration data of the damped structure shown in Fig. 4 where the logarithmic decrement (δ) between two peaks is defined as

$$\delta = logarithmic\ decrement = ln\ y_2/y_1 \quad (1)$$

Where (y_1) and (y_2) are the amplitudes of the peaks

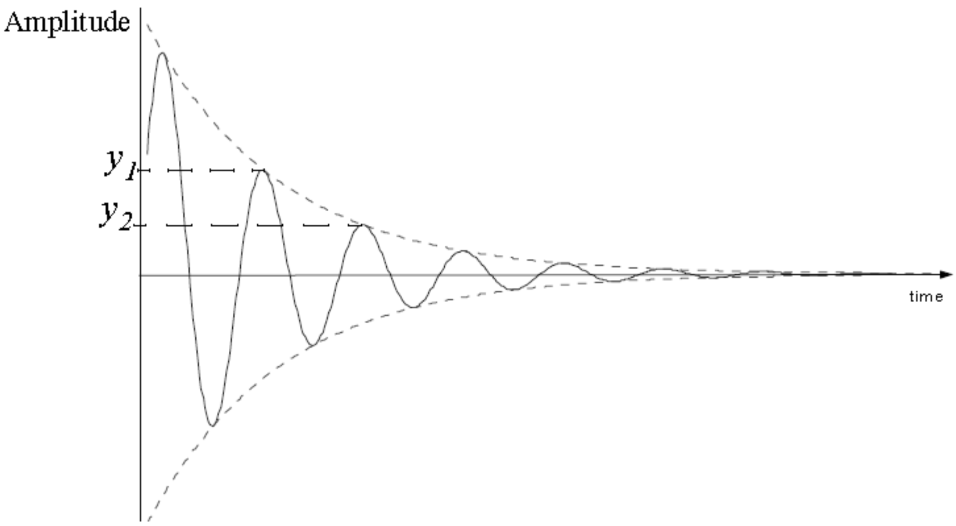

Figure 4: Free vibration of damped system

The natural vibration of a damped system is described as:

$$x(t) = e^{-\zeta\omega nt}\ (C\cos(\omega_d)\,t + Di\sin(\omega_d)\,t) \quad (2)$$

Where, ω_n, ω_d and ζ denotes the natural frequency, damping frequency and damping ratio of the system

And (y_1) and (y_2) can are written as:

$$y_1 = Ce^{-\zeta\omega nt} \quad (3)$$

$$y_2 = C\,e^{-\zeta\omega n(t\,+\,T)} \quad (4)$$

Where the constant C includes the terms of the sine and cosines in equation (2), and (T) is the period of the system. Using equations (3) and (4) in equation (1):

$$\delta = \ln y_2/y_1 = \ln [C\, e^{-\zeta\omega n(t\,+\,T)}/\, Ce^{-\zeta\omega nt}] = \zeta\omega_n T \tag{5}$$

When the damping ratio is small, it can be approximated as

$$\zeta = \delta / 2\pi \tag{6}$$

Fig.5 (a and b) show the free vibration performance of the neat SMP and the glass fibre reinforced SMPC samples respectively at 25°C. Apparently, the glass fibre has negatively affected the vibration amplitude decrement which means a reduction in the damping ratio. This is attributed to the high stiffness of the glass fibre that increased the stiffness of the SMPC. Consequently, amplitude reduction (δ) has significantly reduced as shown in Fig. 5(b). Furthermore, damping ratio (Equ. 6) has dramatically reduced from 0.3 for the neat SMP to 0.07 for the SMPC.

