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Experimental Investigation of Mechanical Properties of the Composite Materials Reinforced by Agro-based Waste Materials

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Abstract

In this work, experiments were carried out to develop the glass fiber reinforced composites using the hand layup method and analyze the mechanical properties of the GFRP hybrid composites. The ultimate Tensile strength (UTS) using rice as a filler (GFRPC/R) was 3.04% and 12.89% higher than coir and wheat as filler, respectively. The hybrid composite using coir as a filler (GFRPC/C) revealed 12.54% greater flexural strength, and the hybrid composite using wheat as a filler (GFRPC/W) revealed 14.95% inferior flexural strength than the plain GFRP composite. Hybrid GFRPC/C composite showed the highest impact strength of 278.93 J/mm^2, and GFRP composite showed the most minor impact strength of 234.37 J/mm^2. Hybrid GFRPC/W showed the most minor impact strength of 245.53 J/mm^2. Hybrid GFRPC/C composite showed 15.95% higher impact strength than plain GFRP composite. Hybrid GFRPC/R showed the highest hardness of 41.375 BHK, comparable with the GFRP composite. Hybrid GFRPC/W showed the lowest impact strength of 33.25 BHK. Hybrid GFRPC/R showed 13.23% and 19.63% higher hardness than hybrid GFRPC/C and GFRPC/W respectively.

Keywords: Tensile strength, Glass fiber, hardness, Impact strength

INTRODUCTION

To maintain each constituent part's specific and recognizable characteristics, composite materials, as seen in Figure 1, combine two or more different materials. The main goal of composites is to provide the created materials with the qualities of both elements, frequently making up for the shortcomings of the constituent materials. On a microscopic level, composites have two (or more) chemically or physically distinct phases separated by a different interface to distinguish these phases—the continuous component known as the matrix is frequently more plentiful in composites. Composites can have a ceramic, metal, or polymer matrix—a composite where the fibers that comprise the dispersed phase are used. The high strength and stiffness ratio to the weight of the composite is due to the use of threads. There are two other categories within this one: continuous and discontinuous fibers. Discontinuous fibers have lengths that are less than this, while continuous fibers often have lengths more significant than 15 times the critical length (l >15 lc) [1]. The direction of the discontinuous fibers might either be aligned or random.

The major challenge was drilling-induced damage due to the interaction between the composite laminate and the tool, which is generally affected during drilling. With the help of

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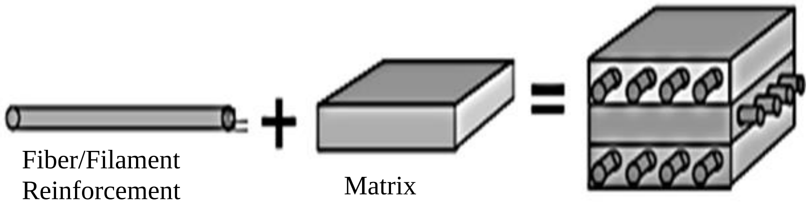

Figure 1. Composite material.

modified drill point geometry, damage-free holes can be made [2]. The application of natural fiber composite has dramatically extended in outdoor applications like marine structures, sports equipment, floor paneling, and automotive industries [3]. The biocomposites (biopolymer and Aloe Vera) were used for fiber surface modification and enhancement of the mechanical properties of the fibers. Alkaline treatment of threads enhanced the natural fibers' compressive, flexural, and tensile properties [4]. As cutting speed increased, so did surface roughness. With growing feed, surface roughness increased. An increase in cutting temperatures accompanied the rise in cutting speeds. The cutting temperature dropped as the natural fiber feed was increased. The effect of the weight percentage varied as 30 to 50% of the Jute fiber-polypropylene reinforced composite, prepared by a compression molding process, was investigated. To fully understand the mechanical properties, they were analyzed as per ASTM standards by a UTM machine [5]. The lowest UTS was perceived as 16.25 MPa in coir fiber at 10% fiber weight, while the maximum UTS of 44 MPa was observed for jute composite at 40% fiber weight [6]. Various works have been done on metal to composite fibers, enhancing the composite material's mechanical properties [7, 8].

The thrust force and torque were measured as responses during each drilling operation and analyzed using RSM and developing the nonlinear regression equations. The investigation concluded that the influence of work sample, feed, and tool angle was predominant on thrust force. It was noticed that speed does not influence the thrust force or selection of synthetic and natural fibers. Their chemical composition significantly reduces the thrust force; the presence of glass fibers and their content increase the thrust force and torque [9]. The investigation of the effect of modulation-assisted drilling (MAD) on hole oversize and delamination around holes of composites was done here. The process parameters were optimized through the Taguchi method [10]. It was found that with an increase in feed rate, surface roughness and thrust force were increased & specific cutting pressure (SCP) decreased. With the increased cutting speed, SR &TF were first found to be improved, then decreased while SCP was increased [11]. In this work, we characterize the developed GFRP Hybrid Composites in terms of the composite materials' UTS, flexural strength, impact strength, and hardness.

