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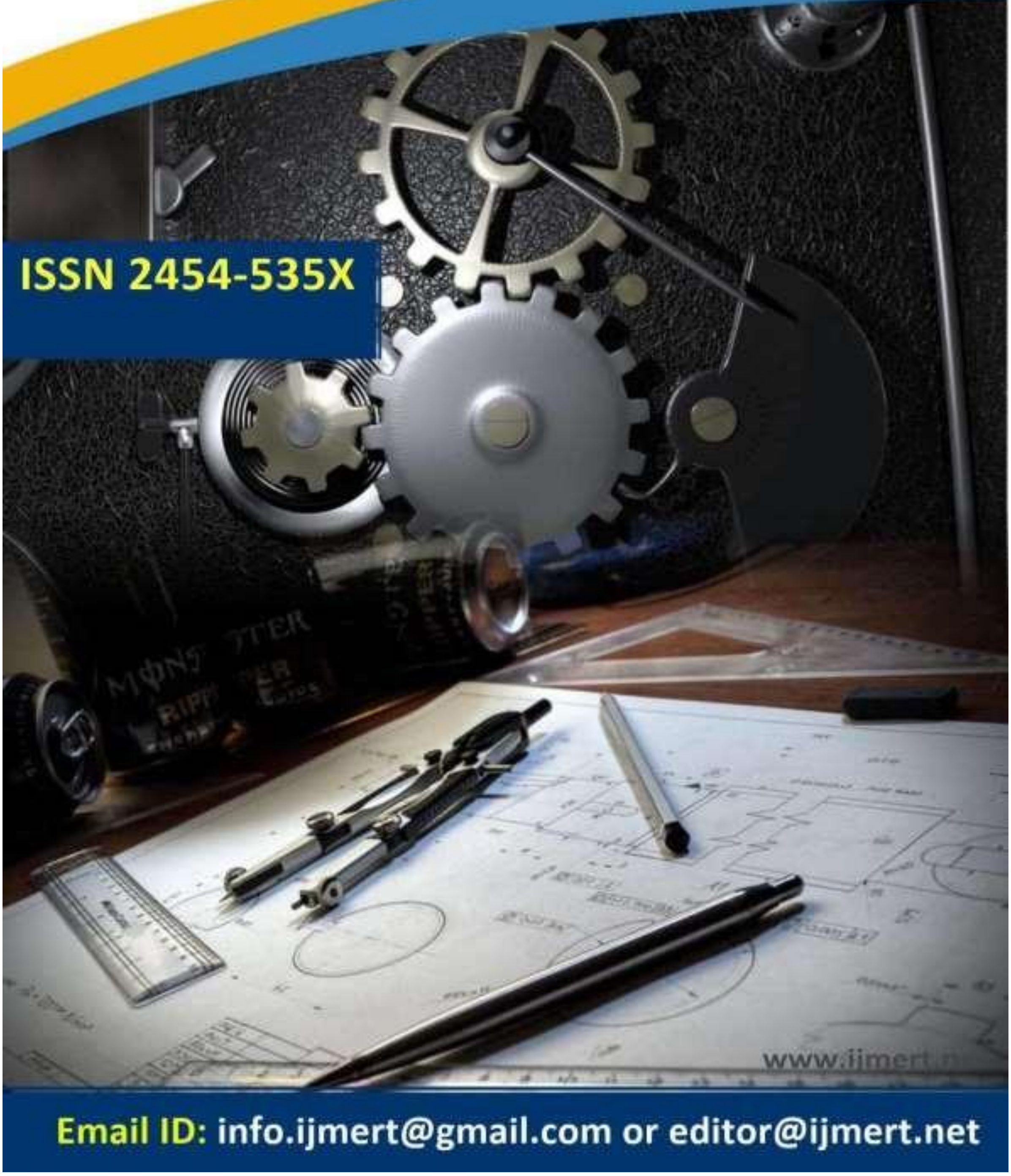

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Impacts on the combination of self-reinforced polypropylene with interlayer composites

