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# THE EFFECT OF NONWOVEN REINFORCEMENT ON FLEXURAL STRENGTH OF GLASS, CARBON AND HYBRID COMPOSITES

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***ABSTRACT:*** This study examines the effect of nonwoven polypropylene veils on the flexural strength (3 and 4-point) of various layers of glass, carbon, and hybrid (glass and carbon) composite structures. The eight layers of the composite structures were manufactured using the vacuum infusion method with woven glass and carbon fabrics in various layer configurations. The flexural strength and elongation of the composites were found to be effectively influenced by the placement and number of nonwoven polypropylene reinforcement veils in the multilayer composite material.

***Keywords:*** Nonwovens, hybrid composite, flexural strength, mechanical properties, glass fiber, carbon fiber

## DOKUSUZ YÜZEY KUMAŞ TAKVİYESİNİN CAM, CARBON VE HİBRİT KOMPOZİTLERİN EĞİLME DAYANIMINA ETKİSİ

***ÖZ:*** Bu çalışmada, polipropilen dokusuz yüzey kumaşların cam, karbon ve hibrit (cam ve karbon) kompozit yapıların farklı katmanlarında kullanımlarının eğilme dayanımlarına (3 ve 4 noktalı) olan etkileri karşılaştırmalı olarak incelenmiştir. Kompozit yapılar, karbon ve cam dokuma kumaştan farklı katman dizilimlerinde ve 8 katlı olacak şekilde, vakum infüzyon metodu ile üretilmişlerdir. Dokusuz yüzey kumaş takviyesinin çok katmanlı kompozit malzemede bulunduğu konumun ve kat sayısının, kompozitlerin eğilme dayanımları ve uzama miktarları üzerinde etkili olduğu görülmüştür.

***Anahtar Kelimeler:*** Dokusuz yüzey kumaş, hibrit kompozit, eğilme dayanımı, mekanik özellikler, cam lifi, karbon lifi

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## 1. INTRODUCTION

Carbon or glass fiber-reinforced composites are widely employed in a variety of applications (aerospace, civil engineering, automotive, marine, military, and so on) due to their unique attributes such as low cost, light weight, specific mechanical capabilities, and corrosion resistance [1-4]. Epoxy or vinyl ester are one of the most commonly used matrix materials for fiber reinforced composites because of its high strength, low water absorption, and great thermal and dimensional stabilities [5-10]. Despite its numerous benefits, epoxy is brittle and has poor resistance to crack initiation and propagation, resulting in low fracture toughness [11].

There are several techniques to improve interlaminar fracture and delamination resistance of thermoset composites, including the use of nanofiller, rubber particles, and thermoplastic veils [12-16]. It has been demonstrated that adding thermoplastic veils to fiber-reinforced composites greatly increases the interlaminar fracture toughness. For the non-meltable veils, thermoplastic fiber bridging and matrix toughening serve as the primary toughening mechanisms [17].

A substantial and expanding amount of research has explored the use of thermoplastic veils to improve the mechanical properties of thermoset composites. Tarih et al. [18] constructed carbon fiber (CF) and glass fiber (GF) reinforced epoxy composites interleaved with different thermoplastic veils such as polyamide (PA), polyetheretherketone (PEEK), polyetherimide (PEI), polyimide (PI), and polyphenylene sulphide (PPS). They discovered that local deformation hardening increased bending stiffness in composite specimens, while thermoplastic veil interleaving improved dynamic characteristics through higher toughness and delamination resistance. Kilicoglu et al. [19] developed electrospun fiber veils based on polycaprolactone (PCL) and polyamide (PA6) blends in various ratios to strengthen carbon fiber reinforced composites against fracture. They discovered that adding fibrous blends of PA6 to the composite surfaces caused improvements in GIC interface toughness values at both the crack initiation and propagation stages. Quan et al. [20] used nonwoven veils based on polyethylene-terephthalate (PET), polyphenylene-sulfide (PPS), and polyamide-12 (PA) fibers as interlayers of unidirectional, non-crimp fabric, and woven carbon fiber/epoxy laminates. The researchers discovered different forms of toughening. Specifically, the addition of PA veils increased the fracture toughness of the epoxy matrix, whereas the interlaying of PET and PPS veils introduced substantial thermoplastic fibre bridging. Kuwata and Hogg [21] used a variety of nonwoven interleaf veils, including carbon, polyester (PE), hybrid (polyester/carbon), and polyamide (PA) fibers, to study the interlaminar toughness of carbon fibre reinforced composites. The Mode-I interlaminar toughness of composites made with polyester veil in the inter-ply area demonstrated significant improvements while the lowest Mode-I interlaminar toughness was found in carbon veil interleaved laminates. Inal et al. [22] studied the effect of thermoplastic nonwoven veils on the interlaminar fracture energy and toughening mechanisms of carbon fiber-epoxy laminates by placing polyetherimide (PEI) and polyphenylene sulphide (PPS) veils between carbon fiber non-crimp fabric preforms. According to their findings, applying of PPS veils increased fracture energy because of a progressive debonding of the fiber matrix, which was followed by bridging and pull-out of the fiber. Beylergil et al. [23] examined the delamination resistance of carbon fibre/epoxy composites at two distinct areal weight densities that were interleaved with nonwoven veils made of polyamide-6,6 (PA 66). Their findings revealed that the addition of PA nonwoven veils improved the interlaminar shear and Charpy impact strength of the composites by 25% and 15%, respectively. However, PA 66 veils decreased the in-plane mechanical properties such as tensile and flexural strength of CF/EP composites due to a lower carbon fibre volume fraction. Narongdej et al. [24] reinforced carbon fiber reinforced composites employing nonwoven polyamide (PA) veils with an area density of 12 gsm. They discovered that the lower resin level in interleaved samples during processing caused a more pronounced decrease, decreasing the adhesion between the PA veil and matrix. This led to noticeably reduced fracture toughness values by making it easier for cracks to spread throughout the composite. Saz Orozco et al. [25] studied the impact of two thermoplastic microveils, polyamide (PA) and polyethylene terephthalate (PET), on the interlaminar fracture toughness of glass fibre/vinyl ester composites. Their microscopic analysis revealed that the PA veil enhanced fiber bridging between neighboring plies and played a significant impact in improving Mode I interlaminar fracture toughness. However, the PET had no effect on the delamination or energy absorption mechanism.

