DYNAMIC PERFORMANCE ANALYSIS OF KNITTED FABRIC TUNGSTEN-REINFORCED GLASS FIBER COMPOSITE

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ABSTRACT

In this study, the mechanical and dynamic performances of knitted fabric reinforced composites with and without tungsten filler were investigated. The composites were produced by hand lay-up and compared in terms of elastic modulus, flexural stiffness, first natural frequency, and damping ratio. The results showed that the addition of tungsten increased the elastic modulus, first natural frequency, and flexural stiffness, while the damping ratio decreased.

INTRODUCTION

Lightweight design and high strength are of significant importance in engineering applications, leading to the extensive use of composite structures. In recent years, textile-reinforced composites have gained particular attention due to their high specific strength and stiffness. However, when lightweight design is prioritized, vibration-related issues may arise in structures subjected to dynamic loading. [1].

The mechanical and dynamic properties of fibre-reinforced polymer composites can be modified by incorporating micro- or particulate fillers. [2] Previous studies have shown that particle addition can influence stiffness, natural frequency, and damping behaviour. [3] Therefore, understanding the effect of filler addition on the dynamic performance of textile-reinforced composites is important for their engineering applications.

AIM OF THE STUDY

In this study, it is aimed to investigate the effects of tungsten filler addition on the mechanical and dynamic performance of knitted fabric reinforced composites.

MATERIAL

136 Tex glass multifilament yarns were used to produce 1×1 rib knitted fabric reinforcements on a 7-gauge V-bed flat knitting machine. The stitch density of the knitted fabrics was 32 loops/cm². Micro-sized tungsten particles (<44 μm) were used as filler material. Huntsman Araldite LY1568 epoxy resin and Aradur 3489 hardener were used as the matrix system with a mixing ratio of 3:1 by weight.

COMPOSITE SPECIMEN DESIGN

Four layers of knitted fabrics were stacked in a [0/90/0/90] lay-up configuration. The 0° direction represents the wale direction of the top fabric layer, while the 90° direction represents the course direction. Two composite configurations were prepared: D without tungsten filler and M1 with a 20 wt.% tungsten filler ratio. The structural and physical properties of the composite specimens are presented in Table 1.

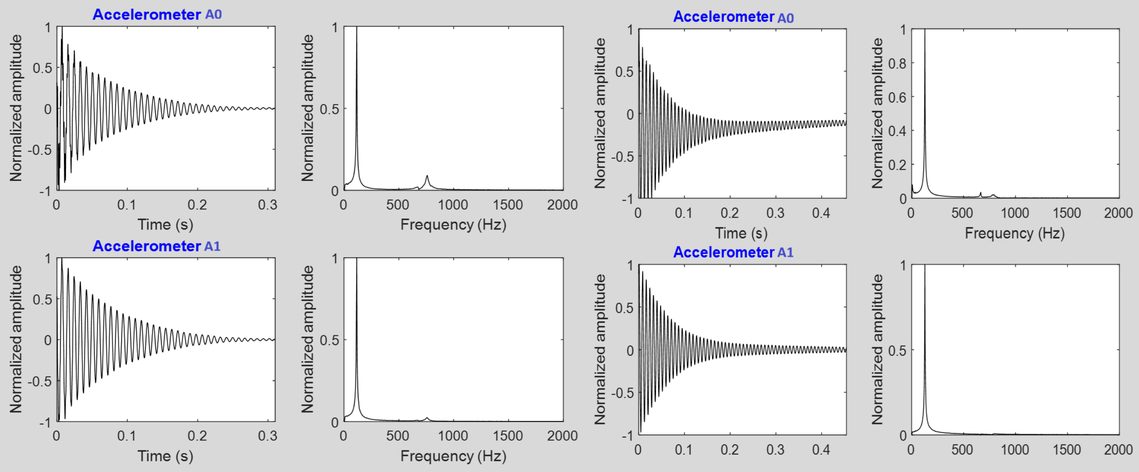


Figure 3. Free vibration response and frequency domain of the composite beams. (a) Knitted fabric reinforced glass fiber composite beam, (b) tungsten-reinforced knitted fabric glass fiber composite beam.

METHOD

Flexural Test

Flexural tests were performed in three-point bending loading according to ASTM D7264 using a Shimadzu AG-IC universal testing machine, as shown in Figure 1. The tests were conducted at a displacement rate of approximately 4 mm/min. Force–displacement data were recorded during the tests, and the bending stiffness and maximum force of the composite specimens were determined.

Free Vibration Test

Free vibration tests were conducted on the composite beams under clamped-free boundary conditions, as shown in Figure 2. The specimens were excited using a PCB 086C01 impact hammer, while the vibration responses were measured using two PCB 352A24 accelerometers (A0 and A1). The accelerometers had a mass of 0.8 g, a sensitivity of 100 mV/g, and a frequency range of 0.4–12,000 Hz. Vibration signals were acquired using an NI PXI 4496 data acquisition system and LabVIEW at a sampling rate of 10,000 Hz.