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ABSTRACT:
Most research has concentrated on the mechanical performances of fiber-reinforced plastics (FRP) like carbon, glass, and aramid, but there has been a recent uptick in interest in creating a high-strength, lightweight composite as a possible replacement for traditional materials in a variety of industries. The hybrid composites, on the other hand, aren't as widespread, but they're thought to have great promise due to their adaptability and capacity to combine the advantages of other composites. Five different composite designs were created in this research utilizing the hand lay-up method. These designs include various kinds of woven fibers and sheets of self-reinforced polypropylene (SRPP). Depending on the manner of interlayer hybridization, several patterns are organized. Composite designs were subjected to the usual tensile and three-point flexural tests to determine their static mechanical characteristics. Carbon fiber-reinforced plastic (CFRP) shown superior tensile properties, according to the results of empirical investigations. The CFRP specimen outperformed the CAFRP specimen in terms of both tensile strength (46% higher) and elastic modulus (33% larger). In contrast to other hybrid composites and single-type carbon/aramid fiber reinforced plastics, CAFRP showed markedly improved flexural properties. In particular, the CAFRP structure outperformed the CFRP structure, showing 50% improvement in flexural strength and 19% improvement in modulus. Despite a decline in tensile and flexural strength, an improvement in overall strain level was seen with the incorporation of SRPP layers into the hybrid arrangement. Based on the results of this investigation, FRP composites are structurally strong and stiff with little elongation, while SRPP-based composites are tougher but less stiff.

1.0

INTRODUCTION

Composites are extensively used in several sectors, including aerospace and defense equipment, due to their high strength-to-weight ratio. Composites have expanded their use to various industries, including the shipping, construction, rail transportation, and automotive industries, thanks to its allure as a study subject for scientists and engineers in recent years [1, 2]. One example is the remarkable energy absorption capacity and exceptional specific mechanical characteristics of fiber-reinforced plastic (FRP) composites [3]. In addition, FRP composites' beneficial mechanical characteristics demonstrate the possibility of mass reduction in any structural and component design [4-6]. The mechanical characteristics, availability, and manufacturability of glass and carbon based FRP composites make them viable candidates for utilization as crashworthiness structures [7]. Additionally, aramid FRP are a kind of composite that is used in light-loaded constructions because of its high tensile strength and outstanding fatigue resistance [8].

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The use of hybridization in FRP composites has been on the rise as of late. Because of the substantial gain in structural flexibility compared to conventional FRP composites, this method is attracting a lot of attention. A number of benefits, including increased structural stiffness, specific strength, failure strain, resilience, and material cost, may be realized via the hybridization of composites, which allows for the merging and generation of diverse fiber properties. To save costs, researchers have looked at hybrid composite constructions made of carbon and glass fibers that are weaved together [9, 10]. When it comes to composite hybridization, there are two basic approaches: interlayer and intralayer. The focus of earlier research has been on improving flexural characteristics. Many possible hybrid combinations may be further investigated, as it has shown clearly [11, 12]. Another thermoplastic composite with good strain-to-failure and high tensile strength was found in another investigation to be self-reinforced polypropylene (SRPP). The SRPP is seen as an additional possibility for composite research and hybridization because to its high impact strength and exceptional fracture resistance [13, 14]. The main objective of this research is to analyze the consequences of combining various kinds of fibers with SRPP in interlayer composites. Carbon, glass, and aramid fibers are the materials used in this research. In order to define the impacts on the hybridization of thermoset and thermoplastic composites, SRPP sheets are also added in the mix.

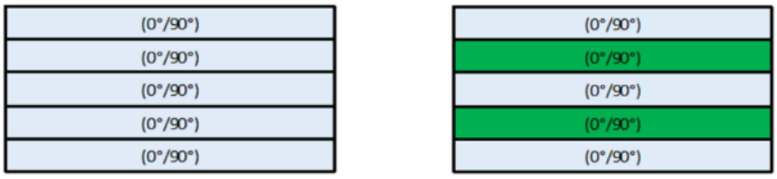
2.0 COMPOSITE MATERIALS PREPARATION

Carbon, glass, and aramid fibers are among the many kinds of materials used in this project. The chosen matrix composition is epoxy and slow-type hardener. In addition, several self-reinforced polypropylene (SRPP) thermoplastic sheets have been included into the hybrid framework. The selected approach of mixing various materials was interlayer hybrid constructions [17]. Accessibility and fundamental qualities dictated the choice of weave orientation for the raw material textiles and sheets. Here, we have twill carbon cloth, plain glass, and aramid textiles. When it comes to stability, longevity, and equilibrium, Koricho and Belingardi [18] state that twill weave and plain weave fibers are the best. Both the tensile and three-point flexural tests can be shown in Table 1, which also provides the stacking sequence and suggested design structures for the test specimens. To guarantee high-quality results, three specimens of each design must be manufactured for the relevant testing. Epoxy resin remained the only matrix material in all design structures, with the weave alignment angle set at 0°/90°. Beyond that, the traditional hand lay-up procedure was used to create all of the composite specimens [19]. Take note that five plies of fabrics and sheets are always used in all model setups. Then, for both kinds of composites, Figure 1 shows the fiber fabric orientation and stacking sequences. Additionally, Figure 1(c) shows a flow diagram of the composite manufacturing process using the typical hand lay-up approach. Both the experimental setup and the specimen sizes adhere to the requirements set forth by ASTM, which are D3039 for the tensile test and D7264 for the three-point flexural test, respectively [15, 20].

