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ANALYSIS OF THE MECHANICAL CHARACTERISTICS OF DATE SEED POWDER-BASED COMPOSITE CARBON FIBER REINFORCED POLYMERS

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Abstract. *Composites with fiber reinforcement are often a popular lightweight option. Due to their unique qualities, fiber-reinforced composites are the best alternative to traditional materials. Mechanical parameters of a carbon fiber-reinforced epoxy resin (CFRE) composite reinforced with date seed granulated powder (DSGP) were examined at the room temperature. The mechanical qualities included tensile, flexural, and impact strength. Enhanced mechanical properties were noticed compared to carbon fiber reinforced epoxy composite produced using the hand lay-up method and vacuum bag. The DSGP-reinforced CFRE with weight ratios of 0%, 15%, 25%, and 35% were considered. The test results revealed the maximum values of breaking force, maximum bending force, energy absorption capacity, and hardness number for 15%, 35%, 25%, 25% Wt DSGP samples. The results show that the optimal composition for carbon fiber reinforced epoxy with date seed granules is in the range from 15% to 25% wt. GDS. This study reveals that carbon fiber-date seed-reinforced composites are excellent substitutes for carbon fiber composites since they offer better mechanical properties at a lower cost.*

Key words: *Mechanical properties, Maximum bending force, Energy absorption capacity, Reinforced epoxy, Seed-reinforced composites*

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1. INTRODUCTION

Due to their superior qualities, ease of manufacture, environmental friendliness, resistance to chemicals and erosion, high quality and solidity, and economically beneficial qualities, composite materials find extensive use in commercial enterprises. Researchers are primarily focused on improving the thermal and mechanical qualities of the newly evolved composites that have excellent properties, as mentioned above. Composites are also characterized by further remarkable properties including high levels of strength, stiffness, and elasticity. The performance of the composites is improved by the filler and fiber mix. The most common material used for matrix of composites is epoxy [1]. A typical composite material is a system of materials made up of two or more materials that have been combined and joined [2]. If the composition is done on a microscopic scale, the new material is known as an alloy for metals or a polymer for plastics [3]. Frequently, composites are used in a metal matrix or a polymer matrix. Both synthetic and natural reinforcements are applied [4]. Glass, carbon, and aramid fibers are examples of synthetic reinforcements [5]. Most commonly, composite materials consist of a continuous matrix phase in the bulk and reinforcement as a single distributed non-continuous phase. The fiber type significantly affects the fiber-reinforced polymer matrix composites used. The importance of the matrix type is secondary, and the fabrication process is of the third importance compared with the effect of the fiber material [6-8]. Hence, mechanical characteristics mostly depend on the fiber content. The fiber-matrix bonding, fiber's characteristics, the micro-voids, and the selected fabrication techniques affect the resulting strength [9]. Delamination and flexure failure are the two failure modes regarded to be significant in designing polymer composites, and their effects on the properties of the composite panel for similar fiber/resin systems were investigated [10].

The adhesion bond of the resin-matrix increases the mechanical properties of CF/Ep composites [11]. Micrographs of CF/Ep composites samples in tensile tests show intrinsic manufacturing defects and cracks propagation, which leads the carbon fiber to get pulled out without breaking. Cracks propagation in the interfacial zones affects the shearing force between the reinforcement and matrix and, therewith, the mechanical properties [12]. Fiber content has a positive effect on mechanical properties in the matrix. Carbon fibers improve strength, yield strength and peak load in composites [9]. The vacuum bagging process provides high quality, defect-free, non-porous composites when through-thickness pathways and prepared formats are used [13]. Both experimental and SEM analysis showed that there was good adhesion between the matrix and fibers [14]. CFRP composites offer advantages over metals and other polymers when used for spring applications. The tensile modulus was improved by using reinforced carbon fibers [9].