Over the last two decades, there has been an increase in research into the use of various types of thermoplastic nonwoven veils to improve the fracture toughness qualities of glass or carbon fiber-reinforced composites. However, there is little research evidence on how thermoplastic nonwoven veils effect hybrid composite laminates. As a result, this research studies the impact of various stacking sequences of polypropylene nonwoven veils on the flexural characteristics of carbon, glass, and carbon/glass fiber-reinforced composites.

## 2. MATERIALS AND METHODS

### 2.1. Materials

Table 1 displays the characteristics of glass, carbon woven fabric, and polypropylene nonwoven surface. The reinforcing nonwoven material is a 100% polypropylene (PP) meltblown mat.

### 2.2. Methods

As seen in Figure 1, the PP nonwoven layers were placed between the carbon and glass fabrics in a variety of stacking configurations. In order to study the effect of nonwoven insertion, some composite preforms (PG, PC, PCGC, and PGCG) are devoid of any nonwoven layers. When the preforms were prepared, the vacuum infusion process was employed to infuse them with Poliya Polives 702 vinyl ester resin. Prior to curing, the resin was combined with 0.2% by weight of 6% Cobalt (accelerator) until a homogenous mixture was achieved at room temperature. After adding 1-2% MEK-P (hardener), the mixing process continued on for a further five minutes. Using the inlet hose, the prepared resin mixture was vacuum-fed into the preforms. After finishing the procedure, it was allowed to cure for two hours at room temperature without the vacuum being turned off. Table 2 presents the composite laminates with the sample codes and nonwoven arrangements. For instance, G-NW-1-2 presents a glass composite reinforced with two nonwoven veils between the 4th and 5th layers, while G-NW-1-3 has three nonwoven veils between the 4th and 5th layers.

The three- and four-point flexural strength of all composite plates was evaluated using the ASTM D7264 standard test method on a Hounsfield H5KS testing equipment. The distance between the supports was 32 times the thickness of the specimen, the test speed was 2 mm/min. Bending tests were carried a load parallel to the warp yarn axis. For each production type, five specimens were tested, and results were averaged. Figure 2 depicts the photos captured during the three- and four-point bending tests. The flexural strength and strain values were calculated using formulae 1-2 for 3-point bending and 3-4 for 4-point bending tests.

$$\sigma_3 = \frac{3PL}{2bd^2} \tag{1}$$

$$\varepsilon_3 = \frac{6Dd}{L^2} \tag{2}$$

$$\sigma_4 = \frac{3PL}{4bd^2} \tag{3}$$

$$\varepsilon_4 = \frac{4.36Dd}{L^2} \tag{4}$$

Where; σ: flexural strength, ε: maximum strain at the outer surface, L: support span, P: applied force, b: specimen width, d: specimen thickness, D: mid-span deflection.

**Table 1.** Properties of reinforcement materials

| Material | Pattern | Linear density | | Density (yarn/cm) | | Areal density (g/m²) |
|---|---|---|---|---|---|---|
| | | Warp | Weft | Warp | Weft | |
| Glass | twill | 320 Tex | 320 Tex | 6 | 6 | 300 |
| Carbon | twill | 3K | 3K | 6 | 6 | 245 |
| PP | nonwoven | - | - | - | - | 12 |