MATERIAL AND METHODS

Fiber Reinforcement Material

Woven boron-free EC-R (alumino-lime silicate with less than 1% w/w alkali oxides), glass fibers mat of 610 GSM (gm/m^2), manufactured by Owens Corning Fiber Glass, USA, was used. EC-R stands for corrosion resistance E-glass fiber with low electrical conductivity. Boron-free E-glass has nearly seven times higher corrosion resistance and a 10% higher dielectric constant than boron-containing E-glass. The EC-R glass had a young’s modulus of 80 GPA and a density of 2.62 gm/cm^3 [12].

Matrix Material

Polyester resin Aropol in 1005 P is a viscous, flammable, pale-colored liquid. Polyester resin, catalyst Methyl Ethyl Ketone Peroxide (MEKP), and accelerator Cobalt Octate (with 6% Cobalt content) were used. Materials were procured from M/s Excellence Resins Limited, Meerut, India. Considering glass fiber as reinforcement and polyester as polymer matrix, the hand layup (HLU) process for composite fabrication will be selected during manufacturing. The development of both pure GFRP composites and hybrid GFRP composites using polyester as the matrix material. The following materials were used to create composite laminates: EC-R glass matting, polyester resins, and natural fillers. Each laminate was 4 mm thick. We used coconut coir, rice, and wheat husk as filler materials. The 560 mm × 460 mm composite laminates were made using the traditional hand layup method in a mild steel mold at room temperature, as illustrated in Figure 2. Every composite has six woven EC-R glass fiber mats devoid of boron. The figure shows that compression dies molding was used to create laminates with precise thicknesses. The 4 mm thick fiber-reinforced polymer plates were primarily intended to be produced using the mold plates.

First, accelerator cobalt octoate (which contains 6% cobalt) was combined with the all-purpose resin. The accelerator hastens the breakdown of catalysts, organic peroxide initiators that promote polymerization. Then, Methyl Ethyl Ketone Peroxide (MEKP), a trigger that starts the polymerization of polyester resins, was added to the wax before it was applied to the glass fiber. MEKP also aids in the cold setting of composites made of polyester. One liter of resin was mixed with 10 ml of cobalt octoate and 10 mL of MEKP. The hand layup procedure must be finished immediately once MEKP has been introduced to the resin; otherwise, the wax will begin to gel, and waste will result.

Similarly, as glass fiber reinforced polyester-based laminates, hybrid composites made of polyester-based glass fiber laminates with natural fillers were also manufactured. The natural fibers comprise 5% of the glass fibers' weight and are first employed in a hand layup process. After that, the entire mold assembly is put under a 15-ton compressive stress. Within three hours, the laminates made of polyester are ready for use. The three separate natural bio-fillers used in the GFRP hybrid composite were rice husk filler (GFRPC/R), wheat husk filler (GFRPC/W), and coconut coir filler (GFRPC/C). The fourth laminate included no filler and only GFRP as reinforcement.