Due to the fact that the tensile strength of composites is greater than the compressive strength, failure in these materials typically manifests as a crack under the roller and delamination in the specimen [15]. More efficient stress transfer from the matrix to the reinforcement increases the ultimate strength, which is due to good interfacial adhesion. Choosing a proper reinforcement and matrix combination is one of the most effective ways to improve the capacity of composites. Changes to the interface may have an impact on the unidirectional (UD) CFRPs' fracture modes and mechanical properties [16]. When UD CFRPs undergo longitudinal tensile failure, those with weak interfacial bonds exhibit splitting or broom fracture behavior, whereas those with strong interfacial bonds exhibit step-like or brittle fracture behavior [17]. In essence, Fiber Reinforced Polymer (FRP) failure mechanisms heavily depend on the matrix parameters.

Due to its simple processing, high strength, and chemical resistance, epoxy resin is the most widely used polymer matrix in the creation of composite for structural and automotive purposes. Researchers used inorganic and synthetic particles made of aluminum, titanium oxide, silica, and different types of carbon nanotubes (CNT) as toughening materials to enhance the mechanical properties of FRPs in order to overcome the drawbacks of FRPs [18-20]. For instance, a study on the possible improvement of interfacial compressive strengths of CFRP composites employing scrolling carbon nanotube (CNT) sheets around individual carbon fibers was reported [21]. Natural fiber-reinforced composites have become more prevalent in a variety of applications. Glass fibers were supplemented with carbon nanotubes and sawdust (additional reinforcements) to enhance the mechanical properties, which helped to some extent to solve the aforementioned issues. Raw sawdust can be used as a material to improve biodegradable polymers [22]. Natural fiber-reinforced composites have become more prevalent in a variety of applications, this is because more people are becoming aware of how synthetic materials affect the environment. Various plant parts are used to produce natural fibers [23-25]. Nevertheless, given the abundance of date plants, particularly in tropical areas, date seeds are frequently viewed as a waste of biomass [26-28]. After eating the fruit's flesh, the majority of date seeds produced in most third-world nations are still thrown away [29-31].

In this work, different plain fabric structures were considered to improve the mechanical properties of composites. A composite material of carbon fiber-reinforced epoxy (CFRE) and date-seed granulated powder (DSGP) were investigated and used as a filler reinforcement material. This investigation was to ascertain the impact of date seed granules on the mechanical characteristics like hardness, strength, impact, tensile, and bending of carbon fiber-reinforced epoxy composite. Additionally, the ideal CFRE to DSGP ratio was established in this work in terms of strength, hardness, and toughness.

2. Materials and Methods

2.1 Materials

The polymer matrix material used was epoxy resin Epolam 2040 and hardener 2047 under the trade name Sika Sikaaxson Shanghai under the trade name Sika Sikaaxson Shanghai (China). It is shown in Fig. 1(a). The mechanical properties of epoxy and carbon fiber are given in Tables 1 and 2, respectively. The plain weave carbon fiber fabric has a weight of 92 g/m². The density of the carbon fibers used was 1.79 g/cm³, Fig. 1(b). The carbon fibers were supplied by Hangzhou Impact new material Co., China.

A hammer mill was used to grind the date seeds into a powder. A date fruit's seed (pit) and meaty pericarp make up the entire fruit. While dietary fiber, protein, fat, ash, and polyphenols are present in tiny levels in the fleshy pericarp, carbohydrates make up the majority of it. The date seed contains a tiny embryo and is a hard-coated seed that is normally rectangular and ventrally grooved. It makes up between 6 and 20% of the fruit's overall weight and weighs between 0.5 and 4 g. Fruit maturity, grade, and variety affect the weight [32-35]. Dates have the following chemical compositions: 3.1-7.1% moisture, 2.3-6.4% protein, 5.0-13.2% fat, and 0.9-1.8% ash. Additionally, seeds have the highest concentrations of antioxidants (580-929 m Trolox equivalent/g), phenolics (3,102-4,430 mg Gallic acid equivalent/100 g), and dietary fiber (78-80 g/100 g) [16].