Table 1. List of composite structures and their stacking arrangements

Model No.	Composite	Stacking Order	Type
1	Carbon fibre-reinforced plastic (CFRP)	CCCCC	Single
2	Glass fibre-reinforced plastic (GFRP)	GGGGG	Single
3	Carbon/Aramid fibre-reinforced plastic (CAFRP)	CACAC	Hybrid
4	CFRP/SRPP	CSCSC	Hybrid
5	GFRP/SRPP	GSGSG	Hybrid

Remarks:
C: Carbon, G: Glass, A: Aramid, S: Self-reinforced Polypropylene



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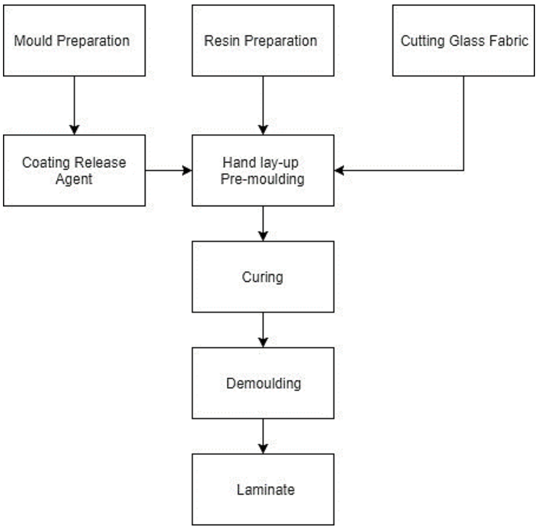

(c)

Figure 1. Schematic fibre direction with lay-up arrangements for the composite of: (a) single material, (b) hybrid type and (c) flow chart of the composite manufacturing process by hand lay-up technique [21]

2.1 Preparation of Testing Specimens

The fiber was first cut to dimensions of around 350 mm in both width and length as part of the composite specimen construction procedure. Before using woven fiber laminates in the hybrid composite that included SRPP layers, the surface of the SRPP sheets was sandblasted on both sides. Afterwards, a 3:1 ratio was achieved by combining EpoxAmite epoxy resin with the catalyst slow-type Hardener. The low-speed stirring technique was completed in 4 minutes utilizing an automated overhead stirrer equipment to ensure a uniform matrix mixture throughout all specimens. By using this technique, the epoxy and hardener mixture was able to be substantially free of air bubbles.

To ensure that the composite laminate surface was free of any imperfections, two glass panels and a roller were cleaned with acetone prior to beginning the lay-up procedure. The glass panels were then treated with the anti-adhesive Stoner Miracle Gloss (Maximum 8 2.0) to facilitate the easy removal of the cured composite laminate. The next step was to put the initial layer of fiber on the glass panel and pour the resin mixture over it. After that, the roller was used to distribute the mixture uniformly throughout the fiber. To ensure proper absorption by all fibers and prevent air bubbles from being trapped in the laminates, this process was executed with great care.

The procedure was thereafter carried out for the succeeding layers in the specified sequence of stacking. The next step in stacking the laminates was to place a 5-kilogram glass panel on top to ensure uniform pressing while they cured. The laminates were allowed to cure at room temperature for 24 hours. The glass panels were prepared for specimen production in accordance with ASTM requirements by removing the laminates and then cutting them out using a wood saw machine. For basic shapes and straight cuts, the cutting quality is adequate. We used a belt and disc sander equipment to grind the parts for a smoother finish and more precise measurements. The dimensions for the tensile specimens were 250 mm long and 25 mm wide, whereas the dimensions for the bending specimens were 130 mm long and 13 mm wide. So, for both kinds of testing, each model structure included three samples. Figure 2 shows the five composite laminate design structures in flexural test specimen size.

(a) (b) (c)

Figure 2. Sample of composite laminate specimens: (a) CFRP, (b) GFRP, (c) CAFRP, (d) CFRP/SRPP and

(e) GFRP/SRPP

Table 2 reviews the composite’s basic specimen specifications accordingly. Three measurements for each parameter were conducted and value acquired were fairly consistent, showing good level of accuracy. Here, each design's average weight, thickness and density are compared. The carbon-based composites are clearly the lightest and thinnest, whereby glass based composites are the heaviest. Meanwhile, the inclusion of SRPP sheets between the layers has significantly increased the overall thickness of the composite. It is noted that density measurement was conducted using AlfaMirage: MD-300S electronic densimeter. The attained density data were relatively consistent between all specimens, indicating the process's conformity during fabrication.