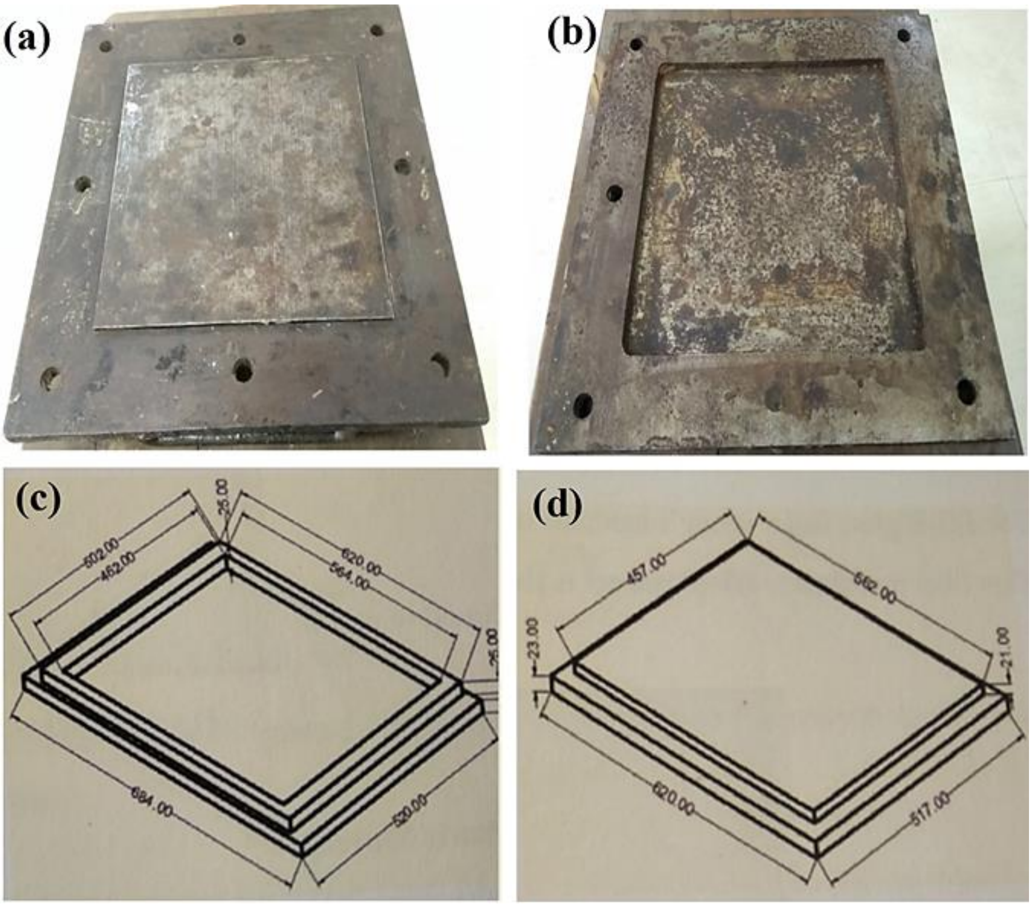

Figure 2. Mould for Hand Layup Process (a) actual isometric view of top plate (b) isometric view of bottom plate (c-d) dimension of the mould plates

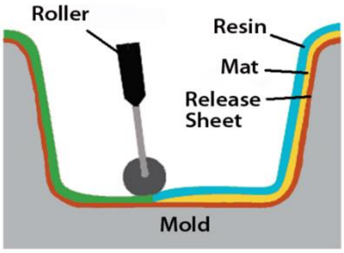

Figure 3. Schematic diagram of hand layup method.

Hand Layup Process

As shown in Figure 3, resins are impregnated by hand into fibers which are in the form of woven, knitted, stitched or bonded fabrics. This is usually done with brushes or rollers, with an increasing use of nip-roller type impregnators for forcing resin into the fabrics by means of rotating rollers and a bath of resin. Laminates are left for curing up to sometime under standard atmospheric condition.

Glass fibers can be used to reinforce both thermosetting and thermoplastics matrices, thermosetting resins such as epoxy, polyester, polyurethane, phenolic are commonly used composites requiring higher performance applications because these provide sufficient stiffness and strength at very low prices.

RESULTS AND DISCUSSION

In this work, the experiments that were carried out for developing the glass fiber reinforced composites using hand layup method. After developing of composites, mechanical testing was done and results were analyzed to investigate joining behavior of the GFRP hybrid composites. The experimental results obtained are analysed and discussed in the following sections.

Tensile Strength

The UTS of different composites under consideration is shown in Figure 4. GFRP composite with no filler showed the highest UTS of 352.5 MPa amongst all four composites. The likely reason for maximum UTS is non-agglomeration in GFRP composite because there is no filler. Hybrid composites have glass fiber and fillers in which aggregation occurs during compression, and fillers' distribution becomes non-homogeneous, resulting in lower UTS. GFRP hybrid composite with rice filler showed the highest UTS of 324.9 MPa, 7.82% less than plain composite. GFRP composite with wheat filler showed the least UTS of 283 MPa, 19.71% less than direct composite. Amongst the hybrid composites, the UTS using rice as filler was 3.04% and 12.89% higher than those obtained using coir and wheat as filler, respectively. GFRP composite with rice husk filler having the highest UTS may be attributed to better polyester bonding with rice husk than other filler materials.

Flexural Strength Analysis

The GFRP hybrid composite with coir filler revealed a greater flexural strength of 702 MPa, the GFRP composite told a flexural strength of 614 MPa, and the GFRP hybrid composite with wheat filler showed a minor flexural strength of 522 MPa. GFRP composite has only glass as a fiber.

In contrast, the GFRP coir hybrid composite also has coir, which replaces the brittle polyester. Due to the coir, the composite's flexibility increases, which in turn increases the composite's flexural strength. The GFRP hybrid composite with coir filler revealed 12.54% greater flexural strength, and the GFRP hybrid composite with wheat filler revealed 14.95% inferior flexural strength than the simple GFRP composite. The Coir-filled GFRP hybrid composite showed greater maximum flexural strength than other composites. In hybrid composites, coir filler is used in the form of chopped strands along with woven glass fiber material, whereas rice and wheat are used in the form of milled fiber, which is shorter in length than chopped strands. Due to this, the flexibility of coir filler is more remarkable than others, resulting in better flexural strength. The flexural strength of different composites under consideration is shown in Figure 5.