a） b）

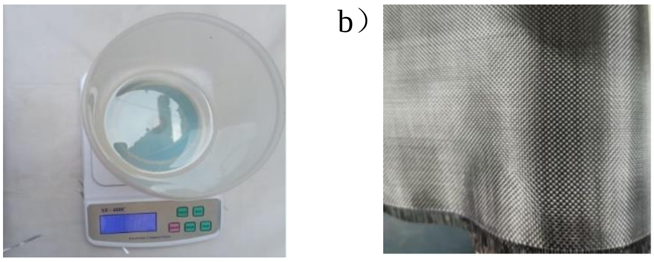

Fig. 1 a) Epoxy and b) Carbon fiber

Table 1 Mechanical properties of epoxy

Property	Flexural modulus [MPa]	Tensile strength [MPa]	Mix ratio by weight at 25°C	color	Density [g/cm³]	Viscosity [MPa·s]
Resin	2900	75	100:30	Light amber	1.1	1100

Table 2 Mechanical properties of carbon fiber

Property	Young's modulus [GPa]	Tensile strength (Mpa)	Elongation to Failure [%]	Density [g/cm³]	Thickness [mm]	Weight [g/m²]
Carbon fiber	238	3845	1.6	1.79	0.15	92

2.1.1 Extraction and Preparation of Date Seeds

Using a knife and a firm brush, the date seed (DS) surface layers were removed locally. The DS was next cleaned with distilled water and left to air dry for 24 hours. An oven set to 70°C for 8 hours was used to dry out the DS's moisture content. The DS was then broken up and put through a hammer mill to create a 200 µm spherical powder as shown in Fig 2. In order to ensure the correct fiber-to-matrix orientation between the granulated date seed and the carbon fiber-reinforced epoxy resin composite, lignocellulose characterization of the date seed powder was performed.

Fig. 2 Date seed after hammer milling in form of 200 µm spherical powder

2.2 Composite Preparation

Composite samples were fabricated using two different methods: the hand lay-up technique and vacuum bagging. The vacuum bagging process involved several components, including vacuum bagging film, vacuum pump, vacuum chamber, molding material, sealing tape, resin feed connector, pipe for resin infusion, epoxy resin, peel-ply material, and resin infusion mesh. These components were crucial for the successful implementation of the vacuum bagging process. These methods were used because of their simplicity and availability of the items. The laminating mixture of the epoxy resin and the granulated date seed powder was applied by pouring in the prepared mold and using a paint roller to properly dress the surface to fit in. The carbon fiber was then applied to the poured resin using the woven-proven method. In consolidating the laminate, paint rollers were used, thoroughly wetting the reinforcement and removing the entrapped air. Subsequent layers of carbon fiber reinforcements laminate mixture of epoxy resin and granulated date seeds were added to build the required composite thickness (Table 3). Both cobalt amine-based accelerator and hardener (Epolam 2042 hardener) were employed as curing agents for epoxy resin and were later vacuum bag consolidated for approximately an hour. The constructed samples were kept at room temperature overnight to finish the curing process.

Table 3 Weight variation of each test piece

No	CFR Epoxy [%]	DS Powder [%]	Weight of CFRE [kg]	Weight of DS [kg]	Total weight of composite [kg]
1	100	0	0.297	-	0.285
2	85	15	0.264	0.016	0.280
3	75	25	0.297	0.031	0.328
4	65	35	0.297	0.083	0.380

Various compositions of the composite have been considered in this work:

1. 100 % Carbon fiber Epoxy and 0 % Date seeds powder
2. 85 % Carbon fiber Epoxy and 15 % Date seeds powder
3. 75 % Carbon fiber Epoxy and 25 % Date seeds powder
4. 65 % Carbon fiber Epoxy and 35 % Date seeds powder

3. Mechanical Tests

Tensile, three-point test (bending), impact and hardness tests were performed using the generated composite samples. For each test, ten samples were used, and the mean values of results are given. An electronic universal testing machine from Sinotest Equipment Co., Td. with a 100 kN load frame (in line with ASTM D3039 standards), was used for the tensile test. To prepare the rectangular composite laminate for mechanical testing, the finished product, measuring 300 mm × 250 mm and with a thickness of 3 mm, underwent precise slicing into the required sizes. For the tensile testing, we followed ASTM D 3039 guidelines and cut rectangular coupons measuring 250 mm × 25 mm from the cured composites. The testing was carried out at a controlled displacement rate of 2 mm/min. Rectangular samples are preferred over dog-bone samples in evaluating the tensile properties of composites because the latter often experience splitting at regions where width changes. To ensure consistency, the rectangular samples were designed with a gauge length of 175 mm.