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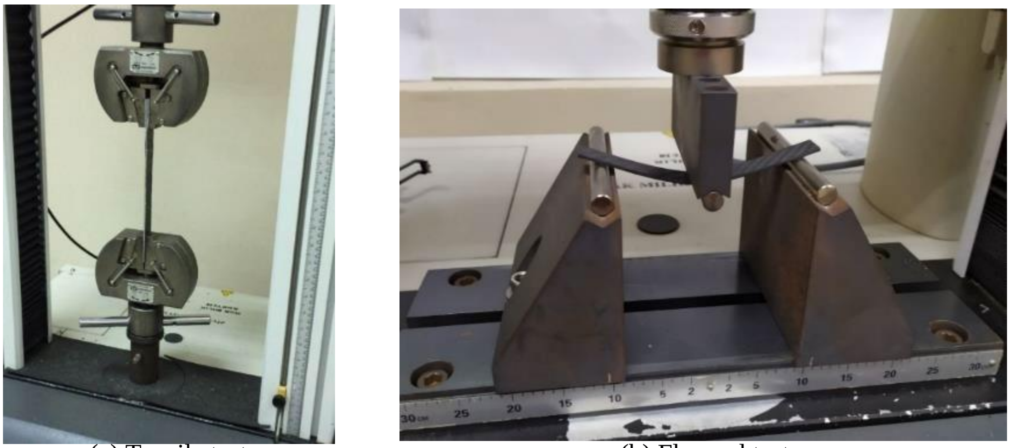
Table 2. Specifications of flexural specimens

Model No.	Stacking order	Average weight (g)	Average thickness (mm)	Average density (g/cm^3)
1	CCCCC	3.99	1.70	1.358
2	GGGGG	8.02	2.95	1.646
3	CACAC	5.06	2.70	1.288
4	CSCSC	5.78	3.30	1.002
5	GSGSG	6.28	3.35	1.125

EQUIPMENT AND EXPERIMENTAL TECHNIQUES

Instron's universal testing machine (Series 3369) was utilized to determine the static mechanical behaviour of composite specimens in accordance to the ASTM guidelines. The test speeds were set at 2 mm/min and 1 mm/min for the measurement of tensile properties and flexural properties, respectively. As illustrated in Figure 3, each specimen for all composite structures were carried out and their mechanical response were recorded and analyzed.



(a) Tensile test (b) Flexural test

Figure 3. Testing set-up: (a) Tensile test and (b) Flexural test

The composite samples will experience both elastic and plastic deformation stages when subjected to tensile loading. In this particular test, the sample initially exhibited elastic deformation, resulting in a linear correlation between the applied load and extension. These two values were subsequently employed to assess the curves for tensile stress versus tensile strain. The equations below were used to calculate the tensile stress and strain in this context.

$$\sigma = \frac{P}{A} \qquad (1)$$

$$\varepsilon\varepsilon = \frac{L_{ff} - L_o}{L_o} = \frac{\Delta L}{L_o} \qquad (2)$$

$$E = \frac{\sigma}{\varepsilon\varepsilon} = \frac{PL_o}{A\Delta L} \qquad (3)$$

where σ represents the tensile stress, $\varepsilon\varepsilon$ signifies the tensile strain, P denotes the axial load, and A denotes the initial cross-

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sectional area of the specimen. It is important to observe that L_{ff} represents the ultimate length of the specimen, while L_o designates the original length of the specimen.

During the three-point flexural experiment, the maximum bending strength and flexural modulus are calculated for each design specimen using the equation below [22].

$$\sigma = \frac{3PL}{2bh^2} \tag{4}$$

$$E = \frac{L^3P}{4bh^3y} \tag{5}$$

In this context, the parameters are defined as follows: The beam width is represented by b in millimeters, the beam thickness is denoted by h in millimeters, the support span length is indicated as L in millimeters, the applied force is represented by P in Newtons, the stress at the outer surface of the mid-span is denoted as σ in megapascals (MPa), and y represents the distance covered by the applied load.