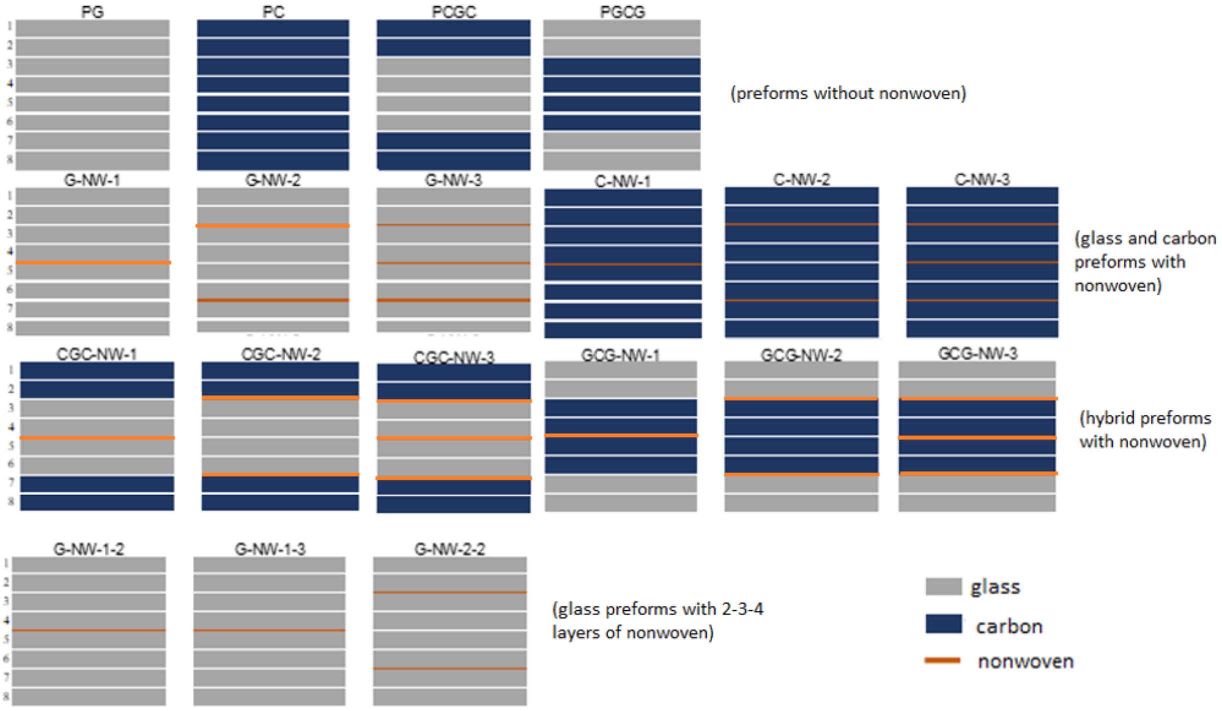


**Figure 1.** stacking sequence of composite preforms

**Table 2.** composites with sampe codes and stacking sequences

| No | Code | Number of layers | Stacking sequence | Non-wowen | | |
|---|---|---|---|---|---|---|
| | | | | **Reinforcement** | **Position** | **Amount** |
| 1 | PG | 8 | glass | - | - | - |
| 2 | PC | 8 | carbon | - | - | - |
| 3 | PCGC | 8 | 2 carbon/2 glass/2 glass/2 carbon | - | - | - |
| 4 | PGCG | 8 | 2 glass/2 carbon/2 carbon/2 glass | - | - | - |
| 5 | G-NW-1 | 8 | glass | + | 4-5 | 1 |
| 6 | G-NW-2 | 8 | glass | + | 2-3 / 6-7 | 1 |
| 7 | G-NW-3 | 8 | glass | + | 2-3 / 4-5 / 6-7 | 1 |
| 8 | C-NW-1 | 8 | carbon | + | 4-5 | 1 |
| 9 | C-NW-2 | 8 | carbon | + | 2-3 / 6-7 | 1 |
| 10 | C-NW-3 | 8 | carbon | + | 2-3 / 4-5 / 6-7 | 1 |
| 11 | CGC-NW-1 | 8 | 2 carbon/2 glass/2 glass/2 carbon | + | 4-5 | 1 |
| 12 | CGC-NW-2 | 8 | 2 carbon/2 glass/2 glass/2 carbon | + | 2-3 / 6-7 | 1 |
| 13 | CGC-NW-3 | 8 | 2 carbon/2 glass/2 glass/2 carbon | + | 2-3 / 4-5 / 6-7 | 1 |
| 14 | GCG-NW-1 | 8 | 2 glass/2 carbon/2 carbon/2 glass | + | 4-5 | 1 |
| 15 | GCG-NW-2 | 8 | 2 glass/2 carbon/2 carbon/2 glass | + | 2-3 / 6-7 | 1 |
| 16 | GCG-NW-3 | 8 | 2 glass/2 carbon/2 carbon/2 glass | + | 2-3 / 4-5 / 6-7 | 1 |
| 17 | G-NW-1-2 | 8 | glass | + | 4-5 | 2 |
| 18 | G-NW-1-3 | 8 | glass | + | 4-5 | 3 |
| 19 | G-NW-2-2 | 8 | glass | + | 2-3 / 6-7 | 2+2 |

Fiber volume ratios of composite materials comprising only glass were determined using the BS EN ISO 1172:1999 test standard. Composite densities were determined using the ASTM D792 - 08 test procedure. After measuring the densities, the samples were allowed to dry before being weighed. The weights were measured and then placed in a muffle furnace at 650 º C for 2 hours to remove the vinyl ester and nonwoven fabric. The burning procedure was exclusively employed for composites comprising glass/vinyl ester. This is because carbon fibre degrades with vinyl ester at high temperatures, causing calculations to fail. As a result, the amount of fibre in carbon-based composites was determined theoretically using formula (5). Where: Vf: volume fraction of fibre, Wf: weight of fiber in the composite, df: fiber density, L sample length, w: sample width, h sample thickness, gr: fabric weight, nlayer: number of layers of fabric contained in the composite.

