Research Article

Study on the Inter-Laminar Shear Strength and Contact Angle of Glass Fiber/ABS and Glass Fiber/Carbon Fiber/ABS Hybrid Composites

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Abstract

In recent days, the uses of 3D printing have been successfully implemented in various applications due to their advantages. Besides, the need for sustainable choice has created a demand for the augmented use of thermoplastic composites. Thus, additive manufacturing techniques have become the essence of composite fabrication to achieve an automated and flexible fabrication technique. The present study used fused deposition modelling (FDM) and hot press moulding technique to produce composite samples. The composite laminates were fabricated by using acrylonitrile butadiene styrene (ABS) as polymer and woven glass fiber (GF) and woven carbon fiber (CF) used as reinforcements. Further, the laminates were subjected to inter-laminar shear strength (ILSS) and contact angle. The inter-laminar shear strength and the contact angle of hybrid samples were compared with virgin ABS and pure glass fiber-reinforced composites. The study reported a maximum ILSS of 198.5MPa achieved by GF/CF/ABS hybrid composites, which was higher by 17% and 217% compared with GF/ABS and ABS samples, respectively. The contact angle results showed an increase due to the incorporation of fibers with ABS by 5% and 13% in GF/ABS and GF/CF/ABS, respectively, contributing to the adhesion. The contact angle values achieved were 100.5°, 105.15°, and 113.39° by ABS, GF/ABS and GF/CF/ABS making them hydrophobic in nature. These developed reinforced materials, such as carbon fiber, glass fiber and ABS matrix composites, could be used in automotive, aerospace and wind energy applications.

Keywords: Acrylonitrile butadiene styrene, Glass fiber, Carbon fiber, 3D printing, Hot compression, Inter-laminar shear strength and contact angle

1 Introduction

The selection of the manufacturing technique could be a challenging search as it plays a vital role in defining the performance of the fabricated composite material. A hybrid manufacturing technique can answer the investigation by combining two or more fabrication techniques into a single process to pull off the combined advantages. Our research study aimed to fabricate fiber-reinforced composites using a hybrid manufacturing process involving fused deposition modelling (FDM) and hot compression moulding.

The additive manufacturing (AM) technique is a flexible fabrication approach to produce complex shapes with less material loss. The AM technique facilitates geometric freedom by using CAD data as the input source. As the name denotes, this technique involves the addition of material as layers successively and is controlled by a computer to achieve the required 3-dimensional shapes [1]–[3]. Stereolithography, selective laser sintering, and FDM are notable additive manufacturing techniques of which FDM is extensively used. Chacón *et al.* used an FDM printer to fabricate continuous fiber-reinforced thermoplastic composites with nylon filament as polymer and glass fiber, carbon fiber, and kevlar fiber as individual reinforcements. The testing results revealed a significant improvement in the mechanical performance of the fiber-reinforced composites. It was ascribed to the increased fiber loading. However, glass and Kevlar-reinforced composites exhibited moderate performance [4]. Ning *et al.* fabricated fiber-reinforced plastics using FDM using ABS as matrix and carbon fiber and graphite fiber as reinforcement. The experimental investigations reported better mechanical performance in carbon fiber-reinforced composites than in graphite-reinforced composites [5].

There are many other fabrication techniques available for producing fiber-reinforced composites. For instance, hand lay-up, open contact moulding, hot compression, resin transfer moulding (RTM), vacuum-assisted resin transfer moulding (VARTM), resin film infusion, hot compression moulding, injection moulding, vacuum-bagging, reaction injection moulding, filament winding, pultrusion, tube rolling, automated fiber placement [6], [7]. Hot compression moulding is the most sought and cost-effective fabrication technique for achieving high-strength composites [8]. Tatsuno *et al.* [9] fabricated carbon fiber-reinforced Polyamide 6 composites using hot press moulding and reported that better-quality performance was obtained by maintaining a constant press load during fabrication. Besides, lateral pressure was observed to play a significant role in removing the voids.