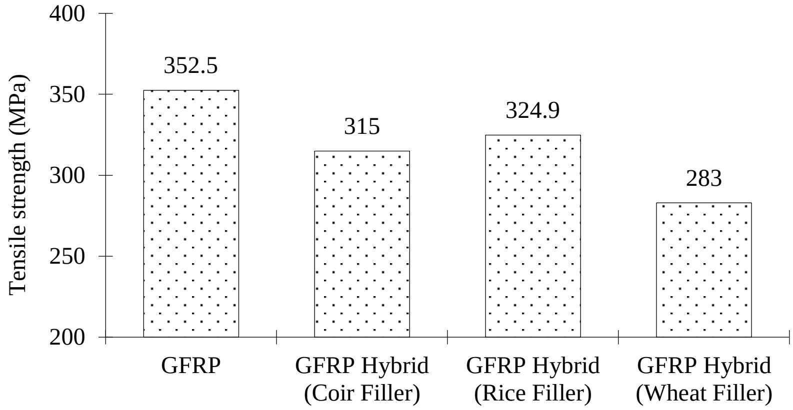

Figure 4. UTS of Pure GFRP and GFRP Hybrid Composites.

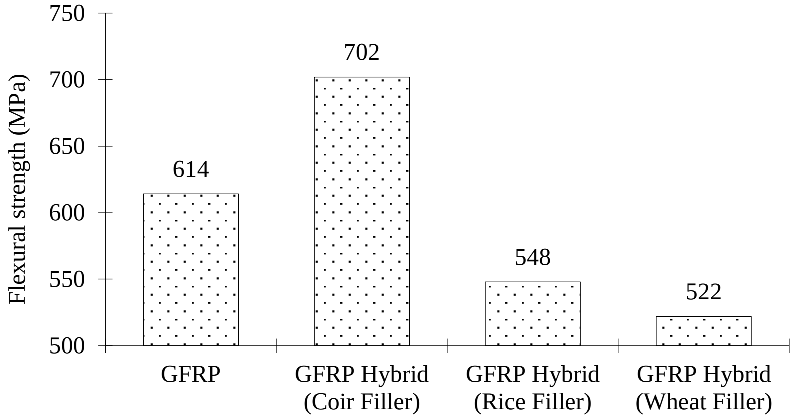

Figure 5. Flexural Strength of Pure GFRP and GFRP Hybrid Composites.

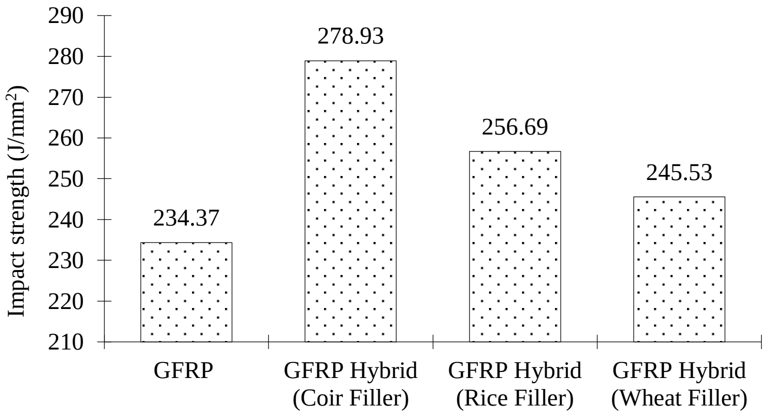

Figure 6. Izod Impact Strength of Pure GFRP and GFRP Hybrid Composites.

Izod Impact Test

The impact strength of different composites under consideration is shown in Figure 6. Hybrid GFRPC/C composite showed the highest impact strength of 278.93 J/mm^2, and the GFRP composite showed a minor impact strength of 234.47 J/mm^2 among all four types of composites. A GFRP hybrid composite with wheat filler showed a nominal impact strength of 245.53 J/mm^2 amongst all three types of hybrid composites. The hybrid GFRPC/C composite showed 15.95% higher impact strength than the plain GFRP composite. As mentioned, the coir filler is filled with chopped strands, whereas rice and wheat are served as milled fiber, resulting in better impact strength. Hybrid composite with rice and wheat as fillers have more accumulation, which results in lower impact strength.

Hardness Test

Hybrid GFRPC/R showed the highest hardness of 41.375 BHK, comparable with the GFRP composite as shown in Figure 7. Hybrid GFRPC/W showed the lowest impact strength of 33.25 BHK. Hybrid GFRPC/R showed 13.23% and 19.63% higher hardness than hybrid GFRPC/C and GFRPC/W, respectively. The highest hardness might be ascribed to the rice husk's superior bonding with polyester than other fillers. Better adhesion reduces the voids present between polyester and filler and hence results in increasing hardness.

Water Absorption Test

The hybrid GFRPC/W showed the highest percentage of water absorption at 1.824, and the GFRP composite showed the lowest at 0.47 demonstrated in Figure 8. The hybrid GFRPC/W composite showed 74.1% higher water absorption than the GFRP composite. Due to the hydrophilic nature of the natural fibers, hybrid composites' capacity to absorb water is higher than GFRP composites, which contain only synthetic fiber. The wheat husk is the most hydrophilic of the three fillers.

