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Mechanical Evaluation of Sustainable Marine Hybrid Composites Combining Kenaf and Fibreglass through Infusion Technique

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ABSTRACT

Hybrid natural and synthetic fibre composites are gaining significant attention as sustainable reinforcement materials. However, hybridization of natural fibres like kenaf with synthetic fibres such as fibreglass for marine applications remains unexplored and the underlying system and mechanisms are yet to be fully understood. Kenaf, a natural fibre, combined with fibreglass, enhances the mechanical performance while reducing environmental impact compared to conventional composites. The composite was fabricated using an optimized infusion technique and its tensile, flexural and impact properties were systematically evaluated. Hybrid kenaf/polypropylene/woven roving fibreglass hybrid composite shows highest in tensile strength and least percentage of water absorption. Meanwhile hybrid kenaf/polypropylene/chopped strand mat fibreglass hybrid composite possess highest in flexural strength and impact strength. Results show that the hybrid composite exhibits improved strength and durability, suitable for marine environments, with the added benefit of sustainability. This contributes to the advancement of green materials engineering, aligning with Sustainable Development Goals (SDGs) 9 (Industry, Innovation and Infrastructure), 12 (Responsible Consumption and Production) and 14 (Life Below Water), by promoting sustainable industrial innovation, reducing synthetic fibre use and protecting marine ecosystems.

1. Introduction

Green marine composites are an emerging class of environmentally friendly materials designed to meet the demanding conditions of marine environments while reducing ecological impact. Traditionally, marine composites have relied heavily on synthetic fibres such as fibreglass and carbon fibre embedded in petroleum-based resin matrices, prized for their strength, durability, corrosion resistance and lightweight nature. However, increasing environmental awareness and regulatory

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pressures have accelerated interest in alternative materials that offer sustainability without compromising performance [1]. Green marine composites typically combine natural fibres such as flax, sisal, kenaf [2], kapok [3], hemp, oil palm waste [4] and jute with bio-based or plant-oil-derived resin matrices to achieve biodegradability, renewability and reduced carbon footprint [5]. Natural fibres contribute benefits like low density, good specific strength and eco-friendliness but inherently possess challenges like higher moisture absorption and lower mechanical durability in harsh saltwater conditions. Advances in fibre treatments, hybrid fibre reinforcements and improved resin formulations have helped address these limitations, enabling green composites to increasingly rival traditional materials in marine applications such as boat hulls, decks and structural components. A major focus of recent research involves the use of plant oil-based resins that provide sustainable alternatives to petroleum-based epoxy, polyester or vinyl ester resins. These green polymer matrices, combined with natural fibres and sometimes hybridized with synthetic fibres, offer promising mechanical, thermal and environmental performance [6]. Manufacturing processes such as vacuum infusion are also optimized to maintain composite integrity and performance. Green marine composites not only help reduce the environmental impact associated with disposal and recycling of conventional composites but also play a role in decreasing water pollution and microplastic generation. They align closely with sustainable development goals aimed at responsible consumption, industry innovation and life below water by fostering greener materials resistant to corrosion and biofouling while supporting the circular economy [7]. The green marine composites represent a crucial step towards sustainable maritime industries, balancing performance requirements with ecological stewardship through innovative material design and processing [8].

The demand for renewable or natural fibre-reinforcing composite has increased nowadays. Kenaf (Hibiscus cannabinus), a fast-growing annual plant, has particularly attracted attention owing to its high tensile strength, low density and adaptability to low-water growth conditions. As a biodegradable, recyclable and non-abrasive material, kenaf has been successfully integrated in automotive components and other industrial applications, leveraging its mechanical properties and environmental advantages. Kenaf fibre has become the most popular use as natural fibre due to its rapid growth is an annual plant with 1700kg/ha for an average yield. Kenaf fibre can be obtained from the base of plant stems, Hibiscus type, Malvaceae family and cannibinus species. Kenaf can growth in less water environment. Kenaf fibres have the advantage of being recyclable, less expensive, lightweight, abundant, non-abrasive and safe to use. Hence, Kenaf can act as an excellent plastic reinforcing agent. Kenaf fibre has a relatively high strength and rigidity and can be used in polymeric resins as a reinforcement material for producing useful composite products. Application of kenaf fibre in automobile parts has already been adopted due to its good mechanical properties and light in weight [9].

