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Examination of the Thermo-mechanical Properties of E-Glass/Carbon Composites

Preizkušanje termomehanskih lastnosti kompozitov E-steklo/ogljik

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Abstract

Eight-ply E-glass, carbon and E-glass/carbon fabric-reinforced polyester based hybrid composites were manufactured in this study. A vacuum infusion system was used as the production method. Dynamic mechanical analysis, thermogravimetric analysis and differential scanning calorimetry analysis were conducted to examine the thermo-mechanical properties of composite samples. The effect of reinforcement type and different stacking sequences of fabric plies on the thermo-mechanical properties of composite samples were also investigated. Results showed that the type and alignment of reinforcement material has a significant effect on the dynamic mechanical properties of composite samples.
Keywords: textile-reinforced composites, dynamic mechanical analysis, thermogravimetric analysis, differential scanning calorimetry

Izvleček

Osemslojni hibridni kompoziti iz poliestra, ojačeni s tkaninami iz E-stekla, ogljika in kombinacije E-steklo/ogljik, so bili v tej študiji izdelani s pomočjo metode vakuumske infuzije. Termomehanske lastnosti kompozitnih vzorcev so bile proučevane z dinamično mehansko in termogravimetrično analizo in dinamično kalorimetrijo. Raziskani so bili tudi učinki vrste ojačitve in različne razporeditve zlaganja tkanin na termomehanske lastnosti kompozitnih vzorcev. Rezultati so pokazali, da vrsta in razporeditev ojačitvenega materiala pomembno vplivata na dinamične mehanske lastnosti kompozitnih vzorcev.
Ključne besede: tekstilni kompoziti, dinamična mehanska analiza, termogravimetrična analiza, dinamična kalorimetrija

1 Introduction

Fibre-reinforced composites are one of the most favoured materials in many sectors owing to their properties, such as high specific strength and stiffness, low thermal expansion, good fatigue performance and processing advantages at a low cost [1].
Hybrid composites include two or more types of reinforcement materials. They possess much better performance characteristics than traditional composites, and are designed for specific applications. By hybridising low-modulus, high-elongation fibres (e.g. E-glass) with high-modulus, low-elongation fibres (e.g. carbon), more damage-tolerant and cost-effective advanced composite materials can be manufactured [2, 3].
E-glass and carbon fibres are the most preferred textile fibres in composite structures. Due to the ease of orientation/manufacture and their excellent mechanical properties, woven carbon fabric-reinforced composites can be used in many applications [4].

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The advantageous properties of E-glass fibres that make them preferable materials for composite structures are their high damping characteristics, lightweight, low cost, high strength, good resistance to corrosion and excellent insulation properties [5–8].
Dynamic mechanical analysis (DMA) is a technique that measures both the mechanical and viscoelastic properties of materials [9]. DMA is a method that applies sinusoidal force to samples to study their viscoelastic properties and structures. It measures the modulus and damping properties of materials [10–12]. Fibre-reinforced composites are exposed to different types of dynamic stresses during handling, which demonstrates the importance of analysing the viscoelastic properties of composite materials [13]. Differential scanning calorimetry (DSC) is a thermal analysis method that measures heat flow rate as a function of time and temperature [14]. By using a reference material, it computes the required amount of heat to make the temperature difference between sample and reference material zero. This heat provides information regarding the physical and chemical transformations of material [15, 16]. Thermogravimetric analysis (TGA) shows the degradation temperature and amount of weight materials lose as temperature is increased [14, 16].
The thermo-mechanical properties of E-glass/carbon fabric-reinforced composite samples were determined in this study using DMA, TGA and DSC analysis methods, while the effect of reinforcement type and different stacking sequences of fabric plies on the thermo-mechanical properties of composite samples were also investigated.