Glass Fiber's Volume Fraction

Figure 9 revealed the volume fraction of different composites. The glass content in the entire composites was found to be 51.41 to 53.19%. This is almost the same because all composites contain six woven glass fiber materials.

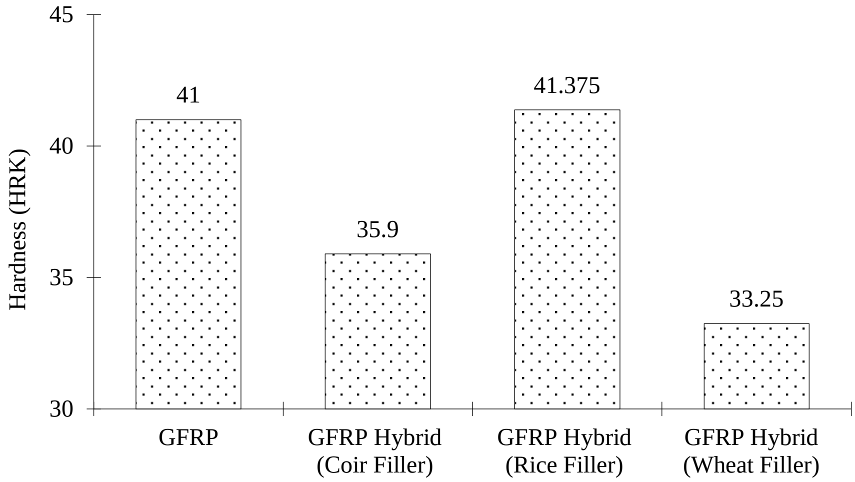

Figure 7. Hardness of different composites.

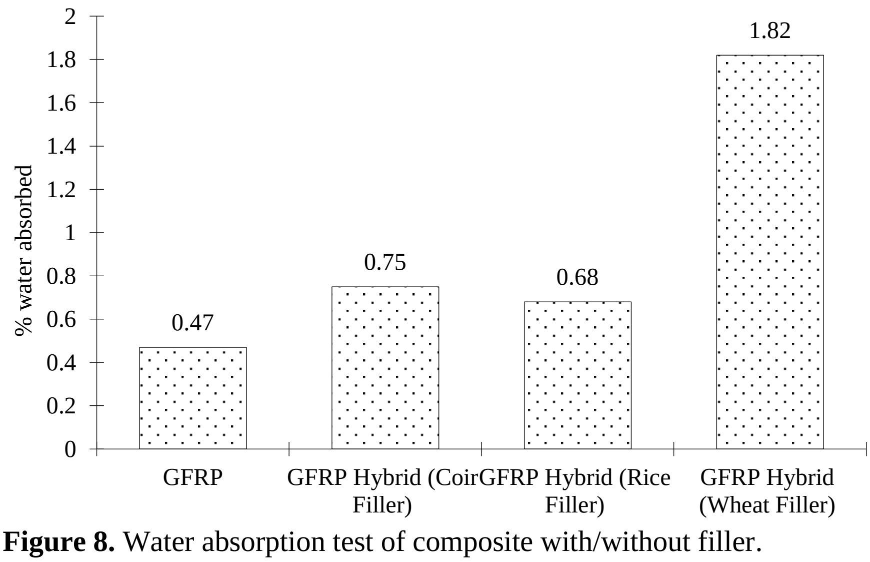

Figure 8. Water absorption test of composite with/without filler.

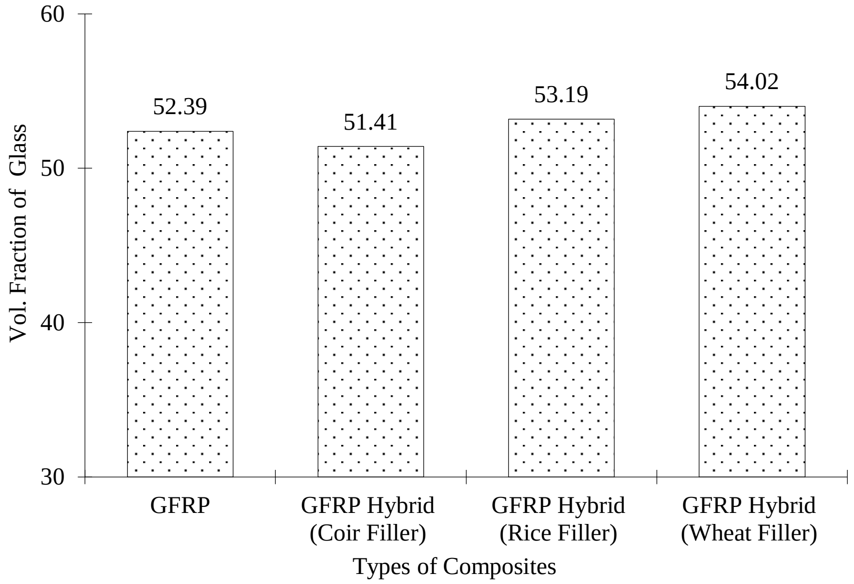

Figure 9. Volume fraction of glass.