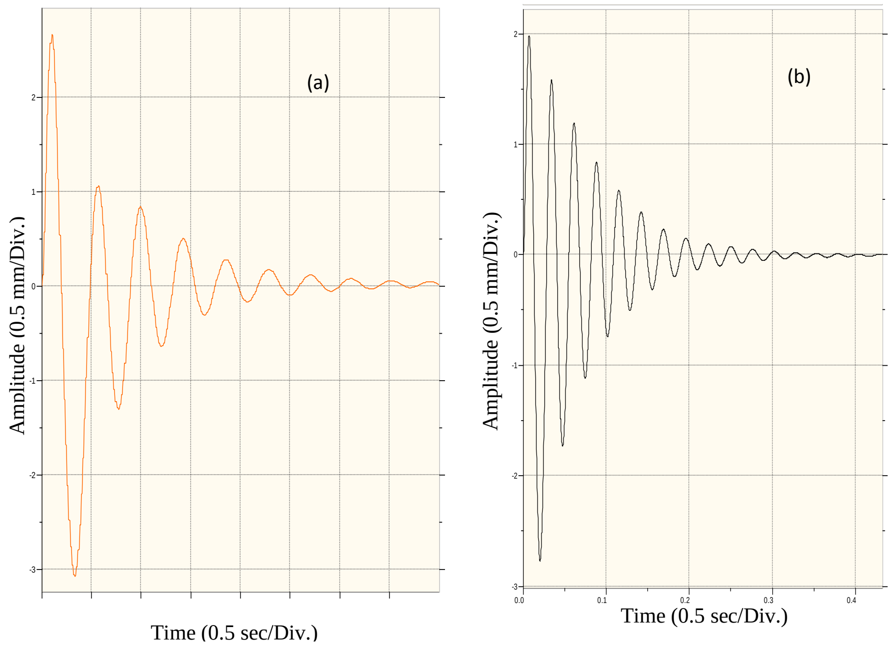

Figure 5: The effect of glass fibre reinforcement on the amplitude decrement at 25°C (a) neat SMP (b) 2-layers wovem glass fiber SMPC

Fig.6 (a and b) shows the free vibration performance of the neat SMP and the glass fibre reinforced SMPC samples respectively when the temperature was increased from room temperature to 65°C. Fig.6 (a) depicts the behaviour of the neat SMP sample. When it was compared with Fig.5 (a), it has found that temperature increase has increased the damping ratio by 35% approximately. This is due to the increase in the material loss factor as it is approaching the glass transition temperature. Likewise, Fig.6 (b) presents the behaviour of the SMPC at elevated temperature, when it was compared with room temperature performance of the SMPC sample Fig.5 (b) it has found that the improvement of the damping ratio in the SMPC is 6 times bigger than that of the neat SMP. This big difference in damping ratio improvement between the neat and reinforced samples can be attributed to the big drop in the stiffness of the SMPC samples comparing to the neat SMP. As at high temperature the contribution of the fibres in the SMPC stiffness was lost because of the transition of the matrix polymer from the glassy to rubbery state. Consequently, the SMPC matrix has lost its stiffness, became pliable and lost its role in combining the fibres leading to big drop in stiffness comparing to neat SMP.

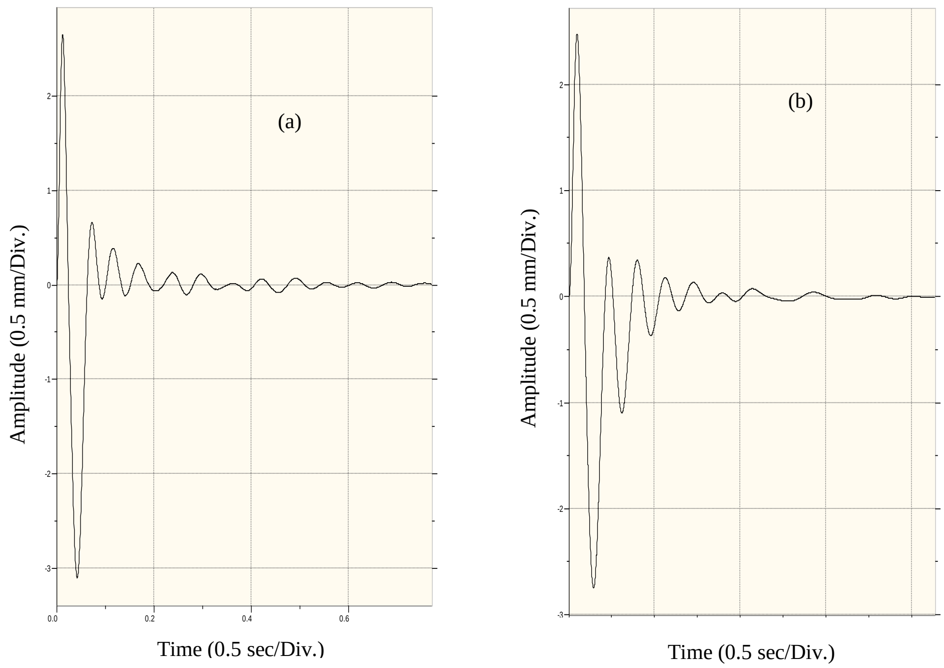

Figure 6: The effect of temperature increse to 65°C on the amplitude decrement of (a) neat SMP (b) 2-layers woven glass fiber SMPC

4 CONCLUSION

The effects of temperature and glass fibre reinforcement on the damping properties of neat SMP and glass fibre SMPC have been investigated in this paper. A substantial decrease in material loss factor has noticed due to the fibre inclusion in the SMPC sample which implies better damping properties of the neat SMP. Furthermore, it has found that at room temperature the glass fibre has reduced the damping ratio of the SMP from to 0.07 from 0.3 for the neat SMP. However, at elevated temperature (65°C) which is almost 85% of the material glass transition temperature, the damping ratio of the neat SMP has increased by 33%, comparing to 6 folds increments for the SMPC sample.

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