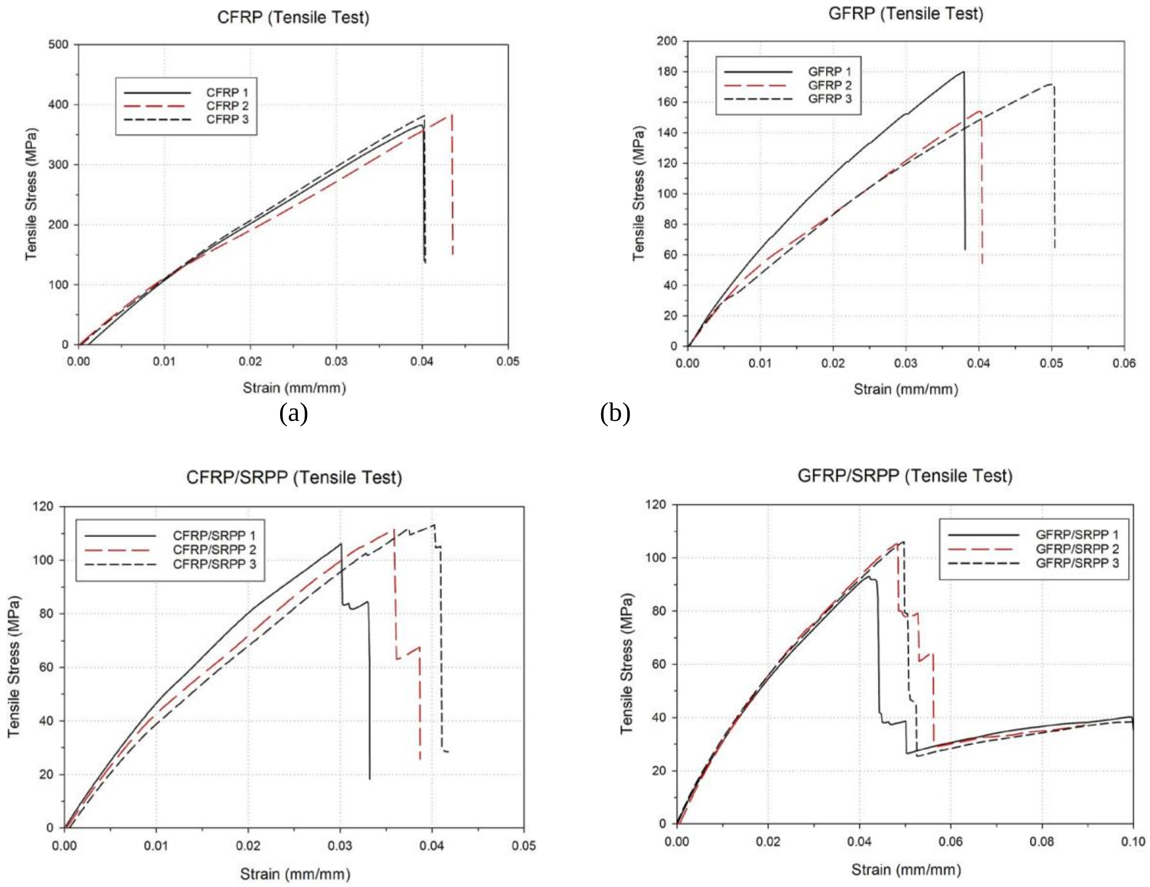
4.0 RESULTS AND DISCUSSION

The Instron testing equipment was used to assess the tensile and flexural strengths of thirty specimens in total. For each test, a total of fifteen samples are used, three of each of the five types of composite specimens. To guarantee that the material's behavior is faithful to the stated characteristics, three independent experiments were conducted. As a consequence, the outcomes are more accurate and trustworthy. The modulus of elasticity, strain at failure, tensile and flexural stresses, and other parameters were monitored throughout the operations. Any future efforts using finite element analysis may make use of this composite data set as input [16].

4.1 Tensile Test Results

The failed tensile specimens are demonstrated in Figure 4. Figure 5 represents the tensile stress-strain curve for each composite specimen. The mechanical response was compared between all structures and the tensile stress-strain curve is illustrated in Figure 6. It can be seen that the tensile strength and modulus for each design structure clearly showed different characteristics.

Figure 4. Failed tensile specimens after undergone test: (a) CFRP, (b) GFRP, (c) CAFRP, (d) CFRP/SRPP and (e) GFRP/SRPP



(a) (b)

(c) (d)

Figure 5. Tensile stress-strain curve results for three samples of each composite design: (a) CFRP, (b) GFRP, (c) CAFRP, (d) CFRP/SRPP