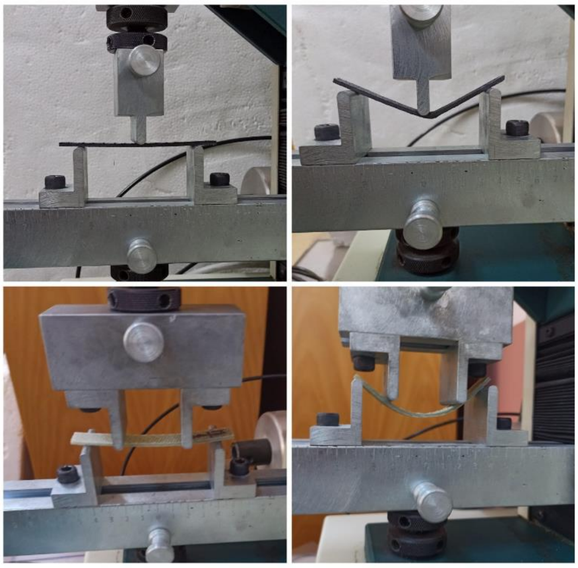


**Figure 2.** composite samples during 3 and 4-point bending tests

$$Fiber\ volume\ fraction\ (Vf)=\frac{Fiber\ volume}{Composite\ volume}=\frac{\frac{Wf}{df}}{L.w.h}=\frac{\frac{nlayer.gr.L.w}{df}}{L.w.h}=\frac{nlayer.gr}{h.df} \qquad (5)$$

## 3. RESULTS AND DISCUSSIONS

Table 3 presents the density, weight fraction, volume fraction, and thickness of the composites. It is clear that the density of PP nonwoven reinforced glass, carbon, and hybrid composites is lower than that of unreinforced glass, carbon, and hybrid composite samples. Densities reduced as the amount of nonwoven in the composite material structure increased. This decrease in density is caused by the addition of low-density PP nonwoven components. Similar findings may be found for fiber volume fraction values, which decrease with the increase of nonwoven layers.

Flexural (3 and 4-point) strengths and % elongation values of glass, carbon and hybrid composites with and without nonwoven reinforcement are presented in Table 4.

**Table 3**. Properties of composites

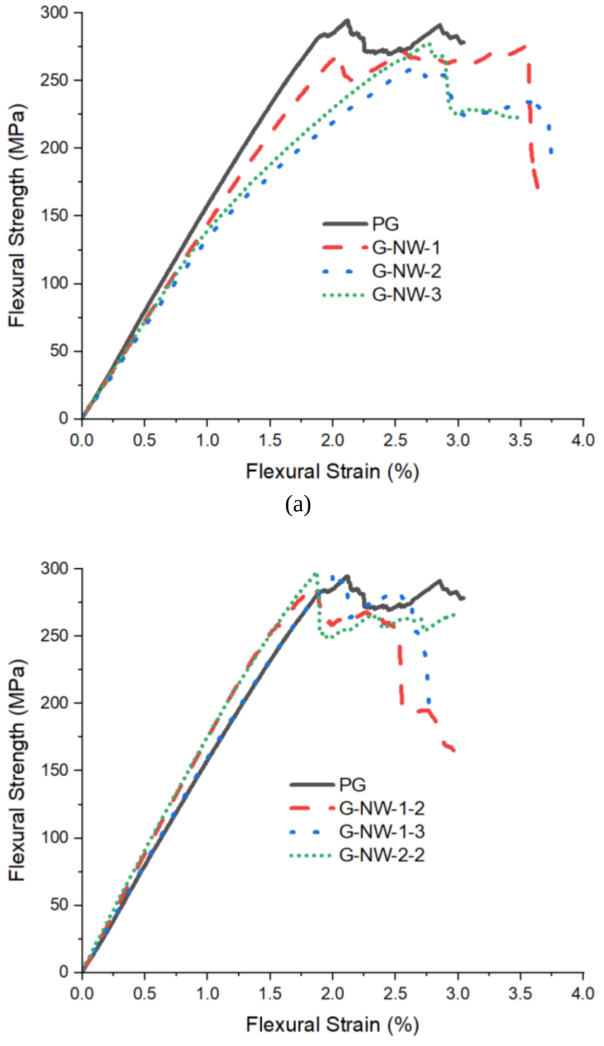
| Sample codes | Density (g/cm$^3$) | Fibre volume ratio (%) | Thickness (mm) |
|---|---|---|---|
| PG | 1.77 (± 0.012) | 42.78 (±0.51) | 2.20 (± 0.043) |
| PC | 1.45 (± 0.001) | 48.60 (±0.55) | 2.20 (± 0.009) |
| PCGC | 1.60 (± 0.002) | 44.07 (±0.26) | 2.27 (± 0.024) |
| PGCG | 1.59 (± 0.007) | 44.66 (±0.16) | 2.24 (± 0.011) |
| G-NW-1 | 1.74 (± 0.008) | 41.64 (±0.28) | 2.26 (± 0.013) |
| G-NW-2 | 1.73 (± 0.008) | 41.46 (±0.18) | 2.27 (± 0.008) |
| G-NW-3 | 1.75 (± 0.010) | 41.28 (±0.29) | 2.22 (± 0.011) |
| C-NW-1 | 1.43 (± 0.016) | 47.09 (±0.24) | 2.25 (± 0.010) |
| C-NW-2 | 1.43 (± 0.006) | 44.52 (±0.22) | 2.40 (± 0.017) |
| C-NW-3 | 1.42 (± 0.004) | 44.70 (±0.29) | 2.37 (± 0.011) |
| CGC-NW-1 | 1.50 (± 0.015) | 44.07 (±0.48) | 2.27 (± 0.018) |
| CGC-NW-2 | 1.60 (± 0.014) | 45.06 (±0.21) | 2.22 (± 0.007) |
| CGC-NW-3 | 1.60 (± 0.005) | 45.06 (±0.33) | 2.22 (± 0.011) |
| GCG-NW-1 | 1.67 (± 0.015) | 49.04 (±0.15) | 2.04 (± 0.007) |
| GCG-NW-2 | 1.65 (± 0.011) | 48.56 (±0.14) | 2.06 (± 0.005) |
| GCG-NW-3 | 1.61 (± 0.002) | 45.06 (±0.53) | 2.22 (± 0.019) |
| G-NW-1-2 | 1.77 (± 0.005) | 44.40 (±0.21) | 2.12 (± 0.008) |
| G-NW-1-3 | 1.69 (± 0.016) | 37.50 (±0.16) | 2.51 (± 0.008) |
| G-NW-2-2 | 1.67 (± 0.006) | 37.20 (±0.09) | 2.53 (± 0.008) |