Figure 1. Experimental setup for the three-point bending test

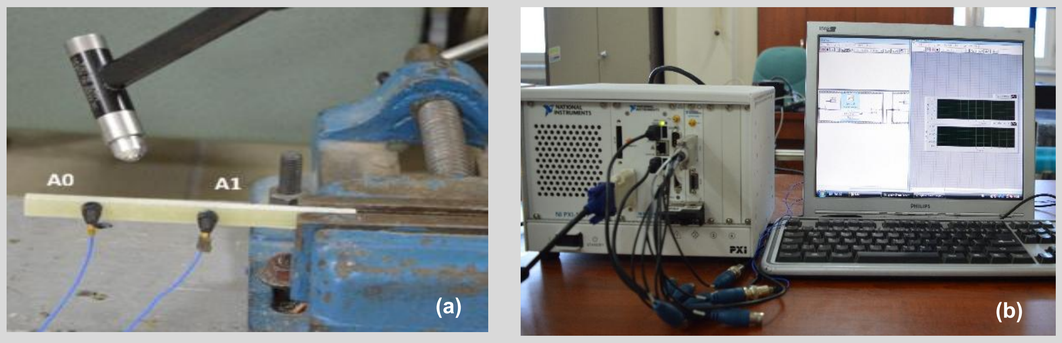


Figure 2. Vibration Test (a) Test rig, (b) Data acquisition system.

Dynamic Parameter Determination

The damping ratios were determined using the logarithmic decrement method from the free vibration responses. The decay of the time-domain acceleration signals was evaluated using 10 successive vibration peaks. The analysis focused on the first natural frequency, which dominated the vibration response. In addition, the elastic modulus of each composite beam was calculated from its first natural frequency using the relationship given in Equation (1) and Equation (2).

$$f_1 = \frac{\beta_1^2}{2\pi L^2}\sqrt{\frac{EI}{\rho A}} \qquad E = \frac{\left(2\pi f_1 L^2\right)^2}{\beta_1^4}\frac{\rho A}{I}$$

Equation 1. First natural frequency and elastic modulus calculations

$$\lambda_1 = 2\pi f_1 L^2\sqrt{\frac{\rho A}{EI}}$$

Equation 2. Dimensionless first natural frequency parameter

where λ_1 is the dimensionless first natural frequency parameter, f_1 is the first natural frequency (Hz), L is the beam length (m), ρ is the material density (kg/m³), A is the cross-sectional area (m²), E is the elastic modulus (N/m), and I is the second moment of area of the cross-section (m⁴), β_1 is the dimensionless characteristic coefficient for the first vibration mode ($\beta_1 \approx 1.875$ for a clamped-free beam)

Table 1. Composite Specimen Properties

Specimen	Knit structure	Stitch density (loops/cm²)	Density (g/cm³)	Lay-up	Filler amount by weight of the composite	Weight (kg/m²)
D	1x1 rib	32	1.43	[0/90/0/90]	0%	6.9
M1	1x1 rib	32	1.77	[0/90/0/90]	20%	8.0

RESULTS & DISCUSSION

The use of tungsten filler increased the stiffness of the knitted fabric composites. The elastic modulus increased from 2.99 to 4.57 GPa, while the bending stiffness increased from 19.12 to 28.15 N/mm. The maximum bending force also increased from 132 to 154 N, showing that the tungsten-filled specimen (M1) was stiffer than the tungsten-free specimen (D). Bhattacharjee and Roy (2020) also reported an increase in tensile strength and Young's modulus with increasing Al_2O_3 filler content in glass fibre/epoxy composites. As shown in Table 2, the tungsten-filled specimen (M1) had higher elastic modulus, bending stiffness, and maximum bending force values than the tungsten-free specimen (D).

Table 2. Mechanical and dynamic properties of the composite specimens

Specimen	Elastic modulus (GPa)	First natural frequency parameter (λ_1)	Damping ratio (ζ_1)	Flexural Performances	
				Bending Stiffness (N/mm)	Maximum force (N)
D	2.99	3.50	0.036	19.11	132
M1	4.57	4.30	0,023	28.15	154

Bommegowda et al. (2021) reported that silicon carbide (SiC) filler increased the storage modulus of glass fibre/epoxy composites from approximately 8,500 to 12,500 MPa. They also found that the SiC-filled composite had a lower damping factor than the composite without particulate filler.

Murcinkova et al. (2022) reported better damping results with smaller filler particles in polymer-matrix composites. They also found that increasing the short carbon fibre content from 3% to 12% increased damping by approximately 8%. In the present study, tungsten filler increased the stiffness-related mechanical properties and the first natural frequency parameter, while the damping ratio decreased.

In terms of dynamic behaviour, the first natural frequency parameter increased from 3.50 to 4.30, whereas the damping ratio decreased from 0.0359 to 0.0235. As shown in Figure 3, the free vibration responses and frequency-domain results of D and M1 show differences between the tungsten-free and tungsten-filled specimens. The increase in bending stiffness, together with the higher elastic modulus, indicates a stiffer response for M1. However, the lower damping ratio shows that the tungsten-filled specimen has a reduced ability to dissipate vibration energy. Rafiee et al. (2019) reported that low carbon nanotube (CNT) filler content increased the natural frequency of fiberglass/epoxy composites, while the damping ratio decreased. However, at higher filler contents, the natural frequency increased and the damping ratio decreased.

CONCLUSION

The results showed that tungsten filler improved the stiffness-related mechanical and dynamic performance of knitted fabric reinforced composites. The tungsten-filled specimen (M1) showed higher elastic modulus, bending stiffness, and maximum bending force compared with the tungsten-free specimen (D). The elastic modulus increased from 2.99 to 4.57 GPa, while the bending stiffness increased from 19.12 to 28.15 N/mm. The first natural frequency parameter also increased from 3.50 to 4.30, showing a higher stiffness-related response for M1.

However, the damping ratio decreased from 0.0359 to 0.0235 with tungsten filler, indicating a reduction in vibration energy dissipation capability. The weight per unit area also increased from 6.9 to 8.0 kg/m². Overall, tungsten filler provided a significant improvement in stiffness-related properties, accompanied by increased weight and reduced damping ratio. These results show the importance of considering both stiffness and damping properties when evaluating the performance of tungsten-filled composites.

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