For the bending strength test, as per ASTM D 790 specifications, each specimen was 4 mm thick and 13 mm wide. The test involved placing the specimen on two supports and loading it in the middle. The flexural testing was conducted to assess the composite's resistance to deflection, and it was carried out at a loading rate of 2 mm/min. To determine the Izod impact strength, we employed the Izod impact device in accordance with ASTM 7136 standard. Each sample had dimensions of 55 mm × 10 mm × 5 mm, as illustrated in Fig. 3.

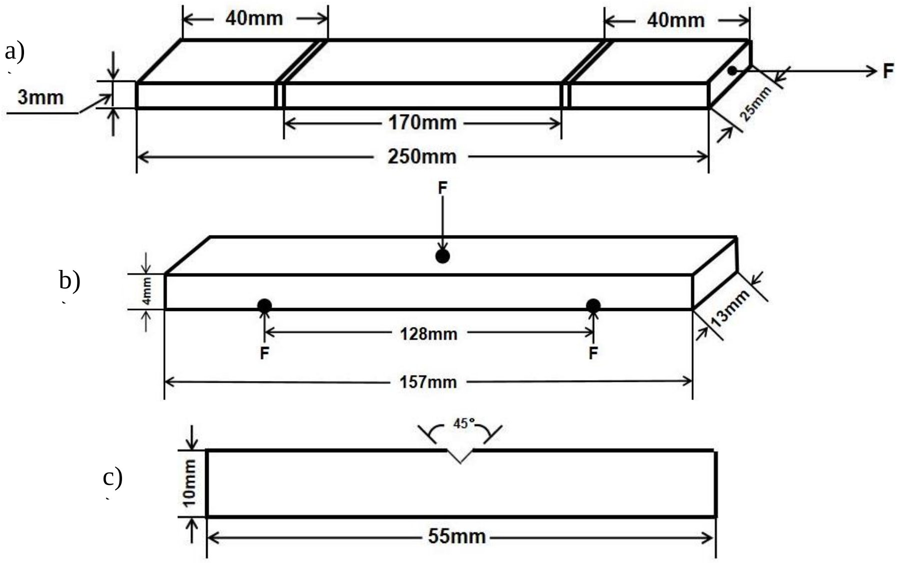

Fig. 3 Sample dimensions in: a) tensile; b) bending; and c) impact test

Additionally, the hardness test was performed using the Hardness Shore D method, following ASTM 2240 guidelines, as depicted in Fig. 4.

Fig. 4 From left to right: tensile device, binding device, impact device, and hardness device

4. Results and Discussion

4.1 Tensile Characteristics

The highest force a material can endure when being pulled apart and the amount of stretching it can withstand before failing are both referred to as tensile strength. The mean results of the experimental runs of tensile tests on four different DS powder-reinforced CFR epoxy ratios are given in Fig. 5.