Hybrid composites, combining natural fibres such as kenaf with synthetic fibres like fibreglass, aim to balance cost, mechanical performance and environmental impact. Although hybridization has been explored in various configurations, discrepancies in mechanical behaviour have been reported, influenced by fibre types, matrix selection and hybrid architecture [10]. Several studies have shown that fibre hybrid configurations can optimize tensile, flexural and impact properties [11], while modulating water absorption characteristics a key concern for marine applications [12]. Despite the increasing knowledge of kenaf/fibreglass hybrid composites, the specific combination of kenaf/polypropylene fibres with fibreglass, especially fabricated via the resin infusion method, remains underexplored in marine contexts. This gap includes limited data on the mechanical properties [13] and water absorption behaviour essential for marine structural durability and longevity [14]. Number of researchers reported on mechanical and absorption properties of kenaf/fibreglass hybrid composite. Sharba *et al.,* [8] recorded unidirectional twisted yam kenaf shows the highest value in tensile and flexural of 194 MPa and 275 MPa. Another research from Sharba *et al.,* [15], a kenaf as core in composite shows highest value in tensile and flexural compared to 2 and 3 kenaf as core. The research shows, increase the number of kenaf decrease the tensile and flexural strength. Additionally, Salman *et al.,* [9,14], recorded that epoxy as reinforcement shows highest value in tensile and flexural strength while least in impact strength. The author states that polyester has the highest value in impact strength compared to vinyl ester and epoxy resin. Meanwhile MR, Sanjay *et al.,* [16] and Salleh *et al.,* [17] state that hybrid composite of kenaf/fibreglass immerse in distilled water shows higher percentage of water absorption than in salt water. Hybridization of kenaf/polypropylene fibre with fibreglass composite is a new method that has not been applied yet in current industry. Mechanical and water absorption data for pure kenaf/fibreglass hybrid composite have been found [8,17], however mechanical data for kenaf/polypropylene fibre with fibreglass hybrid composite has not been found yet. Hybrid Kenaf/fibreglass is a common composite that has been applied in automotive parts [9], however for marine application is not applied yet. Synthetic fibre such as fibreglass, Kevlar and carbon extensively used for the reinforcement of plastics, but these materials are expensive and are non-renewable resources. Thus, this study addresses these research gaps by investigating the mechanical performance and water absorption characteristics of kenaf/polypropylene/fibreglass hybrid composites fabricated by infusion. The research aims to develop sustainable, cost-effective composite materials tailored for marine applications, thereby contributing to environmentally responsible manufacturing and advancing material innovations in line with global sustainability trends

2. Methodology

2.1 Figure Style and Format

Vacuum infusion technique was used in fabricating six specimens for each group. Chopped strand mat 450 (CSM) and Woven roving 600 (WR) types of fibreglass. Releasing agent was applied on the mould before the process for easy removal of the specimen after curing. The kenaf/polypropylene fibre chopped strand mat and woven roving fibreglass were cut according to the requirement and placed in position on the mould. The number of layers and stacking sequences is presented in Table 1. The panels were then characterized by mechanical properties such as tensile (ASTM D3039) and flexural (ASTM D790) by using Instron 1195, Universal Testing Machine, at straining rate of 2mm/min, respectively. Charpy impact testing with U notched shape and unnotched was conducted using Charpy Izod Tester 300J (LS-220060300J). The water absorption test was performed in accordance with ASTM D570. The specimens were immersed in two different solutions, which are distilled water and sea water. The specimens were immersed for 30 days weeks at room temperature. The initial weight was recorded before immersion of specimen and the weight change of specimen was recorded at 18 days, 20 days, 25 days and 30 days. All testing conducted were observed and the data were recorded.