Synthetic fibers have started gaining demand in the modern era due to their physical behavior, ease of fabrication, corrosion resistivity, and better strength-to-weight ratio [10]–[13]. Currently, glass fiber and carbon fiber are in high demand as they are versatile and industrially sought of all fibers. Glass fibers are low in price and exhibit better properties, such as hardness, resistance to chemicals, transparent, stability, inertness, high strength-to-weight ratio, flexibility and stiffness [14], [15]. Carbon fibers are more expensive than glass fibers and exhibit improved properties, such as tensile strength, resistance to chemicals, resistance to high temperature with low coefficient of thermal expansion, and stiffness. The mechanical strength per unit weight of carbon fiber-reinforced composites is higher when compared with steel and aluminium. This minimizes energy consumption during unit operation. Selmy *et al.* fabricated unidirectional glass fiber/epoxy, random glass fiber/epoxy and their hybrid epoxy matrix composites using the hand lay-up technique, and they were subjected to ILSS. The study revealed that the unidirectional composites performed better ILSS than random fiber-reinforced composites. However, the hybrid composites outperformed in ILSS than random fiber composites [16]. Vinay *et al.* compared the mechanical performance of glass fiber/vinyl ester and carbon fiber/vinyl ester matrix composites. They fabricated the composites using a hand lay-up approach. Results reported that carbon fiber-reinforced composites exhibited better performance in mechanical properties, such as ILSS, impact strength and shore-D hardness values [17]. ABS, a thermoplastic polymer, is a terpolymer. The ABS is amorphous and is considered an effective toughener [18]. Mohan *et al.* fabricated short glass fiber-reinforced ABS matrix composites using the FDM technique. It was reported that substantial improvements in impact strength and tensile strength with a reduction in ductility and surface roughness due to the inclusion of short glass fibers [19].

Baştürk *et al.* fabricated thermoplastic polyurethane/barium metaborate composite using a solvent casting technique. This was followed by vacuum drying at 60 °C. A constant thermoplastic polyurethane weight content of 3 grams and a varying weight % of 0, 1, 3, 5, 7 (in F0, F1, F2, F3, F4, respectively) was used. The wettability analysis was carried out with on Kruss (Easy Drop DSA-2) tensiometer using the sessile drop method. The contact angle (θ) was measured with a 3–5 μL distilled water drop. The captured image reflected an increase in contact angle values as follows:

F0 < F < F2 < F3 < F4 with values 71°, 77°, 81°, 83°, and 85°, respectively [20]. Fuentes *et al.* measured the contact angle for different thermoplastics like polypropylene, polyvinylidene fluoride (PVDF), and maleic anhydride-grafted polypropylene (MAPP) on smooth glass fibers and smooth glass plates. Ultrapure water, diiodomethane and ethylene glycol were used as testing liquids under the following conditions: a temperature of 20 °C and humidity of 50%. Both advancing, and receding contact angles were measured with a tensiometer using the Wilhelmy technique. Polypropylene recorded higher values (advancing contact angle –97.8°, receding contact angles –74.1°, equilibrium contact angle –86°) in water as testing liquid [21].

This study implemented a hybrid manufacturing technique to fabricate the composite samples, such as FDM and hot press moulding technique. The composite samples were prepared using glass fiber, carbon fiber and ABS. The performance of the composite samples was analyzed by varying the fiber layering sequences. In addition to the effect of the hybrid manufacturing technique, the ILSS of composites was measured. Scanning electron microscopy images of ILSS tested samples were used to understand the interfacial bonding between the fiber and matrix.

2 Materials and Methods

Bi-directional glass fiber mat (GF) and bi-directional carbon fiber mat (CF) were purchased from M/s Rakshana Agencies, Madurai and M/s Vruksha Composites, Andhra Pradesh, India, respectively. Acrylonitrile butadiene styrene (ABS) matrix was purchased from M/s Filament Wol3D, Maharashtra, India. Besides, the physical and mechanical properties of GF, CF and ABS are reported in Tables 1 and 2, respectively.