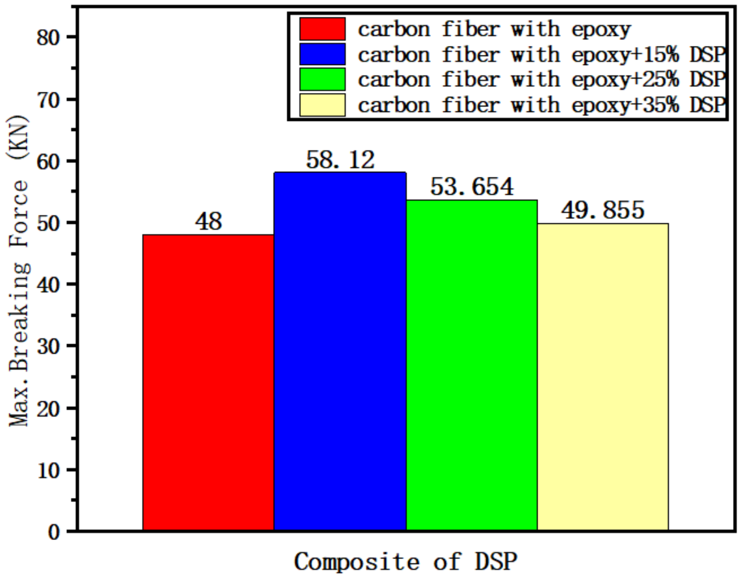

Fig. 5 Maximal breaking force for different composites

It can be seen that the CFR- 15 %wt from DS has the highest ultimate force breaking value (58.12 kN). The maximum breaking force of the reference sample was measured to be 48 kN. The incorporation of DS to the epoxy obviously increased the tensile strength It should be emphasized that this result is in agreement with the observations made in the available literature [15-22] that blending an amount of DS to epoxies considerably increased the tensile strength. This is achieved by the variable interfacial adhesion of DS and epoxies in various systems. For active reinforcing potential, adequate load transmission between the epoxy matrix and DS is necessary. Since efficient load transfer during the elastic deformation stage under loading is possible due to the interfacial adhesion, a 10% increase in the breaking force was seen in the current study, and, consequently, it was possible to obtain efficient reinforcement in terms of both strength and tensile modulus. It is crucial to point out that the mechanical characteristics of DS modified epoxies rely on the DS content as well.

The samples used in the tensile test are depicted in Fig. 6.

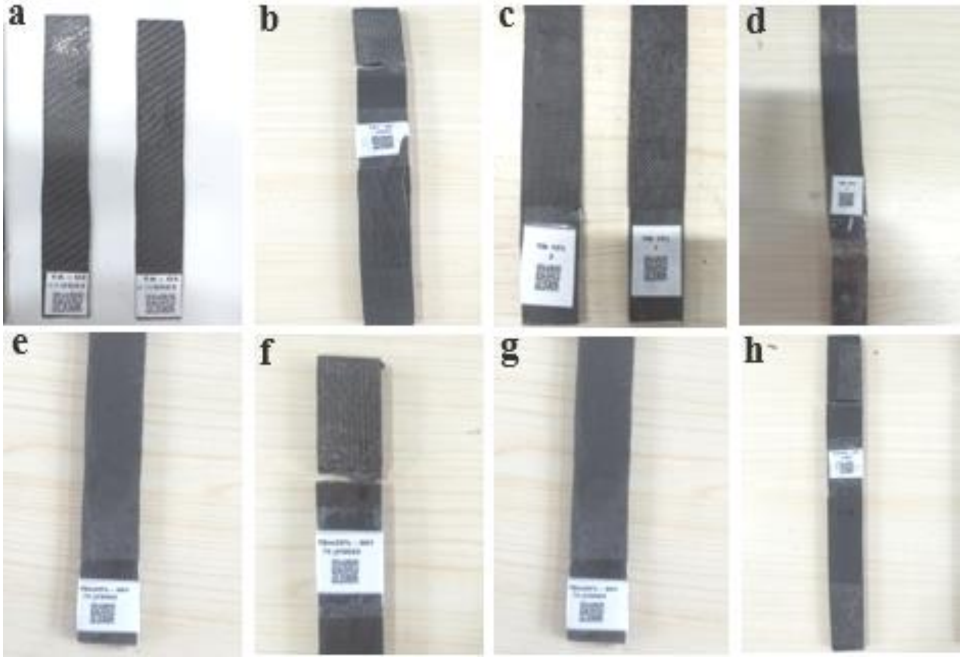

Fig. 6 Sample tensile test: a) and b) 0% DS before and after the test; c) and d) 15% DS before and after test; e) and f) 25% DS before and after the test; g) and h) 35% DS before and after the test