**Table 4.** Flexural properties of composites

| Sample codes | 3-point bending tests | | 4-point bending tests | |
|---|---|---|---|---|
| | Flexural Strength (MPa) | Elongation (%) | Flexural Strength (MPa) | Elongation (%) |
| PG | 292.5 (±14.0) | 3.65(±0.06) | 297.3 (±45.3) | 3.59 (±0.06) |
| PC | 292.0 (±14.4) | 3.60(±0.03) | 240.1 (± 31.9) | 3.64 (±0.05) |
| PCGC | 298.9 (±9.30) | 3.41(±0.04) | 290.7 (±29.7) | 3.68 (±0.05) |
| PGCG | 303.3 (±9.40) | 3.67(±0.07) | 262.4 (±36.5) | 3.67 (±0.09) |
| G-NW-1 | 286.9 (±11.7) | 3.42(±0.09) | 305.0 (±7.90) | 3.66 (±0.05) |
| G-NW-2 | 279.9 (±15.7) | 3.43(±0.06) | 291.3 (±31.2) | 3.61 (±0.05) |
| G-NW-3 | 275.5 (±10.0) | 3.36(±0.04) | 287.2 (±39.7) | 3.58 (±0.03) |
| C-NW-1 | 345.4 (±26.5) | 3.31(±0.05) | 275.1(± 24.4) | 3.62 (±0.04) |
| C-NW-2 | 331.8 (±16.7) | 3.40(±0.05) | 305.8 (±13.2) | 3.29 (±0.05) |
| C-NW-3 | 325.2 (±11.7) | 3.28(±0.05) | 283.0 (±47.8) | 3.22 (±0.02) |
| CGC-NW-1 | 253.1 (±7.20) | 3.36(±0.02) | 246.5 (±35.6) | 3.65 (±0.04) |
| CGC-NW-2 | 281.2 (±10.7) | 3.55(±0.03) | 266.7 (±36.2) | 3.59 (±0.04) |
| CGC-NW-3 | 265.7 (±9.00) | 3.60(±0.03) | 260.2 (±19.9) | 3.58 (±0.04) |
| GCG-NW-1 | 285.5 (±13.6) | 3.88(±0.02) | 259.3 (±31.0) | 3.73 (±0.05) |
| GCG-NW-2 | 301.7 (±24.4) | 3.89(±0.02) | 225.1 (± 13.5) | 3.77 (±0.04) |
| GCG-NW-3 | 313.6 (±9.20) | 3.60(±0.02) | 274.5 (± 34.3) | 3.60 (±0.03) |
| G-NW-1-2 | 281.2 (±7.80) | 3.46(±0.04) | 277.4 (± 13.5) | 3.59 (±0.11) |
| G-NW-1-3 | 283.0 (±8.30) | 3.13(±0.04) | 265.6 (±17.7) | 3.11 (±0.04) |
| G-NW-2-2 | 291.4 (±13.5) | 2.78(±0.02) | 268.7 (± 18.2) | 3.17 (±0.01) |

### 3.1. 3-point bending test results

The data in Figures 3 and Table 4 show that nonwoven veil reinforced glass composites (G-NWs) have lower flexural strength than unreinforced glass composites (PG). Similarly, Molnar et al. [26] noticed a 12% drop in flexural strength after adding polyacrylonitrile (PAN) nanofiber veils to carbon/epoxy composites. The three-point bending test revealed an average strength loss of 1.9% in glass composite plates with a single layer (G-NW-1) of nonwoven reinforcement, 4.3% in double layers (G-NW-2), and 5.8% in triple layers (G-NW-3). Furthermore, nonwoven reinforcements reduced the flexural strength of the composite structure for both single and multilayer reinforcement. The strength losses were around 3.9%, 3.3%, and 0.4% for the G-NW-1-2, G-NW-1-3, and G-NW-2-2 samples, respectively. The reduction in flexural strength can be attributed to the addition of a PP surface to the structure, which has a lower strength than glass fiber, and the nonwoven web has no positive influence on plies adhesion.



(a)

(b)

**Figure 3. T**hree-point bending of glass fiber reinforced composites: a) one layer of nonwoven reinforcement, b) multi-layers of nonwoven reinforcement

Unlike reinforced glass laminates, Figure 4 and Table 4 show that the reinforcement material increases the three-point flexural strength in carbon composites. Bahmani et al. [27] noted comparable outcomes, indicating that the maximum flexural loads of glass/epoxy composites were positively impacted by the nonwoven polypropylene interlayer. Nonwoven reinforcing increased the flexural strength of carbon composites by approximately 18.3% for a single layer (C-NW-1), 13.6% for double layers (C-NW-2), and 11.4% for triple layers. The increase in flexural strength tended to decrease as the amount of nonwoven reinforcements in the structure increased. The elongation % of the composites was also affected by the PP reinforcement material, and carbon composites with nonwoven had lower elongation than carbon composites without reinforcement. The drop in flexural strength reported in glass composites wasn't seen in carbon composites, and the strength increased with the addition of nonwoven. This could be due to the PP nonwoven structure having greater bonding with carbon fibers than glass fabrics. Similar behaviour was reported in other studies due to fiber bridging, which resulted in strong interfacial bonding when carrying flexural load to reinforce the contact [28].