Table 1: Important properties of GF and CF

Details	Glass Fiber	Carbon Fiber
Tensile strength (MPa)	3100–3800	4100
Young's modulus (GPa)	80–81	240
Elongation at break %	4.8	1.8
Density (g/cm^3)	2.62	1.77
Grams per square meter (GSM)	300	200

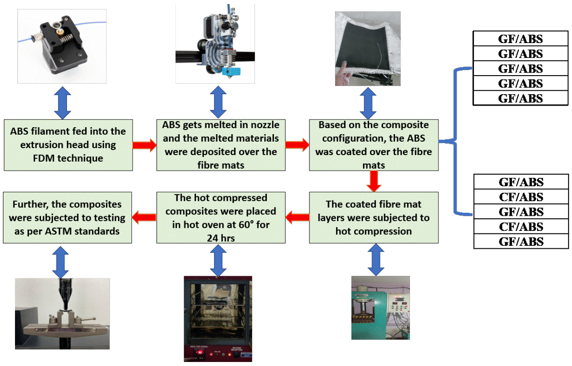

Figure 1: Step-by-step procedure of composite fabrication.

Table 2: Important properties of ABS

Details	ABS
Tensile strength	≥ 43 MPa
Flexural strength	≥ 70 MPa
Flexural modulus	≥ 2300 MPa
Impact strength (IZOD, 23 °C)	≥ 108 J/m (ASTM 256)
Elongation at break	≥ 30%
Distortion temperature	≥ 88 °C

2.1 *Composite fabrication*

Figure 1 explains the step-by-step procedure of composite fabrication. In brief composite fabrication involves hybrid manufacturing techniques, such as FDM and hot press moulding techniques. Tables 3 and 4 give the essential parameters of 3D printers and hot press machines, such as printing temperature, printing speed, etc.

Table 3: Important parameters of 3D printer

Parameters	Range
Printing temperature	220–240 °C
Printing speed	60–90 mm/s
Suggested printing layer resolution	0.1–0.2 mm
Hot bed temperature	80–110 °C
Printing raft	Necessary

Table 4: Important parameters for hot compression

Parameters	Range
Compression temperature	230 °C
Compression duration	5 min
Load	1000 psi

2.2 *Characterization*

2.2.1 Inter-laminar shear stress test

The Inter-laminar shear strength (ILSS) test was conducted using a three-point bending test. The span length of 24 mm and bending rate of 1.27 mm/min were maintained. The ILSS was calculated using Equation (1). Five samples were tested, and average values were reported.

$$\text{ILSS (MPa)} = \frac{3P}{4bh} \quad (1)$$

Where,
P = maximum load in kN;
b and h = width and thickness of samples (mm)

2.2.2 Microscopic analysis

The microstructures of ILSS-tested samples were examined using a scanning electron microscope (SEM) using the TESCAN VEGA3 SBH model (Czech Republic).

2.2.3 Contact angle

The contact angle of ABS, GF/ABS and GF/CF/ABS hybrid composites were measured at room temperature using a Contact angle goniometer (Kyowa Contact Angle Meter, Japan). Besides, ca. 6 μL distilled water was placed over the composite samples to measure the contact angles. Ten measurements were taken for each sample configuration to check their accuracy, and average values were reported.