4.2 Flexural Test

To evaluate the stiffness, the bending strength and modulus of the composite materials were evaluated using a three-point bending test. The experimental results are shown in Fig. 7, which displays the outcomes of the flexural test performed on the carbon fiber reinforced epoxy resin composite and various compositions of powder date seed. Obviously, the maximum bending force is exhibited by CFR-% 35 wt. DS and it is 1.010 KN. This indicates that the composition will be able to withstand the most bending caused by flexural loads at this composite combination ratio. It is inevitable that fractures in flexural tests start on the tension side (the side opposing the loading direction) and steadily advance to the compression side until the composite fails completely. Beginning of a fracture on the tension side means that the material's strength has been loosened, which will cause the curve to depart from linearity. Because of this, the maximum stress at failure on the tension side is regarded as a material's flexural strength. Flexural strengths are improved when the DS loading is raised to 35 wt% percent, which boosted both flexural force by 24% in comparison to the reference sample. Similarly to this, 15 wt%, 25 wt% percent of DS loading added to GFRP improved flexural strength, when measured at lab temperature, was 7% and 9 %, respectively. This increase in strength and modulus might be explained by the effective load transfer from the polymer matrix to the DS via the delicate matrix/DS contact.

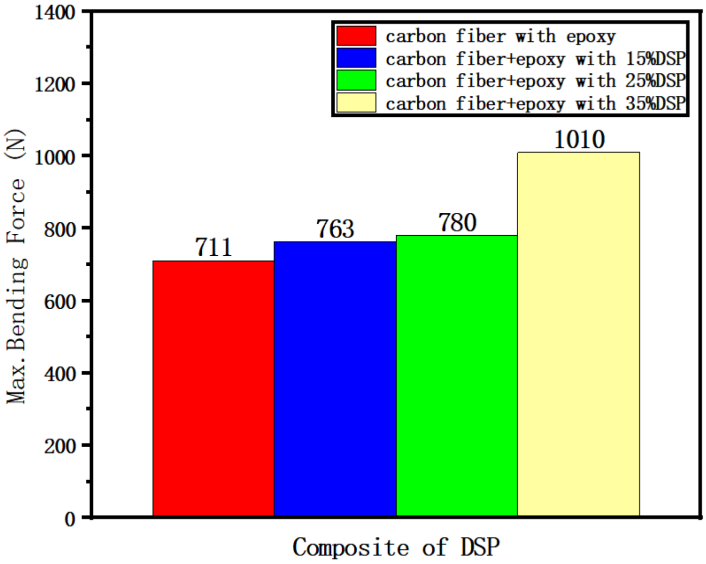

Fig. 7 Maximum bending force in different composites

Fig. 8 shows the samples used for bending, before and after testing.