Table 1
Staking sequence of specimens

Designation	Number of Layers	Stacking sequence
3WR	3	[WR/WR/WR]
3CSM	3	[CSM/CSM/CSM]
2WR + 1K	3	[WR/K/WR]
2CM + 1K	3	[CM/K/CM]
1W + 1K+ CSM	3	[WR/K/CSM]
3K	3	[K/K/K]

3. Results

3.1 Tensile Analysis

Figure 1 shows WR/K/WR composite possess the highest tensile strength of 125 MPa while pure kenaf have the lowest tensile strength with 25 MPa. Hybridization of kenaf/woven roving fibre glass has the highest tensile strength of 92 MPa among the other kenaf/fibreglass hybrid composite. Kenaf/woven roving fibreglass hybrid composite shows least reduction in tensile strength with only 26%, 53% reduction for kenaf/chopped strand mat hybrid composite compared with woven roving fibreglass reinforced composite. Kenaf/woven hybrid composite have better tensile strength due to even distribution of stress while chopped strand mat have an anisotropic behaviour that decreases the tensile strength [18].

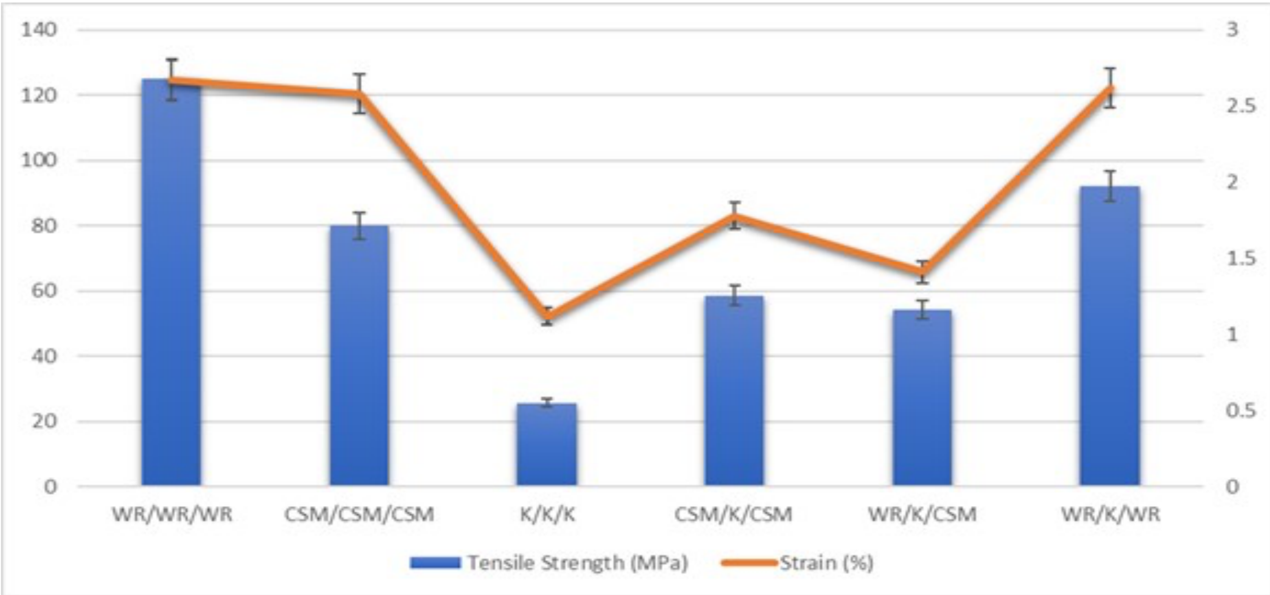

Fig. 1. Tensile strength of specimens

3.2 Flexural Analysis

Woven roving fibreglass reinforced composite shows the highest flexural strength of 557 MPa compared to poor strength of pure kenaf reinforced composite of 90 MPa as shown in Figure 2. Hybridization of kenaf with chopped strand mat possess superior flexural strength of 271 MPa between the other hybrid composite. Kenaf/ woven roving/chopped strand mat hybrid composite shows slightly higher flexibility than combination of kenaf/ woven roving hybrid composite with differences of 3 MPa. The fibres in chopped strand mat are randomly oriented and are held together which increases thickness strength thereby providing good resistance to bending forces [19].