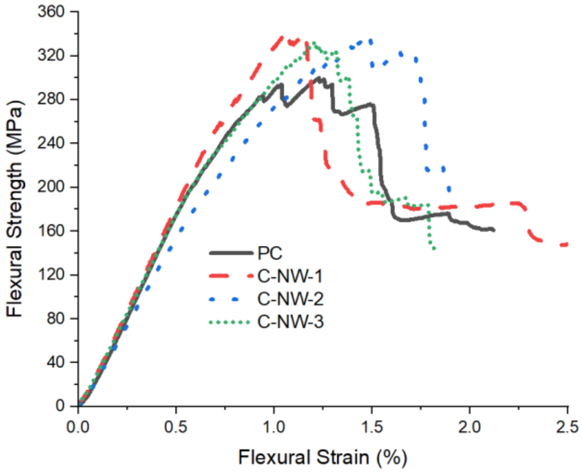


**Figure 4.** Three-point bending of carbon fibre reinforced composites

Figures 5-6 display the hybrid structures' flexural 3-point bending strengths. Examining Figure 5, it can be seen that although the PCGC sample's flexural strength value was 298.9 MPa, the addition of nonwoven (CGC-NW-1) positioned between the layers caused the flexural strength to drop to 253.1 MPa. Because the nonwoven structure was positioned in the middle, it only came into contact with the glass fabrics, weakening the composite structure's interface in a manner similar to that of the glass composite (Fig.3). Hence, the flexural strength was lowered as a result. The value reached to 281.2 MPa when the nonwoven content was increased and the adding sequence (CGC-NW-2) was altered. This rise can be attributed to the interaction between the nonwoven structures and carbon and glass structures together. The value was 265.7 MPa in the sample (CGC-NW-3) containing the largest amount of nonwoven material. For that sample, there is more glass-to-nonwoven material interaction than CGC-NW-2.

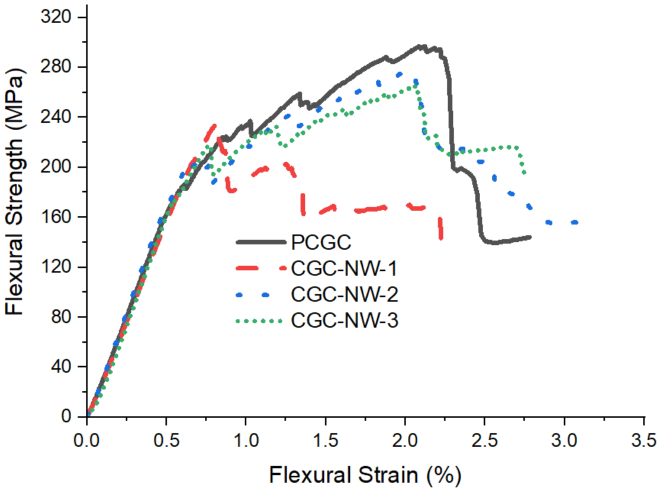


**Figure 5.** Three-point bending behavior of hybrid composites-outer layers are carbon fabric

Differences in outcomes are noted when the hybrid structures' sequencing order changed (Figure 6). As various investigations in the literature have shown, the addition of nonwoven layers may improve the flexural strength of composites by improving their ductility through a synergistic effect [29]. Without the nonwoven (PGCG) portion, the composite specimen has a flexural strength of 303.3 MPa. The strength dropped to 285.5 MPa when there was only nonwoven veil in the middle (GCG-NW-1). As the nonwoven material content increased, the strength also increased to 301.7 and 313.6 MPa. In comparison to the hybrid specimens depicted in Figure 5, the bending interfaces increased and showed larger values in these specimens because the nonwoven layers were in greater contact with the carbon fabrics, resulting in better bonding. Tarih et al. [30] observed comparable behaviour while polyether ether ketone (PEEK) and polyamide (PA) thermoplastic veils formed a new interface with epoxy, increasing interlaminar toughness and stiffness.