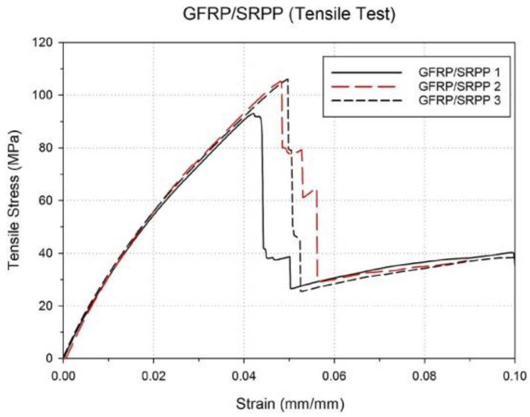


Figure 5. (cont.) (e) GFRP/SRPP

CFRP specimen displayed the best tensile strength and elastic modulus among the other structures. For hybrid structures comparison, CAFRP coupon exhibited good tensile response, which indicated impressive interlayer bonding in-between different weave of fibres. In contrast, GFRP/SRPP hybrid specimen exposed a relatively high ductility at the expense of tensile strength and elastic modulus. As a result, both GFRP/SRPP and CFRP/SRPP hybrid composites scored the lowest tensile strength, which could be due to poor bonding character between the woven fibre and PP sheets.

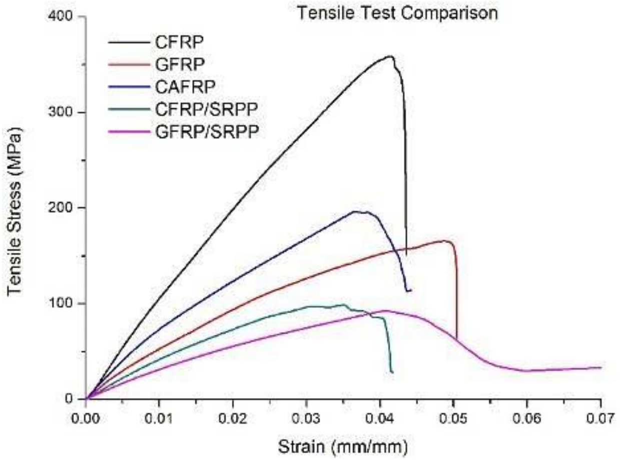


Figure 6. Tensile stress-strain curves at various composite configurations

Elastic modulus and tensile strength values obtained by each composite structures were extracted, compared and presented in Figure 7. The CFRP structure was noticed to have 46% and 33% higher than CAFRP specimen in terms of tensile strength and elastic modulus, respectively. However, the hybridization of CFRP/SRPP has decreased the tensile strength by 71% when compared to the value obtained by single type CFRP. It can be concluded that insertion of SRPP sheets to create hybrid composite structure showcased a significant decrease on mechanical response in tensile mode.

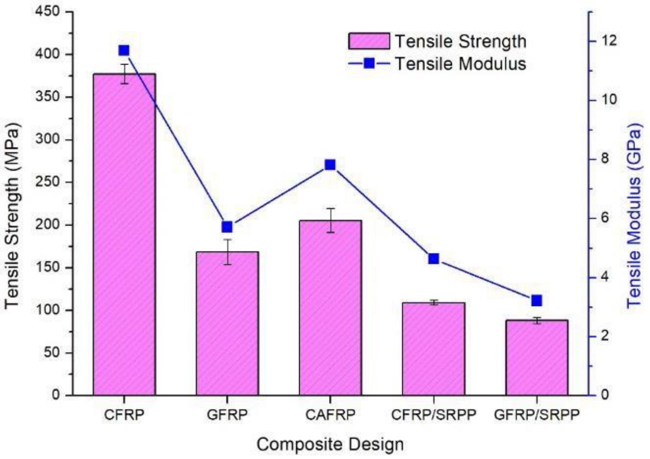


Figure 7. Tensile properties comparison with different composite configurations

4.2 Three-Point Flexural Result

Figure 8 displays the results of a battery of three-point bend tests performed on flexural composite specimens. The flexural stress-strain curve for the corresponding composite samples is shown in Figure 9. As for the flexural response, Figure 10 shows a comparison of stress-strain curves. In comparison to the complete carbon structures, the hybrid CAFRP specimens showed a much higher flexural response, according to this study. The stress-strain curve for CAFRP constructions showed that the flexural strength was significantly improved by stacking aramid layers between the carbon plies. The mechanical performance was unaffected by the hybridization of glass fiber reinforced plastic with structural rubber, as expected. The SRPP hybrid specimens showed the weakest flexural strength, which was in line with the tensile data. When compared to the entire carbon and glass constructions, the experimental flexural strengths of the GFRP/SRPP and CFRP/SRPP combinations are 58% and 25% lower, respectively. Composites based on SRPP have shown the capacity to achieve greater strain levels in this test. Hybris based on SRPP are highlighted for their toughness in the research.