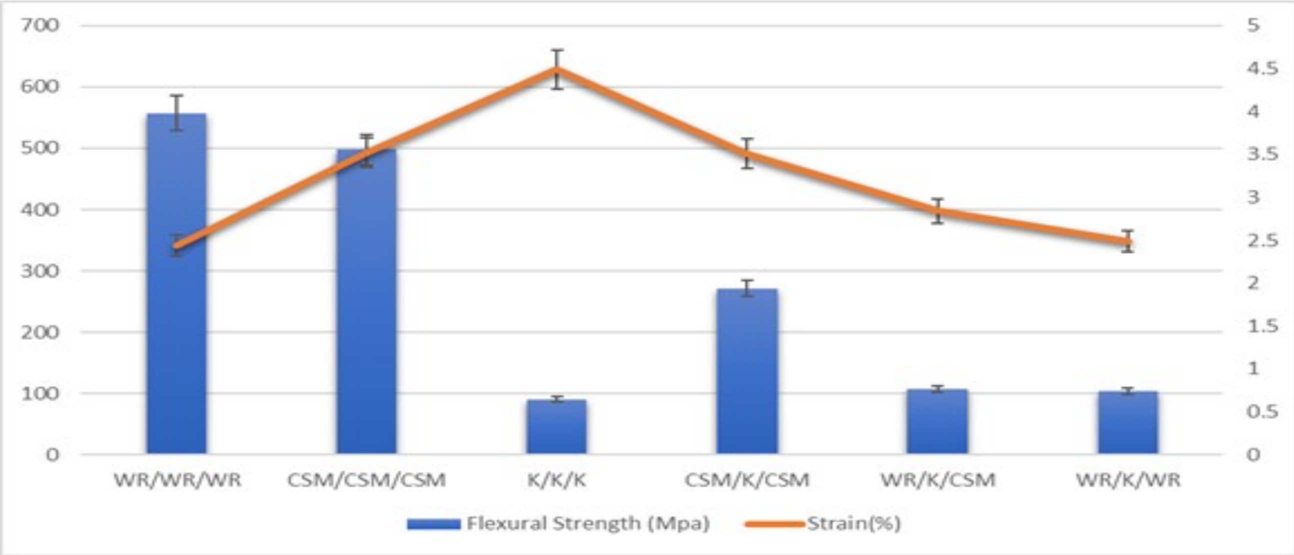

Fig. 2. Flexural strength of specimen

3.3 Impact Analysis

Figure 3 shows impact strength of notched and unnotched specimen. Chopped strand mat fibreglass reinforced composite possess the highest impact strength for both notched and unnotched condition of 275 KJ/m^2 and 345 KJ/m^2 while pure kenaf reinforced composite have the lowest energy impact strength with 76 KJ/m^2 and 128 KJ/m^2 respectively. Hybridization of kenaf/chopped strand mat fibreglass shows the highest impact strength with 205.67 KJ/m^2 and 275 KJ/m^2 among another hybrid composite. However, combination of kenaf/chopped strand mat and woven roving in one reinforced composite shows higher impact strength for both notched and unnotched specimen compared to kenaf/woven roving fibreglass hybrid composite. This is due to presence of chopped strand mat which increases the nesting to make it difficult to crack through the layer of fabric and attributed to better bonding between layer interface [18]. This also can be noticed that presence of kenaf fibre decreases the impact strength of composite due its low mechanical properties.