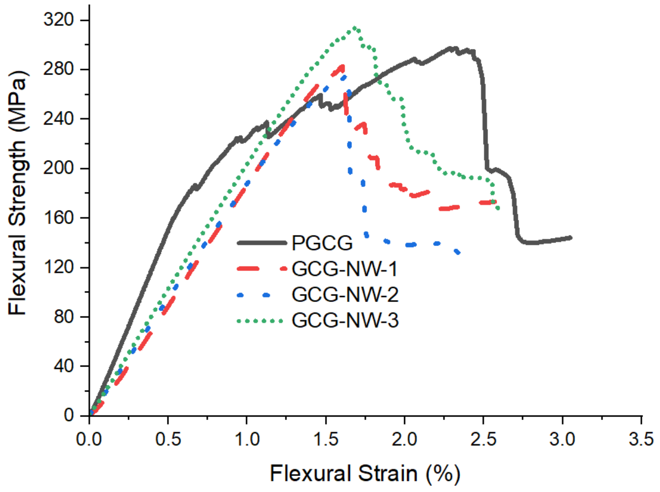
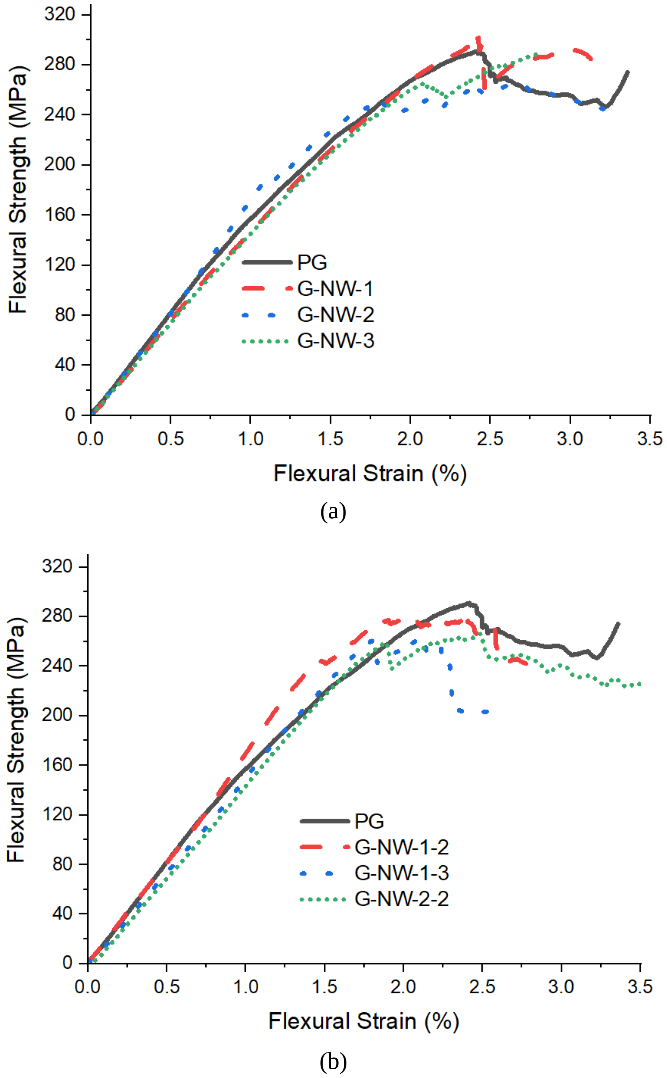


**Figure 6.** Three-point bending behavior of hybrid composites-outer layers are glass fabric

### 3.2. Four-point bending test results

Figure 7 and Table 4 show the values obtained from the four-point bending test for every layer configuration of glass-based composites. Analysis of the data reveals that the specimen with code G-NW-1 has a higher flexural strength than the other combinations of G-NW-2 and G-NW-3 plates. The delamination of the composite layers as a result of poor bonding between the vinyl ester resin, PP nonwoven, and glass fabric employed in manufacture can account for the decrease in flexural strength. The elongation values of composite have not changed significantly. The addition of multilayers in the middle (G-NW-1-2 and G-NW-1-3) or close to the surface (G-NW-2-2) reduced the 4-point bending strength of the glass composites, as demonstrated by the 3-point bending test results. It is obvious that increasing the number of nonwoven veils in the middle reduced the 4-point bending strength of composites, as G-NW-1-3 contains more nonwoven than G-NW-1-2.



(a)

(b)

**Figure 7.** Four-point bending of glass fiber reinforced composites: a) one layer of nonwoven reinforcement, b) multi-layers of nonwoven reinforcement

Figure 8 and Table 4 show the results of four-point bending tests performed on carbon composites. The flexural strength of the carbon composite rose by 11.1% for the single layer (C-NW-1) of nonwoven veil, while the double (C-NW-2) and triple (C-NW-3) veils contributed around 27.4% and 17.8%, respectively, as compared to unreinforced carbon (PC) composites. This demonstrates that the positioning of the nonwoven reinforcement in the composite laminate structure is efficient in enhancing flexural strength. The improvements in 4-point bending strengths were greater than those in 3-point bending test results. This is because the nonwoven veil structure exhibits varied plastic deformation in response to the applied load, which contributes to the structure's strength.

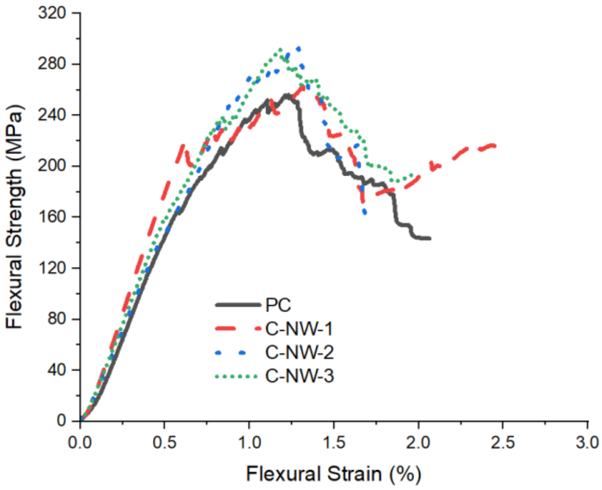


**Figure 8.** Four-point bending of carbon fibre reinforced composites

The flexural strengths of the nonwoven reinforced hybrid composites are lower than those of the hybrid composites with the same arrangement (PCGC) without PP reinforcement, according to the findings of the four-point bending test of the hybrid composite plates, which are displayed in Table 4 and Figure 9. The flexural strength decreased by 15.2%, 8.3%, and 10.5% with the addition of single layer (CGC-NW-1), double layer (CGC-NW-2), and triple layer (CGC-NW-3) nonwoven veils in this arrangement where the glass fabric is in the core of the composite. The reason for this drop-in strength can be attributed to the nonwoven material's poor interaction with the glass fabrics. Polyphenylene-sulphide (PPS) veils were employed by Quan [31] for carbon fiber/epoxy prepregs, and it was discovered that the PPS fiber/epoxy adhesion was relatively low. It can be noticed that these hybrid composites have a lower four-point bending strength than three-point bending strength. This is because there are more locations through which the offered bending load is communicated to the material.