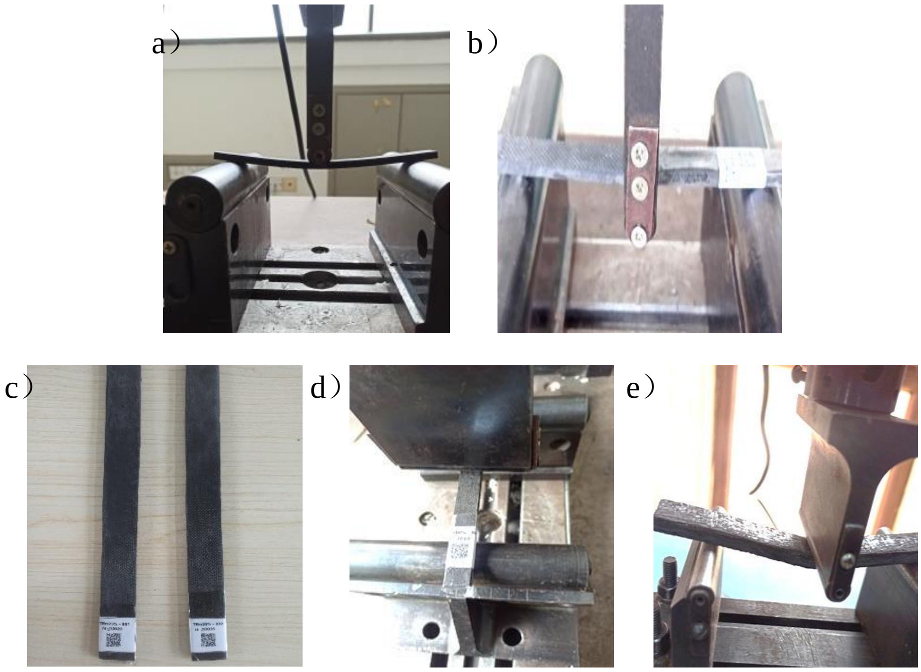

Fig. 8 Sample bending test: a) 0% DS after the test, b) 15% DS during the test, c) 25% DS before the test, d) 35% DS under the test, and e) 35% DS after the test

4.3 Impact Test

The impact resistance ability of the materials was also tested. The hybrid biocomposite (Carbon fiber + (epoxy + 25% DS)) added more strength to the material compared to the reference CFRP. It has increased by 17% with addition of DS, as shown in Fig. 9, and it is about 4.7 J of energy absorbing.

The fracture behavior for laminate structure design combinations is depicted in a close-up image, Fig. 10. The behavior of composite materials might change depending on the laminate structure. Before they fail, composite materials may show a variety of damage, including matrix cracking, fiber fracture, fiber pullout, fiber rupture, and fiber debonding. Typically, when fibers break, the entire structure might also fail. According to damage behavior seen upon impact, fiber rupture is the primary cause of the total damage, as shown in Fig. 10c. This suggests that in order to assure the capacity of the composite lamination structure, the choice of reinforcing type is a very crucial issue to be considered. Additionally, the impacts of various matrix types revealed varying capacities for withstanding impact, with epoxy resin with a 25 wt% DS having a greater capacity than the standard. The behavior of the hybrid and architecture-oriented structures under impact also differed dramatically. The impact energy absorption of the various composite lamination structures revealed that, when compared to other composite structures, the carbon fiber + epoxy with 25wt%DS specimen had a greater energy absorbing performance, reaching the value of 4.7 J. Overall, the findings demonstrate the impacts of various composite material reinforcement, matrix, and structural types. In the analysis of contrasts between the experimental.

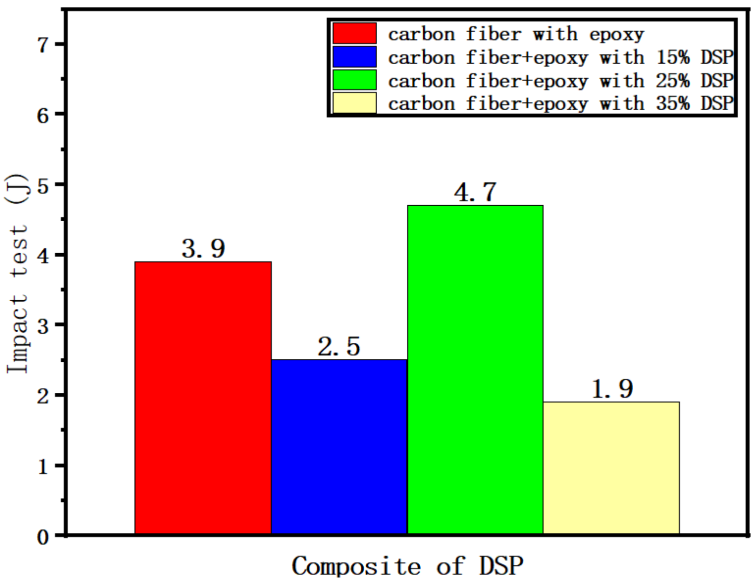

Fig. 9 Maximum strength Impact

a) b) c) d)