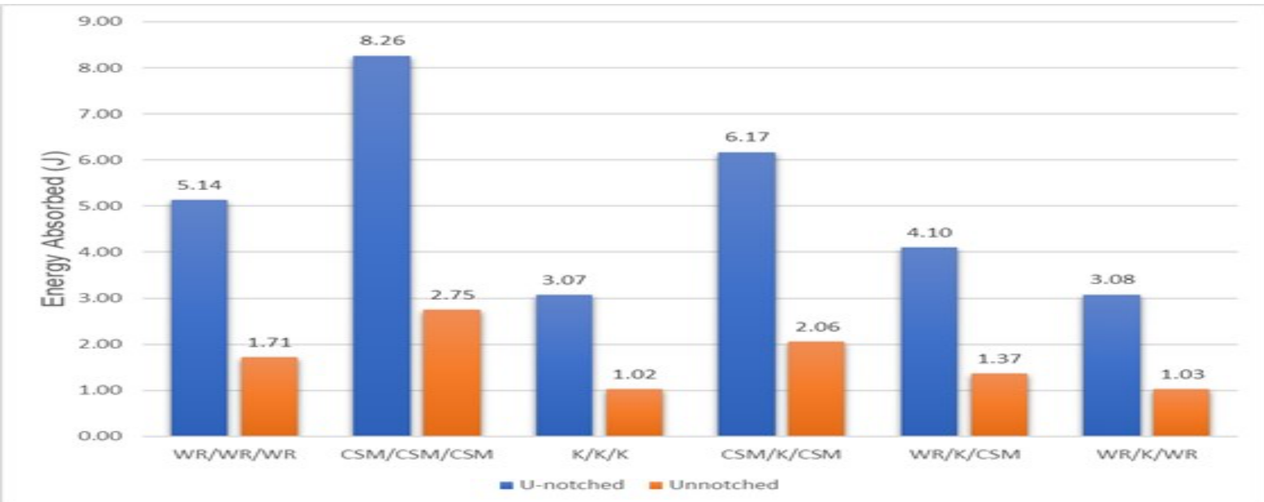

Fig. 3. Impact strength of specimens

3.4 Water Absorbance Analysis

In Figure 4, kenaf/chopped strand mat hybrid composite shows the highest percentage of water absorption of 21 % on the 30 days while kenaf/woven roving hybrid composite possess the lowest percentage of water absorption of 6 % in salt water.

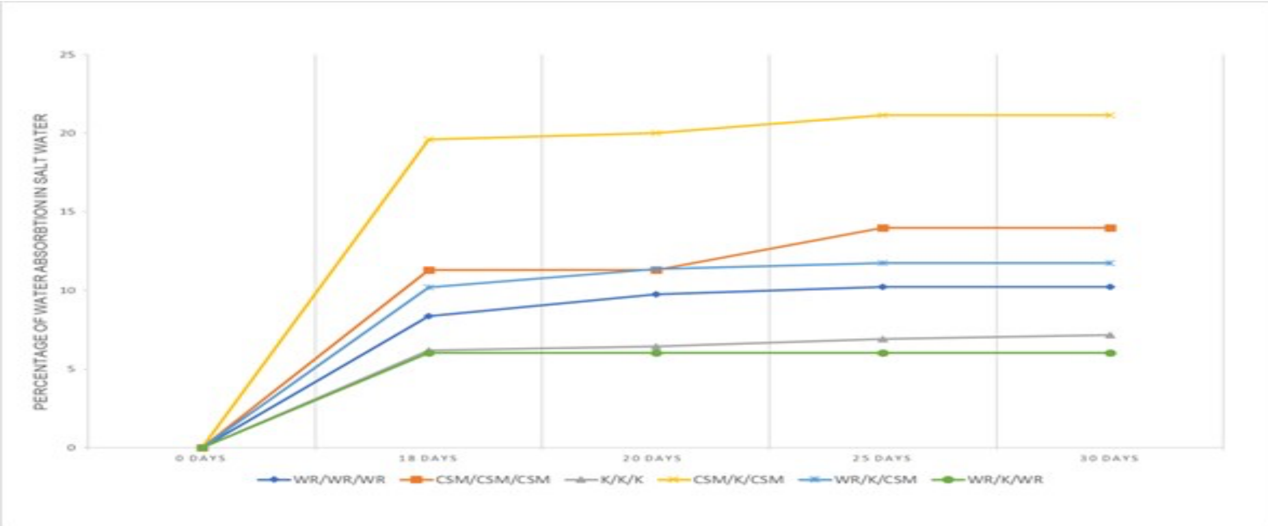

Fig. 4. Percentage of water absorption in sea water

Meanwhile in Figure 5, kenaf/chopped strand mat hybrid composite possess the highest percentage of water absorption of 24 % while chopped strand mat fibreglass reinforced composite shows the lowest percentage of water absorption of 30 days in distilled water. Panels immersed in distilled water show significantly higher percentage water absorption compared to panels immersed in sea water. This is due to the presence of salt molecules in sea water, which reduces the activity of water molecules and results in addition of salt particles on the surface of specimen which could further inhibit the water absorption [16]. The percentage of water absorption in distilled water is larger than in salt water is due to the hydrolysis mechanism of the cellulose within natural fibre.