Figure 10 and Table 4 display the four-point bending test results for hybrid composites with glass fabric on the exterior surfaces. The table and graph show that the triple layer of nonwoven veils (GCG-NW-3) in the composite design increases flexural strength when compared to the unreinforced composite (PGCG). Flexural strength reduced in the other GCG hybrid combinations with PP reinforcement (GCG-NW-1 and -2). The elongation values of GCG hybrid composite materials reduced with nonwoven reinforcing. When the four-point flexural strengths of the hybrid composites are examined based on the location of the nonwoven reinforcement, only the GCG-NW-3 hybrid composite with PP nonwoven reinforcement between the 2-3/4-5/6-7th plies show an increase in flexural strength (4.6%). In all other hybrid composites, the presence of nonwoven reinforcement in the structure resulted in decreased flexural strength. The hybrid specimen designated CGC-NW-1 lost the most strength (15.2%). When average data are compared, it is clear that hybrid composite plates with carbon fabric on the outside surface have a lower flexural strength than hybrid composite with glass fabrics.

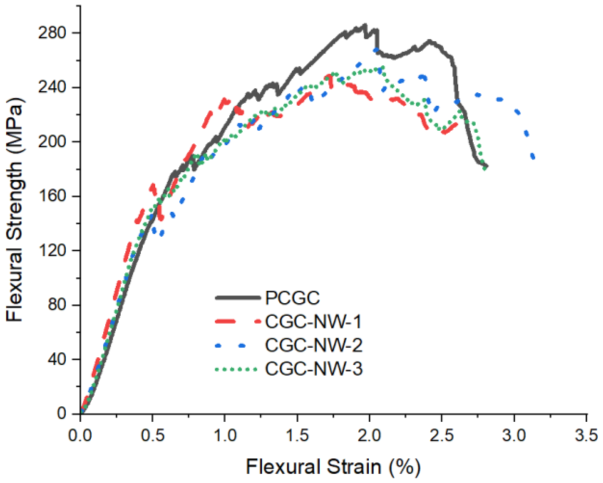


**Figure 9.** Four-point bending behavior of hybrid composites-outer layers are carbon fabric

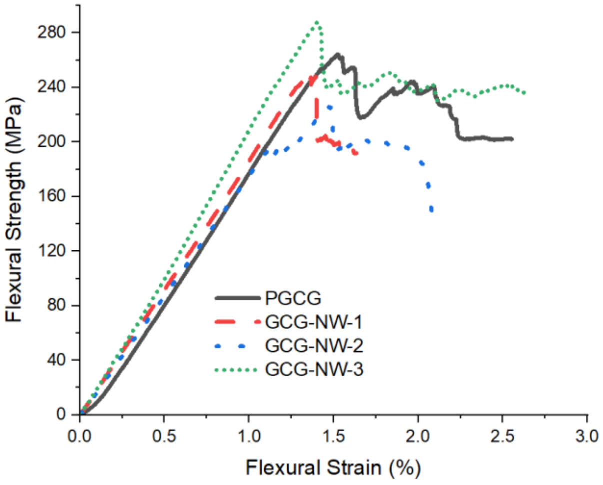


**Figure 10.** Four-point bending behavior of hybrid composites-outer layers are glass fabric

## 4. CONCLUSION

In this study, 100% polypropylene nonwoven veils were applied to glass, carbon, and hybrid (glass and carbon) composite materials to investigate the changes in mechanical properties. The results were evaluated for both reinforced and unreinforced composites. This work focusses on the influence of hybridisation on composite laminates utilising thermoplastic nonwoven veils, which is a relatively new study for fiber-reinforced composites that are frequently subjected to flexural loads. The results demonstrate that polypropylene reinforcement is a material that improves the attributes of composite structures such as flexural strength, elongation, and so on, particularly when combined with carbon fiber, in addition to its low density and cost-effectiveness. Some of the findings of the study are as follows:

- Single-ply nonwoven reinforcing of glass-based composites reduced the flexural performance of the composite material while having no noticeable effect on the material's ductility. However, it was discovered that composite with several layers of nonwoven addition were more brittle, and the elongation of glass composites dropped as the number of layers of reinforcing PP increased.
- The inclusion of nonwoven veils enhanced the four-point bending performance of the glass composites (single PP layer) by around 2.6% (from 297 MPa to 305 MPa), but it had a detrimental influence on the overall findings.
- Nonwoven reinforcement of carbon composites was found to significantly increase the strength of the composite materials in both three- and four-point bending tests. This may be due to the fact that carbon fabric forms a stronger interface with the PP nonwoven structure than glass fabric. The increase in the amount of nonwoven reinforcement had an overall negative effect on the rate of increase in flexural strength.
- After nonwoven reinforcing, hybrid plates with carbon fibre as the outer layer and glass fibre as the inner layer (CGC) demonstrated inferior flexural performance. The elongation of the hybrid composites showed no significant difference.
- When the nonwoven layers of hybrid composites came into greater contact with the carbon fabrics than the glass fabrics, better bonding occurred and the flexural strength rose.
- This study shows that nonwoven veils can be utilised to improve the flexural strength of composites if the interfacial strength between the matrix and the veils is sufficient.

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