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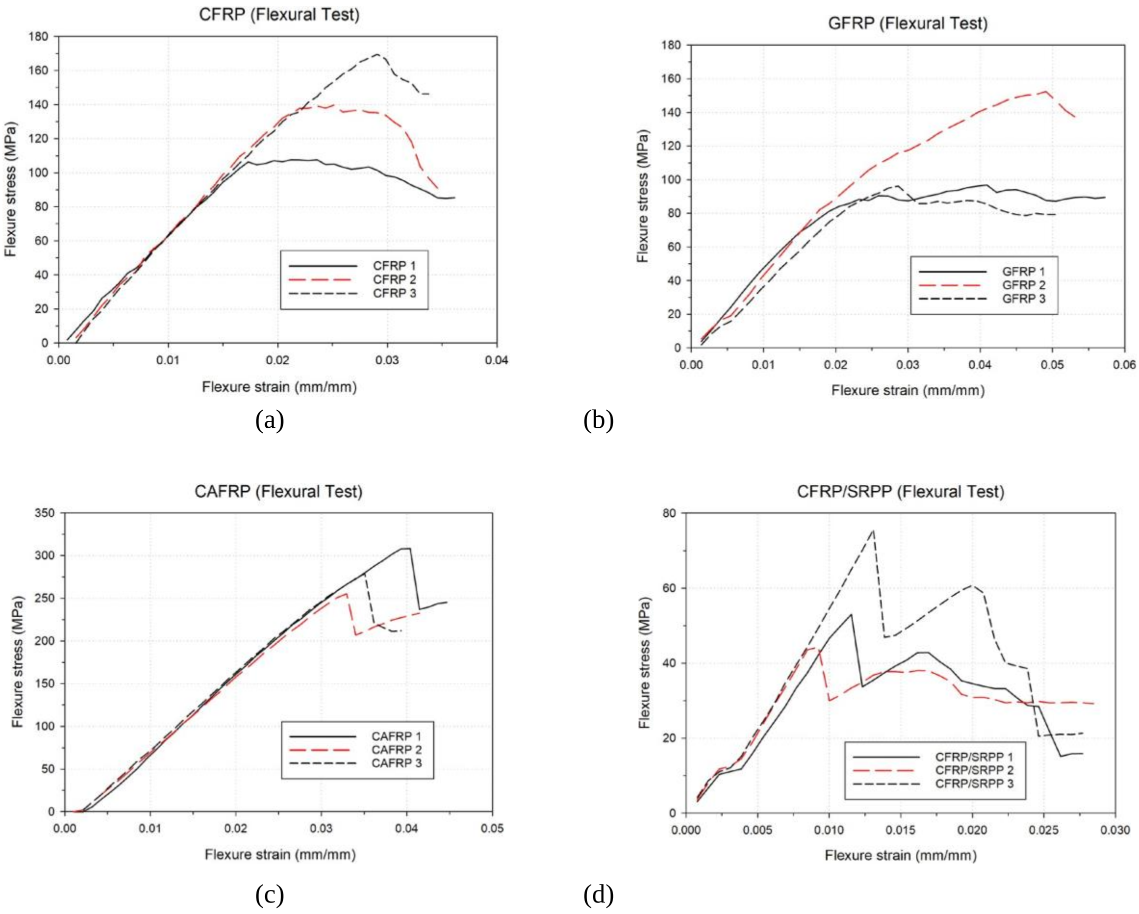
(a) (b) (c) (d) (e)

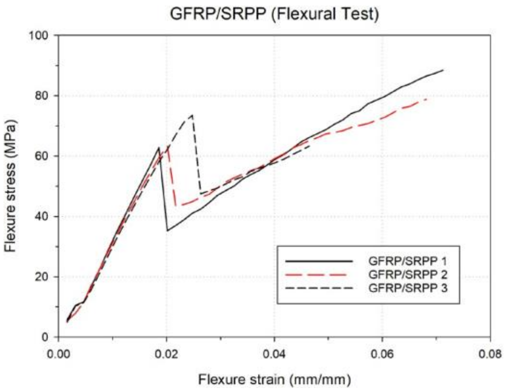
Figure 8. Damaged flexural specimens: (a) CFRP, (b) GFRP, (c) CAFRP, (d) CFRP/SRPP and (e) GFRP/SRPP



(a) (b)

(c) (d)

Figure 9. Flexural stress-strain curve results for three samples of each composite design: (a) CFRP, (b) GFRP, (c) CAFRP, (d) CFRP/SRPP



(e)

Figure 9. (cont.) (e) GFRP/SRPP

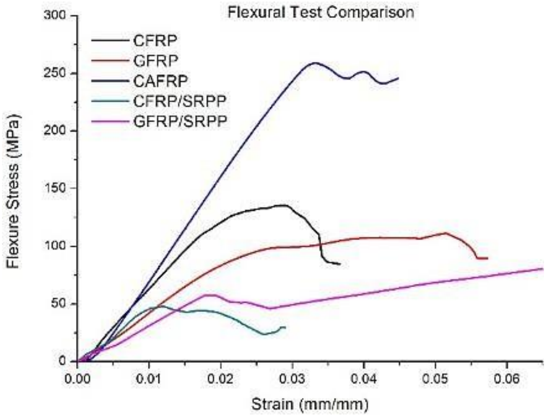


Figure 10. Flexural stress-strain curves compared between composite structures

Furthermore, flexural response by the composite specimens were summarized in Figure 11. The CAFRP structure demonstrated superior performance compared to the CFRP structure, exhibiting higher results by 50% in flexural strength and by 19% in flexural modulus, respectively.