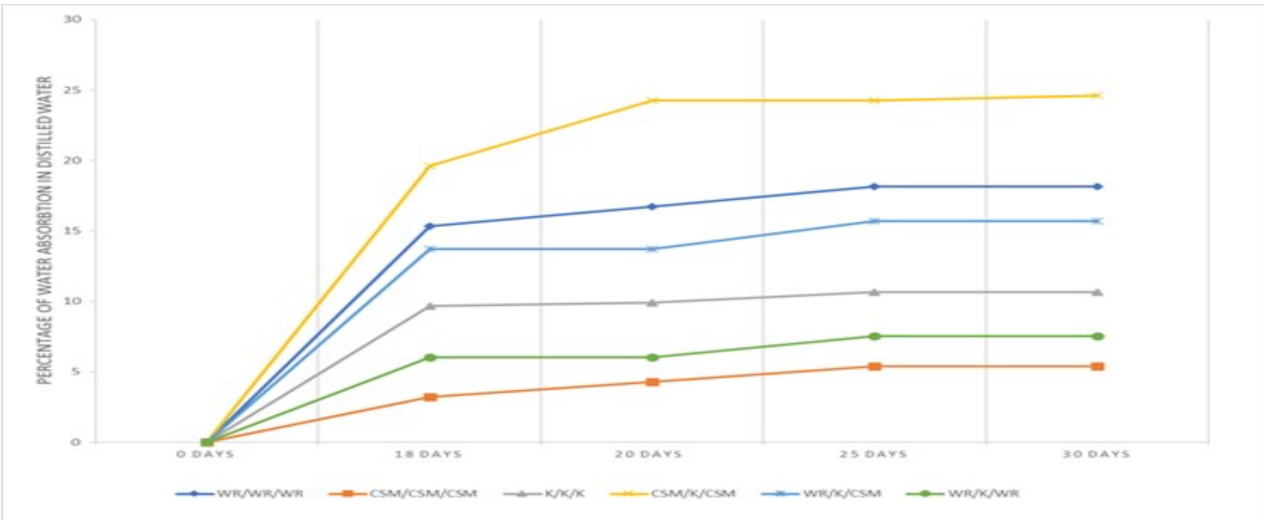

Fig. 5. Percentage of water absorption in distilled water

3.5 Visual Observation Analysis

From visual observation in Figure 6(a), samples with pure WR show break with angle of 45 degree meanwhile for pure CSM show break with angle of 30 degree and perpendicular direction of force applied**.** All tensile samples for hybrid composite and pure kenaf show break at perpendicular direction. However, some of the samples do not totally break into two parts, especially samples with WR. Flexural samples observed in Figure 6(b) show no complete break. All samples bend without significant fracture. Figure 6(c) and 6(d) shows similar failure for pure kenaf sample which totally breaks into half, meanwhile sample with pure WR and CSM still attach. Impact sample of Kenaf/CSM hybrid composite for notched condition shows the samples still attach meanwhile for unnotched condition the samples tend to break into half. However, impact samples with WR still attach to both notched and unnotched condition.