3 Results and Discussion

3.1 *Inter-laminar shear strength*

Figure 2(a)–(c) shows the load vs displacement curves, ILSS and tested samples of ABS, GF/ABS and GF/CF/ABS hybrid composites. It was observed from Figure 2(a) that the force increased linearly for fiber-reinforced composites, followed by a decreasing trend. It was ascribed to the effect of fiber delamination. Among the composite samples, GF/ABS failed earlier than GF/CF/ABS hybrid composites; the transverse

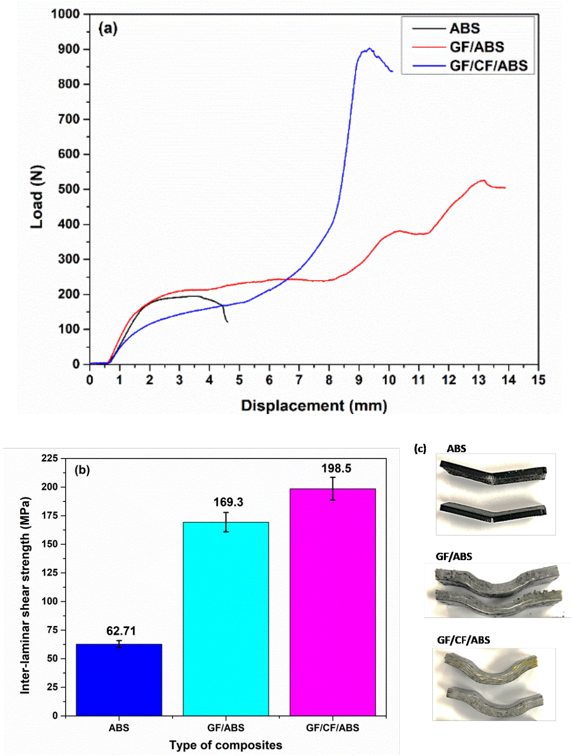

Figure 2: (a) Inter-laminar shear strength load vs displacement of ABS, GF/ABS and GF/CF/ABS hybrid composites; (b) Inter-laminar shear strength and Inter-laminar shear modulus of ABS, GF/ABS and GF/CF/ABS hybrid composites; and (c) tested samples.

shear load experienced by the former exceeded the inter-laminar shear strength and caused delamination [Figure 3(b)]. Chandrasekaran *et al.* [22] reported that inter-laminar shear failure could also happen due to the combination of crushing at the point load and/or flexural load due to bending. Based on the results, the order of the increasing trend of load vs displacement curve was ABS> GF/ABS> GF/CF/ABS. Besides, the inter-laminar shear strength obtained from Figure 2(a) is shown in Figure 2(b). From Figure 2(b), it was clear that the GF/CF/ABS hybrid composites exhibited higher inter-laminar shear strength (198.5MPa) than GF/ABS (169.3MPa) and ABS (62.71MPa) composites. This can be explained by the nature of high-strength carbon fibers compared to glass fibers (Table 1).

When the inter-laminar shear strength of composites was compared, the GF/CF/ABS hybrid composites