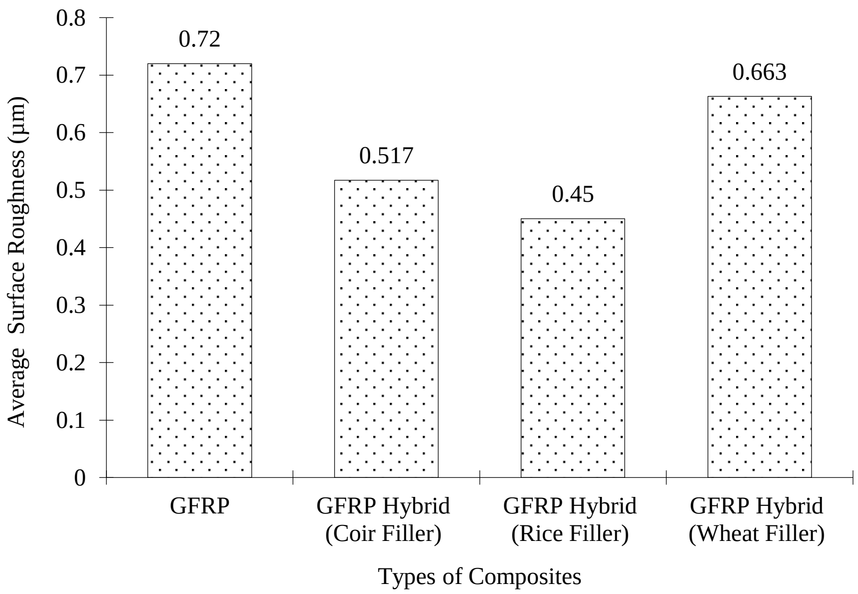

Figure 10. Average surface roughness of developed composites.

Analysis of Surface Roughness

The surface roughness of different composites under consideration is shown in Fig. 10. The GFRP composite showed the highest surface roughness of 0.72 Ra compared with the GFRPC/R composite of 0.45 Ra, which has the most minor surface roughness. This indicates that GFRPC/R has the highest surface finish [13, 14]. The hybrid GFRPC/W showed the most elevated surface roughness of 0.66 Ra, slightly less than the plain GFRP composite. By adding wheat filler to the simple GFRP composite, the surface roughness decreased slightly by 7.91%, and by adding rice filler, the surface roughness reduced by 37.5%. When adding fillers to the GFRP, the surface roughness decreases because the fillers smooth the surface of the composites.

Characterization Summary of Developed Hybrid Composite

Table 1 shows the summary of characterization of developed hybrid composite. Figure showed in bold letter shows the maximum/best value.

The characteristics of plain composites and hybrid composites are summarized below.

- Hybrid composites showed better characteristics than GFRP composites except for UTS, which is comparable to the hybrid GFRPC/R composite.
- GFRP/R showed the highest UTS, surface finish, and hardness among all hybrid composites.
- GFRP/C showed higher flexural and impact strength amongst all hybrid composites.
- GFRP/W showed a higher percentage of water absorption due to its hydrophilic nature and higher surface roughness than other hybrid composites.
- The glass content of all the composites is almost in the same range as all the composites containing six layers of woven mat glass fiber.

Load Analysis

Maximum load of GFRP hybrid composite joint configurations was perceived on UTM and found the following values as shown in Table 2.

Figure 11 reveals the configuration of load-resisting hybrid composites in various joints. GFRPC/R hybrid composite may endure the highest load of 6298.8 N while joined by polyester (joint configuration 2), followed by GFRPC/C of 5758.57 N of the same joint configuration and GFRPC/C of 5651 N of mechanical (i.e., nut-bolt type joint configuration). The weakest joint (configuration 4) was observed in all the composite joints, which have withstood a load of 2573 N. Polyester adhesive joints have high cohesive shear strength (interface) between all eleven joints. Rice husk filler has the highest bonding strength with glass fiber and matrix material among all three types of filler, which may be the reason for its better load-carrying capacity. The load can quickly spread over a large area as compared to others. The adhesive may also be used as the matrix material to achieve excellent joint strength. Epoxy is more brittle than polyester, resulting in early failure. The stress concentration factor is more due to joints failing at early stages due to geometry changes overlapping areas.