2 Materials and methods

2.1 Materials

E-glass and carbon fabrics were used as reinforcement material, while unsaturated polyester resin was used as matrix material. Fabric parameters are given in Table 1. The matrix system included an accelerator (cobalt) and hardener (methyl ethyl ketone peroxide-MEKP), together with polyester resin. The ratio of polyester:cobalt:MEKP was 1:0.00175:0.002 by weight.

2.2 Methods

A vacuum infusion system was used as the production method for composite laminates (Figure 1). Fabrication was carried out at the room temperature (20 °C ±2 °C). Four composite samples, one of which had eight plies of E-glass fabric (GGGGGGGG), one of which had eight plies of carbon fabric (CCCCCCCC) and two of which had both E-glass and carbon fabrics with different stacking sequences (GGCCCCGG, CCGGGGCC), were manufactured. A CNC milling machine was used for cutting the samples to the required dimensions.
An RMI DX04T dynamic mechanical analyser with a three-point bending configuration was used for the dynamic mechanical analysis of composite samples. Samples measuring 10 mm x 50 mm were cut from composite plates. Tests were performed at a frequency of 1 Hz, while temperature programs were run from 30 to 150 °C under a controlled sinusoidal strain, at a heating rate of 3 °C/min.
A Mettler Toledo TGA/SDTA851e analyser was used for thermogravimetric analysis. Samples weighing between 6 and 7 mg were heated from 25 °C to 600 °C with a heating rate of 5 °C/min in a nitrogen atmosphere.

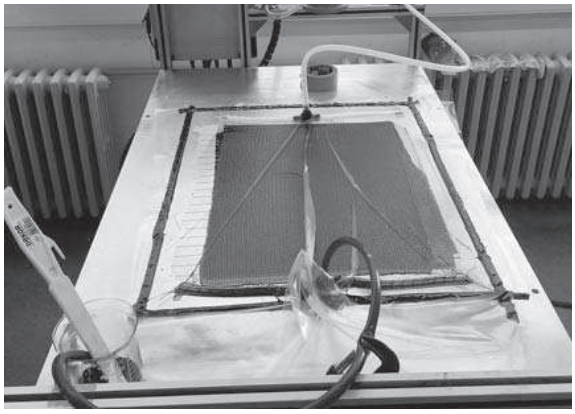

Figure 1: Vacuum infusion system

Table 1: Fabric parameters

Fabric type	Areal density [g/m^2]	Thickness [mm]	Warp X weft densities [ends/cm X picks/cm]
E-glass	300	0.57 (±0.02)	3X2
Carbon	300	0.43 (±0.008)	6X5

A DSC-6 Perkin–Elmer differential scanning calorimeter was used for differential scanning calorimetry. Samples weighing approximately 8 mg were heated from 25 °C to 200 °C at a heating rate of 10 °C/min, with a pause of one minute at 25 °C. They were then cooled to 25 °C at a rate of 10 °C/min.

3 Results and discussion

3.1 Dynamic mechanical analysis

Figure 2 shows the variation of storage modulus results of the samples as a function of temperature. Storage modulus demonstrates the elastic behaviour of a material and is proportional to the energy stored in one cycle [17].