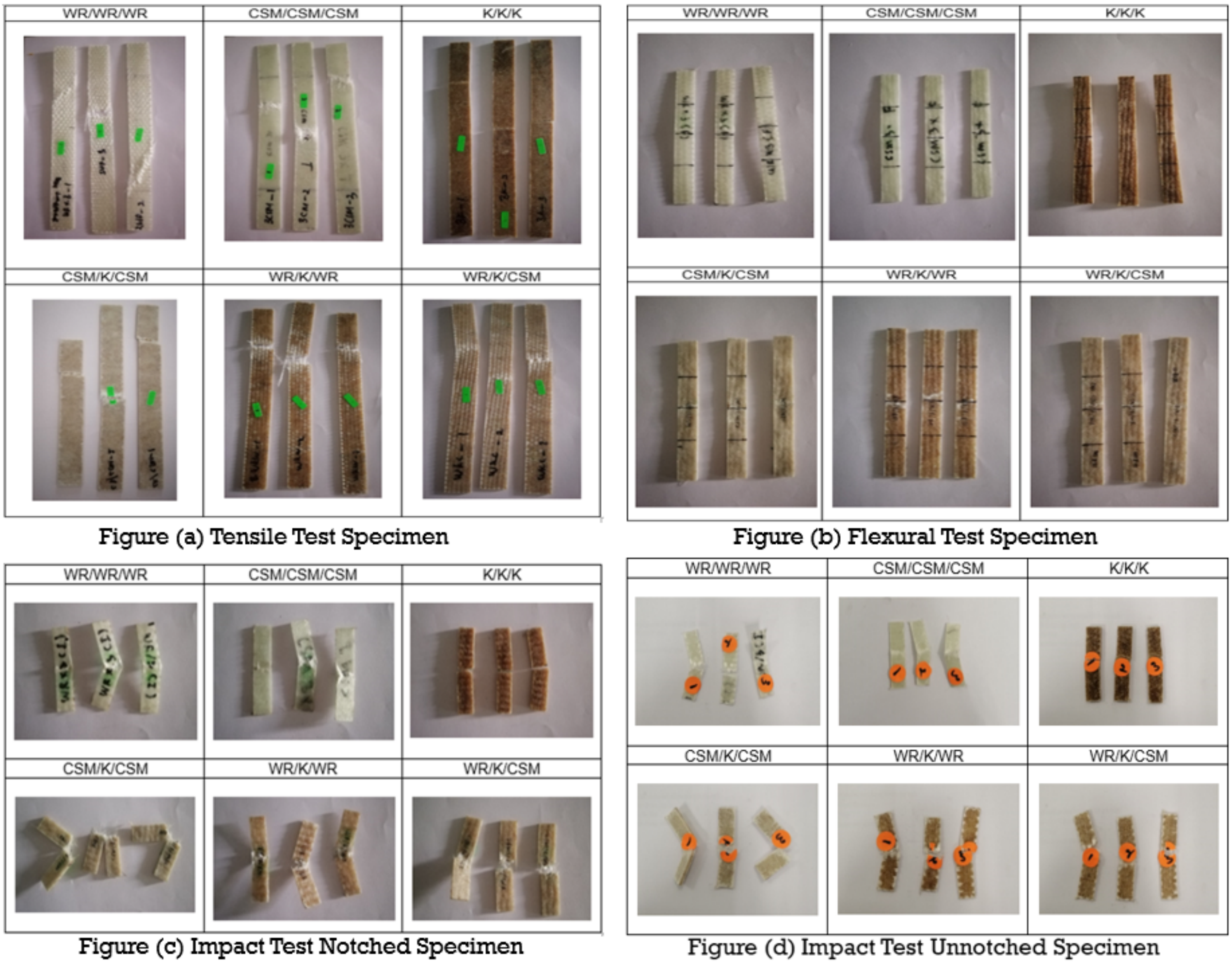

Fig. 6. Visual Image (a) tensile specimen (b) flexural specimen (c) impact notched specimen (d) impact unnotched specimen

4. Conclusions

Samples of kenaf/polypropylene fibreglass hybrid composite were successfully fabricated and characterized. Analysis of mechanical and absorption properties related to kenaf/polypropylene hybrid composite has led to the following conclusion:

i. Tensile tests show that kenaf/woven roving fibreglass hybrid composite possess the highest tensile strength of 92 MPa compared to another hybrid composite.
ii. Flexure test shows, kenaf/chopped strand mat fibreglass hybrid composite shows the highest flexural strength of 271 MPa among another hybrid composite
iii. Impact test shows, kenaf/chopped strand mat fibreglass hybrid composite have the highest impact strength for both notched and unnotched condition with 275 KJ/m^2 and 345 KJ/m^2 respectively.
iv. Water absorption test shows, kenaf/woven roving fibreglass hybrid composite obtain the lowest percentage of water absorption for both salt water and distilled water of 6% and 7% respectively compared to another hybrid composite.

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