Table 1. Summary of Experimental Findings

S.N.	Property	GFRP	GFRPC/C	GFRPC/R	GFRPC/W
1	UTS (MPa)	352.5	315	324.9	283
2	Flexural Strength (MPa)	614	702	548	522
3	Hardness (K-Scale)	41	35.9	41.375	33.25
4	Impact Strength (J/mm^2)	234.4	278.93	256.69	245.53
5	% Water Absorption	0.474	0.7522	0.685	1.824
6	% Glass Content	52.39	51.41	53.19	54.02
7	Surface Roughness (μm)	0.72	0.517	0.45	0.663

Table 2. Maximum Load Variations of GFRP Hybrid Composite

Joint Configuration	Joint Type	GFRPC/C	GFRPC/R	GFRPC/W
C-1	Adhesive	5149	4940	4709
C-2		5758.57	6298.8	5210.3
C-3		3124.5	2771	3008
C-4		3096	2573	3000
C-5		3052	2588	3050
C-6		2671.94	4890.82	4189.18
C-7		3750	3415	3721.5
C-8		3831.5	3607.5	3708.5
C-9	Mechanical	5651	5500	5650
C-10	Hybrid	3743	3618	3278
C-11		5583	5430	5077

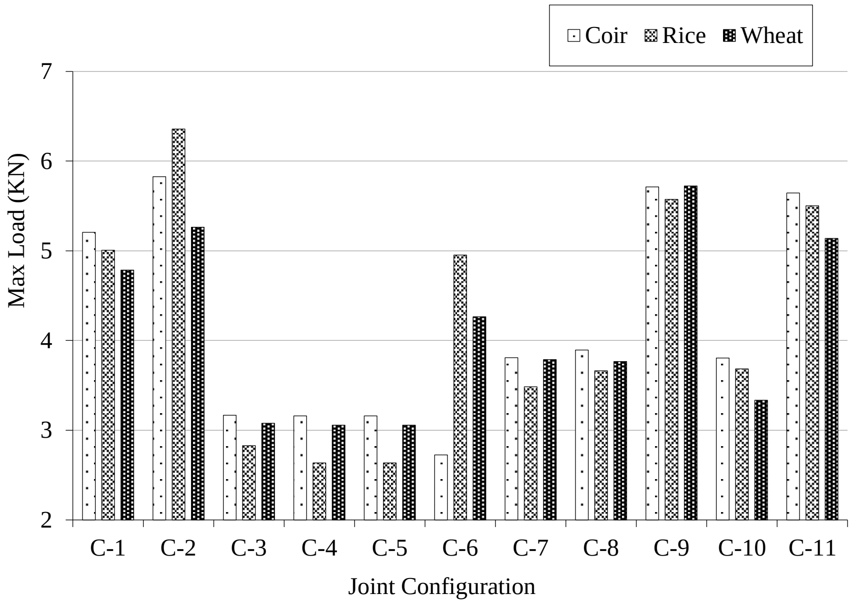

Figure 11. Maximum load variations of GFRP hybrid composites.

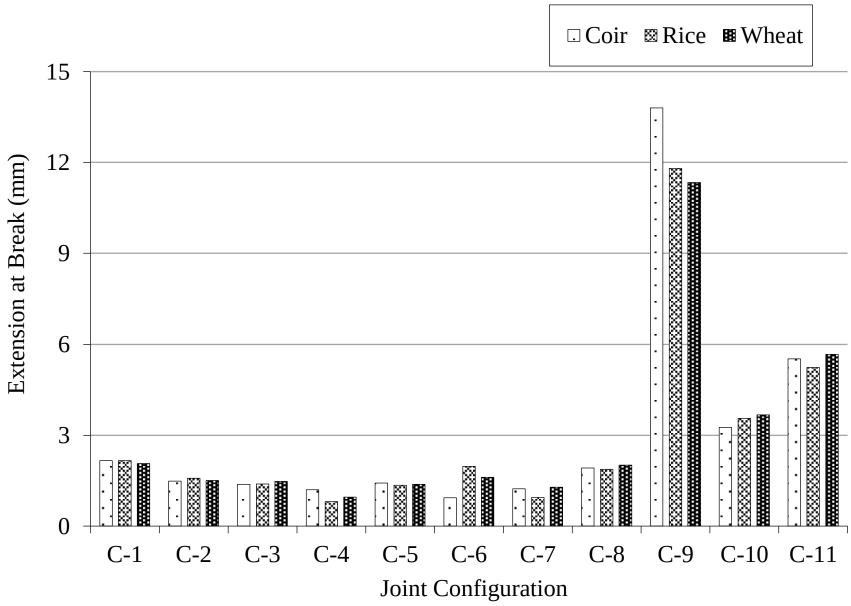

Figure 12. Extension variations of GFRP hybrid composites.