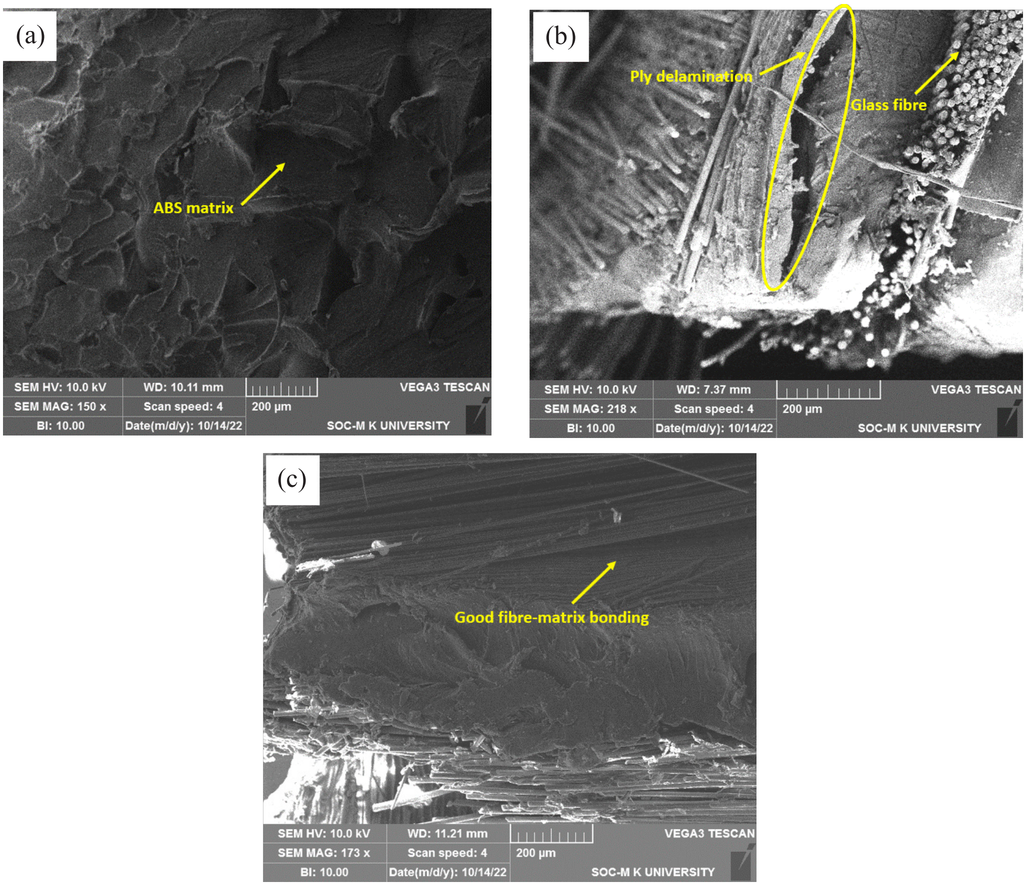

Figure 3: SEM photograph of inter-laminar tested samples (a) ABS, (b) GF/ABS, and (c) GF/CF/ABS hybrid composites.

were 17% and 217% higher than GF/ABS and ABS samples, respectively. The improved inter-laminar shear strength of hybrid composites was attributed to better mechanical properties of carbon fibers, improved interfacial bonding, as well as enhanced load transfer between GF, CF and ABS matrices [23], [24].

Figure 3(a)–(c) shows fracture images of ABS, GF/ABS and GF/CF/ABS hybrid composites. GF/ABS composites failed due to fiber ply delamination [Figure 3(b)]. This failure happened due to the imperfect bond between GF and ABS matrix. Thus, the poor bonding initiated the inefficient stress transfer between glass fibers and matrix at the interface. Figure 3(c) shows the better compatibility of fibers in the GF/CF/ABS hybrid composites. Due to the enhanced fiber-matrix adhesion characteristics, the hybrid composites exhibited improved inter-laminar shear strength than other counterparts.

3.2 *Contact angle*

The hydrophilicity and hydrophobicity of the composites can be determined by measuring their contact angle [25]. Figure 4(a) and (b) show the contact angle measurements of ABS, GF/ABS and GF/CF/ABS and their images, respectively. It was observed from Figure 4(a) that the contact angle values were increased by incorporating fiber reinforcements within the ABS. For instance, the contact angle of GF/ABS and GF/CF/ABS hybrid composites increased by 5%, 13% compared to ABS. Besides, the work of adhesion decreased, and the spreading co-efficient was increased (Table 5). Thus, incorporating GF and CF within the ABS increased the hardness of composites and exhibited hydrophobic behaviour.