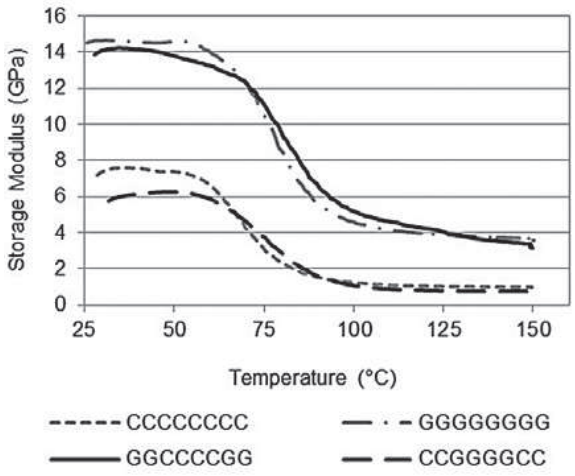

Figure 2: Storage modulus results of samples

It was shown that the storage modulus values of composites are found to decrease as temperature increases as the result of a loss in the stiffness of fibres at high temperature [9]. The E-glass-reinforced composite sample and the hybrid sample with E-glass fabric plies at the outer layers demonstrated the highest storage modulus values. It was shown while studying the storage modulus values of samples at 30 °C that while the storage modulus values of GGGGGGGG and GGCCCCGG samples were approximately 14 GPa, the storage modulus values of CCCCCCCC and CCGGGGCC samples were between 6 and 8 GPa. Although there was a decrease in the storage modulus values of all samples as temperature was increased, GGGGGGGG and GGCCCCGG samples maintained higher storage modulus values (approximately 4 GPa at between 100 and 150 °C) than the other samples (approximately 1 GPa at between 100 and 150 °C) at higher temperatures.

Figure 3 shows the loss modulus results of the samples. Loss modulus demonstrates the viscous behaviour of a material and is proportional to the energy dissipated in one cycle [17].

Similar to storage modulus results, it was shown that the E-glass-reinforced composite sample and the hybrid sample with E-glass fabric plies at the outer layers had the highest loss modulus values (2 GPa). Moreover, it was shown that the peak point of the loss modulus curve of the carbon fabric-reinforced sample also reached 2 GPa, but at a lower temperature.

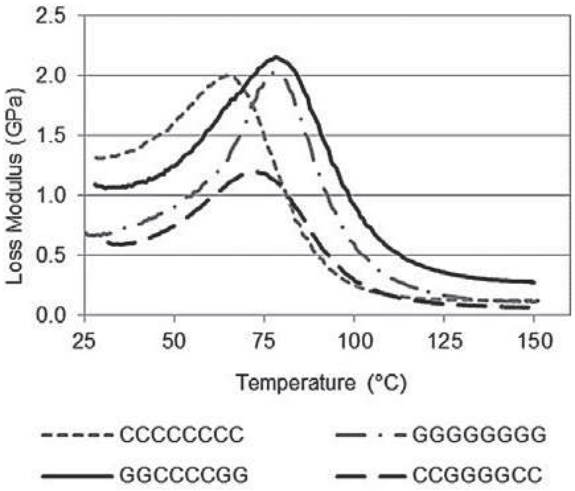

Figure 3: Loss modulus results of samples

Figure 4 shows the tangent delta results of samples. The ratio of loss modulus to storage modulus is known as the tan delta, while the peak points

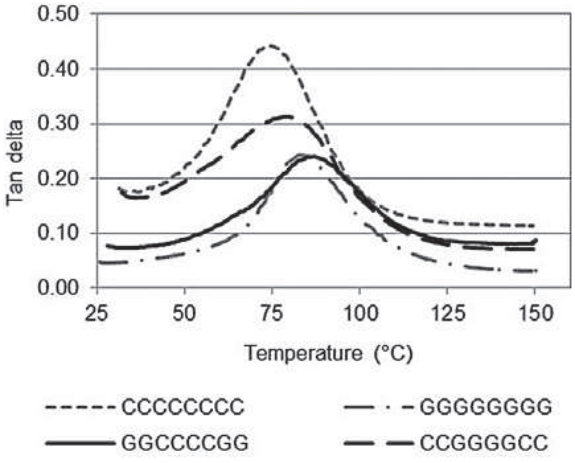

Figure 4: Tangent delta results of samples

Table 2: Thermogravimetric analysis results of samples

Sample codes	Initial weight [g]	Final weight [g]	Weight loss [%]	Onset temperature [°C]
CCCCCCCC	6.32	4.20	33.54	317.70
GGGGGGGG	6.59	4.51	31.56	309.91
CCGGGGCC	6.61	4.72	28.59	311.62
GGCCCCGG	6.54	4.89	25.22	309.64

of the of the lines show the glass transition temperatures (T_g) of the materials [17]. We observed that GGGGGGGG and GGCCCCGG samples had higher T_g values than the other samples. It is a well-known fact that E-glass is very durable to heat. Thus, by reinforcing polyester resin with E-glass fibre, the temperature point at which the composite changes from a glassy state to a rubbery state becomes higher than that of the carbon fibre-reinforced sample.