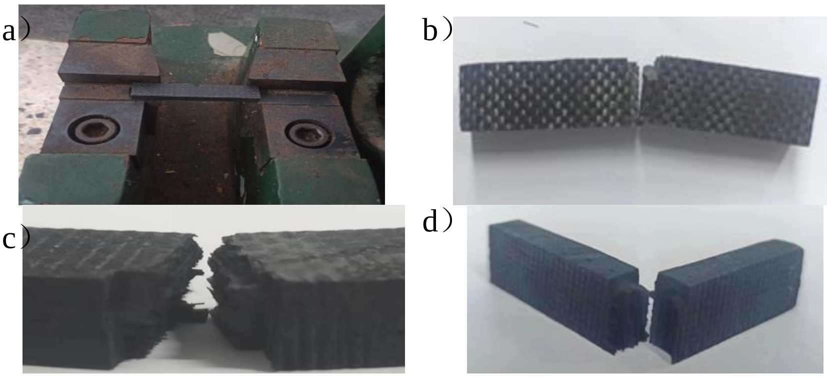

Fig. 10 Sample Impact: a) 0% DS before the test, b) 15% DS after the test, (c) 25% DS after the test, and d) 35% DS before the test

4.4 Hardness Test

Hardness of the composites was determined by using Shore D hardness testing machine. The machine measures the ability of the sample to resist penetration by measuring the depth of indention). The four samples: carbon fiber epoxy resin, reinforced carbon fiber epoxy resin with 35 %wt. GD, 25 %wt. GD, 15 %wt. GD and 0 %wt. GD were tested for hardness by determining their various Shore D hardness number, which is based on the depth of the indent. The results are presented in Fig. 11, which shows that the granulated date seed reinforced carbon fiber epoxy resin with 25 % wt. GD has the highest hardness value of 84HRB. The chart also shows that the hardness of the reinforcement increased as the percentage composition of the date seed granule reduced, with the exception at the 15-25 %wt. ratio of the reinforcement.

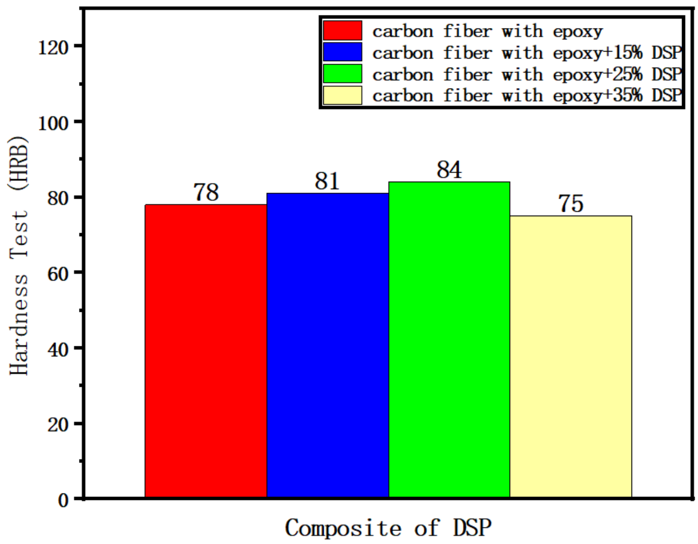

Fig. 11 Shore hardness number HRB in different composition

5. Conclusions

The focus of this study was on evaluating the mechanical properties of carbon fiber-reinforced polymers using date-seed micro fillers (DS) in combination with epoxy. The aim was to analyze the effects of different design configurations of laminated structures. For this purpose, composite specimens were fabricated using both vacuum bagging and hand layup techniques. Upon analyzing the results, the study yielded the following findings:

1. During the mechanical testing and loading of the specimens, in comparison to GFR epoxy, deformation was greater with the carbon fiber reinforced epoxy resin GDS composite.
2. As the content of GDS increased, the composite's impact strength also increased.
3. The specimen's ability to absorb energy is greater in the CFR 25 %wt GDS composite and declined as GDS's content increased.
4. The best variation of the reinforcement of carbon fiber reinforced epoxy with the date seed granules is the GFR-15-25% wt. GDS composition, according to observations made regarding the mechanical properties of carbon fiber reinforced epoxy resin reinforced with 35, 25, and 15 and 0% wt. GDS. It is important to note that the carbon fiber reinforced epoxy composite performs best at 15 %wt. GDS, having the highest breaking force, 35%wt. GDS the highest bending force, 25% wt. GDS the highest energy absorption capacity, and 25 %wt. GDS the highest hardness.

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