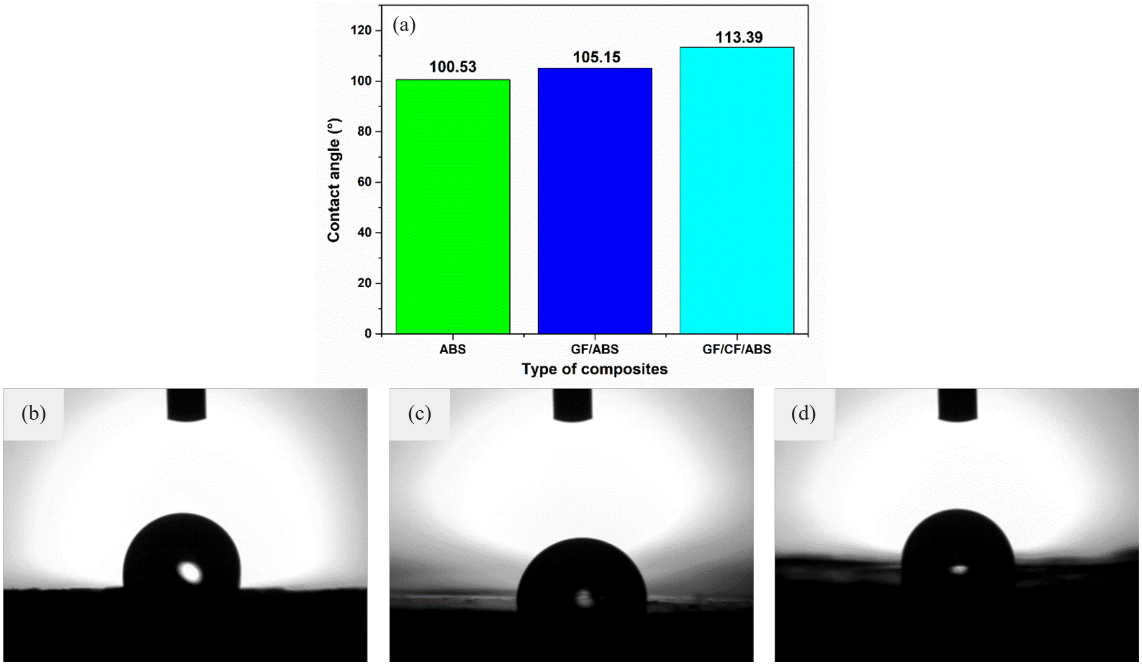

Figure 4: (a) Contact angle values of ABS, GF/ABS and GF/CF/ABS hybrid composites; Contact angle images of (b)ABS, (c) GF/ABS, and (d) GF/CF/ABS

Table 5: Work of adhesion and spreading co-efficient of composites

Type of Composites	Work of Adhesion (Wa)	Spreading Co-efficient (Sc)
ABS	54.69538	–90.90462
GF/ABS	75.59463	–70.00537
GF/CF/ABS	50.66639	–94.93361

4 Conclusions

In this study, the composite laminates were fabricated based on a novel approach by combining FDM and hot press moulding techniques. Effects on ILSS and contact angle measurements of ABS, GF/ABS and GF/CF/ABS composites were investigated. Besides, ILSS-tested samples were examined by using SEM. The major conclusions were drawn from this investigation. Compared to the pure ABS and the GF/ABS, adding CF with GF/ABS, the ILSS behavior was increased. The percentage of increment was obtained as 170% (ABS to GF/ABS) and 17% (GF/ABS to GF/CF/ABS), respectively. Based on the results, the increasing trend of ILSS was ABS> GF/ABS> GF/CF/ABS. SEM images supported these results. Regarding the contact angle, the GF/ABS and GF/CF/ABS composites increased by 5%, 13% more than the ABS samples. Besides, work of adhesion was raised in the order of ABS> GF/CF/ABS > GF/ABS and spreading co-efficient was observed to decrease in the order of ABS> GF/CF/ABS > GF/ABS.

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Author Contributions

A.D.: conceptualization, investigation, reviewing and editing; S.K.: investigation, methodology, writing an original draft; R.N: conceptualization, data curation, writing—reviewing and editing; S.M.T: reviewing and editing; C.M.: reviewing and editing. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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