3.2 Thermogravimetric analysis

TGA results (weight loss and onset temperature) are given in Table 2. It can be seen from Table 2 that the onset temperatures of all samples were approximately the same (around 310 °C). It is a well-known fact that E-glass and carbon fibres begin to degrade at 850 °C and 300 °C, respectively [18]. Because the samples were heated to 600 °C, we can conclude that E-glass fibre does not begin to degrade during the measurement process. It can be observed, however, from TGA results that the degradation temperature of the E-glass-reinforced sample was also around 310 °C. This fact shows that polyester resin also begins to degrade at about same temperature.

When the weight losses of composite samples were taken into account, it was shown that hybrid samples had lower weight losses than the other samples. It can thus be concluded that hybrid samples are more durable than the other samples.

3.3 Differential Scanning Calorimetry

The results of the DSC analysis of samples are given in Figure 5. Samples were heated from 25 °C to 200 °C. It was shown that none of the samples demonstrated any endothermic or exothermic reactions between these temperatures. This can be explained by the thermal characteristics of matrix and reinforcement materials. The polyester that was used in this study is a thermoset polyester that does not have a melting point. Moreover, as previously mentioned, E-glass and carbon fibres are very durable to heat.

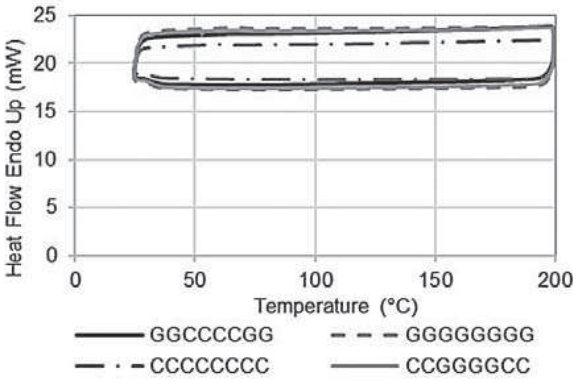

Figure 5: Differential scanning calorimetry results of samples

Although it cannot be seen precisely from the above figure, the glass transition temperatures of samples were obtained from DSC graphs. Table 3 shows the glass transition temperatures of samples that were

Table 3: Glass transition temperatures of samples from loss modulus, tangent delta and differential scanning calorimetry curves

Sample codes	T_g (loss modulus) [°C]	T_g (tan delta) [°C]	T_g (DSC) [°C]
CCCCCCCC	66.2	75.3	60.4
GGGGGGGG	79.0	85.0	67.0
CCGGGGCC	72.9	79.6	65.8
GGCCCCGG	78.9	87.6	61.4

obtained from loss modulus, tangent delta and differential scanning calorimetry curves. The highest T_g values were achieved with the eight-ply E-glass-reinforced samples. It was also seen that the T_g values obtained from tan delta curves were higher than other values.

4 Conclusion

In conclusion, the DSC analysis indicated that composite samples did not demonstrate any phase changes until 200 °C. Moreover, the TGA results demonstrated that hybrid samples had a lower weight loss than the other samples and that all samples began to degrade at around 310 °C. We also observed that the stacking sequence had a significant effect on the dynamic mechanical properties of E-glass/carbon hybrid polyester composites. The E-glass-reinforced sample and hybrid sample with E-glass fabric at the outer layers had higher modulus values than the other samples. We can conclude that E-glass fabric-reinforced samples displayed higher viscosity and elasticity than the carbon fabric-reinforced samples. In addition, higher viscosity and elasticity in hybrid structures were obtained by placing E-glass fabric plies at the outer layers of the structure.

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