Breaking Analysis

Breaking of GFRP hybrid composite joint configurations was observed on UTM, and different values were obtained. Figure 12 shows the schematic presentation of extension at break resists by hybrid composites in various standard formats. At joint configuration nine, i.e., mechanical joints, elongation revealed the highest extension at the break with a different filler (natural) than the other joining techniques [15]. Hybrid GFRPC/C was found to have an elongation (13.7 mm) higher than the GFRPC/R (17.83%). At the same time, GFRPC/R was observed with the lowest elongation of 0.81 mm for the 4th joint configuration. In this case, an extension was 94.06% lower than GFRPC/C in typical configuration 9. In mechanical joining, the load is supported by a bolt and nut. The nut bolts are made of mild steel, so they resist higher loads. The material will fail only in failure to adhere. This type of joint has only one problem: bolts and nut and weight, which was a critical constraint in the automobile sector. Drilled holes also require special solid carbide drills. Coir fillers have the highest flexibility among all three fillers, which may be attributed to their higher extension.

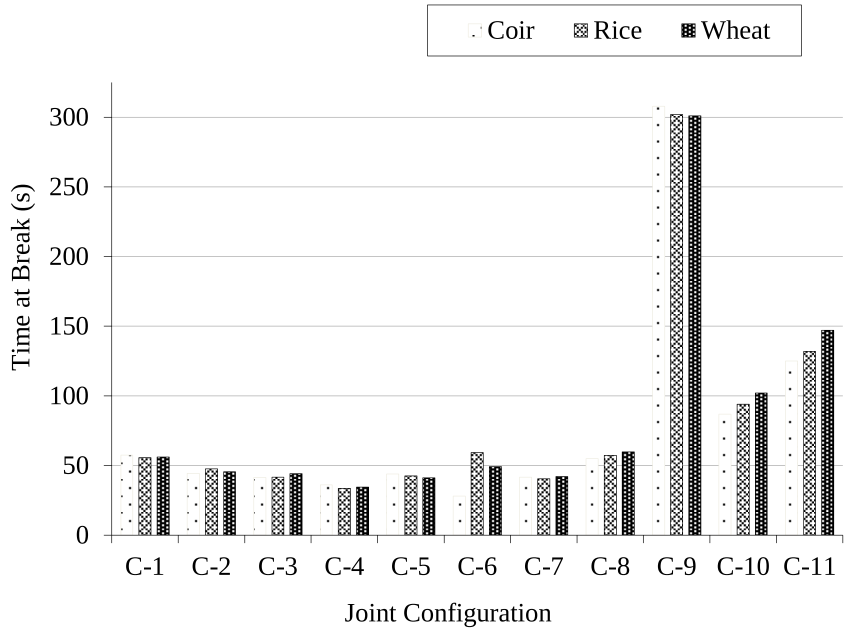

Figure 13. Breaking time of GFRP composites.

Time at Break Analysis

Figure 13 shows the schematic presentation of time at the break by hybrid composites in various joint configurations. It has been observed that amongst the entire standard structure under study, typical configuration nine was found to be the strongest. Hybrid GFRPC/C time at break was a maximum of 308 s, followed by 302 s and 301 s of GFRPC/R and GFRPC/W, respectively. GFRPC/C has shown a 1.94% higher time at break than GFRPC/R and 2.27% higher than GFRPC/W, respectively. GFRPC/C time at break was found to be a minimum of 28.03 s in configuration 6. It is 90.89% weaker than the GFRP/C joint configuration. 9. Nut bolts can resist the load for long, resulting in more significant time.

CONCLUSIONS

In this work, experiments were carried out to develop the glass fiber reinforced composites using the hand layup method and analyze the mechanical properties of the GFRP hybrid composites. The following conclusions have been drawn from the above work.

- UTS using rice as a filler (GFRPC/R) was 3.04% and 12.89% higher than coir and wheat, respectively. A hybrid composite using coir as a filler (GFRPC/C) revealed 12.54% greater flexural strength, and a hybrid composite using wheat as a filler (GFRPC/W) showed 14.95% inferior flexural strength than the simple GFRP composite.
- The Hybrid GFRPC/C composite showed the highest impact strength of 278.93 J/mm^2, and the GFRP composite showed a minor impact strength of 234.47 J/mm^2. Hybrid GFRPC/W showed the most minor impact strength of 245.53 J/mm^2. The hybrid GFRPC/C composite showed a 15.95% higher impact strength than the plain GFRP composite. The Hybrid GFRPC/R showed the highest hardness of 41.375 BHK, comparable with the GFRP composite. The Hybrid GFRPC/W showed the lowest impact strength of 33.25 BHK. Hybrid GFRPC/R showed 13.23% and 19.63% higher hardness than hybrid GFRPC/C and GFRPC/W, respectively.
- The hybrid GFRPC/W composite showed 74.01% higher water absorption than the GFRP composite. The GFRP composite showed the most elevated surface roughness of 0.72 Ra compared with the GFRPC/R composite of 0.45 Ra, which has the most minor surface roughness.
- The maximum and minimum times at break were 308 s and 28.03 s for hybrid GFRPC/C in joint configuration nine and joint configuration 6, respectively. It is 90.89% weaker than GFRP/C standard configuration 9.

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