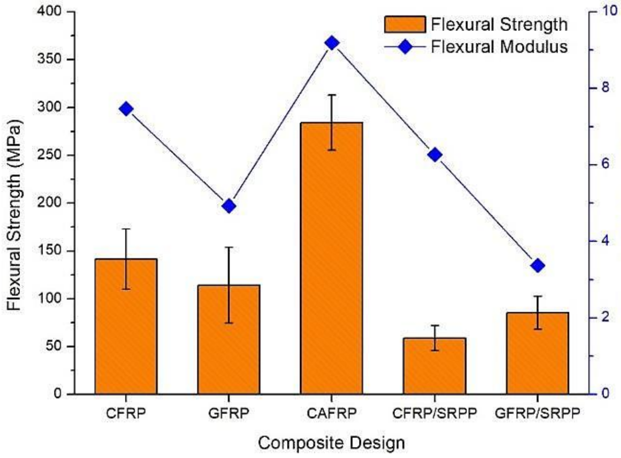


Figure 11. Flexural properties comparison with different composite configurations

According to the findings of the experiments, composite structures made of either single-type CFRP or hybrid CAFRP show remarkable reaction when tested under tensile and flexural loads, respectively. This study shows that CFRP and GFRP obtain somewhat better outcomes in terms of tensile strength and modulus than what Hunain et al. [12] reported. The majority of the specimens exhibited a linear response up to the maximal load in both tests. The flexural test conducted by Dong et al. [22] confirmed the existence of favorable hybrid effects when carbon fibers are replaced with other materials, such as glass fibers. Concurring with that, the current study shows that flexural strength and modulus are both significantly improved when carbon-aramid fibers are hybridized. The presence of aramid plies, which aid in absorbing flexural energy, is shown by this. On the other hand, it is readily apparent that thermoplastic SRPP and thermoset composites are not designed to withstand large loads. The failure was caused in part by bonding factor, which led to delamination between their plies. Table 3 summarizes the mechanical parameters of the composite constructions according to their results in tensile and flexural tests. Interlayer composites show properties of high strength and stiffness but poor elongation, while composites comprising SRPP laminates provide high toughness but low stiffness, as this research reveals. However, one must note that the findings may have been impacted by the study's extremely small sample size. The reliability of the findings may be improved by expanding the sample size.

Table 3. Summary of mechanical characteristic results

Composite Type	Tensile modulus, E_t (GPa)	Tensile strength, σ_{ut} (MPa)	Flexural modulus, E_f (GPa)	Flexural strength, σ_f (MPa)
CFRP	11.69	377	7.47	141
GFRP	5.71	169	4.93	114
CAFRP	7.82	205	9.19	284
CFRP/SRPP	4.63	109	6.27	59
GFRP/SRPP	3.22	88	3.37	85

5.0 CONCLUSIONS

The purpose of this research was to examine the effects of different interlayer hybridizations on the tensile and flexural strengths of various composite structures. The hand lay-up method was used to produce five different composite configurations, each made up of a different kind of woven fiber and self-reinforced polypropylene (SRPP) sheet. Results from tensile experiments showed that CFRP had the greatest tensile strength, with a 46% advantage over CAFRP and a 33% advantage over CAFRP in elastic modulus. The tensile strength was 71% lower when CFRP/SRPP hybridization was introduced in comparison to pure CFRP. But in the three-point flexural test, hybrid CAFRP constructions showed far better flexural strength than CFRP, which was 50% lower and had a flexural modulus that was 19% higher. The results show that CAFRP might be a good material stiffener. The flexural strength of GFRP/SRPP and CFRP/SRPP hybrids was 58% lower than that of pure carbon and 25% lower than that of glass, respectively, due to the addition of SRPP sheets, which also reduced the tensile strength. It was found that SRPP's weak interlayer bonding was the main factor, even though it could produce greater strain levels. In general, the research shows how SRPP-based hybrids are versatile by describing the stiffness vs. toughness trade-off in various composite designs.

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