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Research Article

Epoxy–Date Palm Fiber Composites: Study on Manufacturing and Properties

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Epoxy-date palm fiber (DPF) composites have been synthesized and characterized successfully with various reinforced ratios of DPF (i.e., 5, 10, 15, and 20 wt%), where the mixture of Epoxy–DPF is poured into different prepared silicone molds. The first type of silicon molds is prepared to produce the samples of the Epoxy–DPF composites to conduct mechanical tests (i.e., impact, creep, and tensile). When the ratio of DPF is increased in the Epoxy matrix, a significant improvement was observed in the results of the mechanical tests. The Epoxy–DPF composites with 15 wt% exhibit a high hardness of 38.4 in comparison with other composite specimens. Maximum impact strength, creep strain, and tensile strengths were recorded to be 0.13 J/mm^2, 0.03112, and 23.4 N/mm^2, respectively, using 20 wt% DPF.

1. Introduction

Nowadays, public concerns about the environment, climate, emissions of gases, and energy consumption increase the focus on the use of natural and biodegradable materials in various applications [1, 2]. The primary categories of materials are polymers, ceramics, and metals, and these primary materials may be used to create a variety of composite materials [3–5]. In addition, replacing metallic materials with polymer has become an obsession in modern industries to reduce cost, time, and ease of manufacturing processes. Most synthetic polymers are produced from non-biodegradable petrochemicals. Petrochemicals are harmful to wildlife and a source of environmental pollution. Using natural fiber–polymer composites in many applications is the most appropriate solution for integrating public concerns to reduce cost and time. Advanced engineering materials, such as polymer–natural fiber composites, are used in various components such as aircraft structures, space vehicles, cars, helicopters, ship structures, boats, sporting goods, and structural engineering applications [6, 7]. To replace metals with thermosetting composites, mechanical properties for thermosetting composites must be enhanced. Thermosetting composites (i.e., natural fiber and Epoxy) offer many advantages such as (1) low-cost materials, (2) obtainable, (3) simple manufacturing technique (4) low density, (5) high degradability, and (6) not harmful to the human body. These features make Epoxy–date palm fiber (DPF) composites a good candidate to replace traditional materials like steel and aluminum [8, 9]. Natural fibers' low compatibility with the matrix and relatively significant moisture absorption are the primary drawbacks of employing them as reinforcement in composites [10]. Therefore, modification of the surface properties of the fibers is necessary to improve their adhesion to various matrices. As a result of a large number of researchers' studies and experiments on the properties of thermoplastics and DPF composites, it has become clear that thermoplastics and DPF composites are well known, and most of their aspects have been covered [11, 12]. This study improved the mechanical properties of thermosetting composites Epoxy–DPF by using new fabrication techniques (silicone molds), types of fibers (leaf sheath), and weight ratios of DPF (i.e., 5, 10, 15, and 20 wt%), in contrast to previous studies that have been analyzed in detail (Table 1), in terms of type of fibers, DPF ratios, fabrication method, type of mold, and mechanical tests. It was observed that most previous studies (Table 1) used the hand lay-up technique as the fabrication method and used the following

Table 1: Research studies on epoxy–DPF composites.

Type of fibers	DPF ratios	Fabrication method and type of mold	Mechanical tests	Main conclusion	Reference
Date palm fibers	Neat epoxy	Hand lay-up technique	Three-point bending flexural	Based on the outcomes of this search, the addition of DPF has been shown to improve the flexural strength and modulus of epoxy composites. 50% DPF load produces better results.	Gheith et al. [13]
	40% DPF		Dynamic mechanical analysis		
	50% DPF				
	60% DPF				
Date palm tree lignocellulosic fibers	5 wt%	A mold ($100 \times 60 \times 6\ mm^3$) made of a composite material	Three-point bending and Charpy impact tests	The higher mechanical properties were due to the better adhesion between the fibers and the matrix in the case of the composites containing oxidized fibers.	Sbiai et al. [14]
	10 wt%				
	15 wt%				
Trunk fibers of date palm tree were utilized	20 wt%	Hand molding method	Tensile and three-point bending	The addition of DPFs did not effect on the tensile strength when compared to the pure matrix. A bending test revealed that increasing the volume percent of DPFs by 7.5 results in an increase in the composites' flexural strength.	Ahmadi et al. [15]
	30 wt%				
	75 wt%				
Date palm fiber (DPF) and kenaf fiber	30 wt%	Hand lay-up and then hot pressing	Tensile, impact, and morphological properties	The tensile strength of the DPF/epoxy composites is improved by kenaf fibers. Composites with DPF 30% have improved mechanical characteristics.	Ghori and Srinivasa Rao [16]
	50 wt%	Hot press technique			
	70 wt%				
Date palm leaf sheath (G), palm tree trunk (L), fruit bunch stalk (AA), and leaf stalk (A)	50 wt%	Hand lay-up technique	Tensile, impact strength, and flexural strength	The mechanical strength, water absorption, and morphological characteristics of fibers derived from various date palm tree components were studied. The findings demonstrate that as compared to epoxy composites, the strength and modulus of the synthesized composite are greatly improved by the application of DPF.	Alshammari et al. [17]
Date palm meshes	Single fiber	Hand lay-up	Tensile test and microbond test	After plasma treatment for DPF, the single fiber tensile strength and modulus tests for DPF/epoxy composites clearly improved.	Gholami et al. [18]

Table 1: Continued.

Type of fibers	DPF ratios	Fabrication method and type of mold	Mechanical tests	Main conclusion	Reference
Date palm tree fiber	Not mentioned	Hand lay-up technique	Tensile test, impact test, and deflection test.	The mechanical properties were tested such as tensile test, impact test, hardness test, and deflection test. The results showed that the strength of the composite increases due to the addition of glass fibers.	Nandhakumar et al. [19]
Date palm petiole fibers	5 wt%	Hand lay-up	Tensile strength, Young's modulus, flexural, and impact strength	Experiments in this study confirmed that the composite containing a fiber concentration of 20% by weight shows good tensile strength, Young's modulus, impact strength, and flexural strength.	Dehury et al. [20]
	10 wt%				
	15 wt%				
	20 wt%				
	25 wt%				
Date palm textile	5 wt%	Hand lay-up technique	Bending, impact, tensile, and hardness tests	There was an increase in the values of Young's modulus, impact strength, and hardness by increasing the rate of reinforcement. Tensile strength, the values were increased using reinforcements of 5% and 10% of DPF but decreased using 15% and 20%, due to a weak link between the fiber and matrix.	Samah [21]
	10 wt%				
	15 wt%				
	20 wt%				

type of fibers: mixed DPF, trunk fibers, kenaf fiber, fruit bunch stalk, leaf stalk, petiole fibers, and date palm textile, whereas this study was using a silicone mold and leaf sheath.

Table 2 shows the results of the mechanical tests listed in the literature. It should be noted that these results differ from each other due to the differences in the chemical composition of fibers, manufacturing methods, and weight ratios.

The mechanical properties of Epoxy–DPF are improved in this study with a lower cost, easy fabrication method, and a shorter fabrication time (by using natural fibers, Epoxy, and silicone molds) in comparison to the conventional methods.

2. Experimental Setup

2.1. Raw Materials. In the present study, the raw materials utilized in the experiments were Epoxy as the matrix and DPF as the reinforcement. They have been used to synthesize the mechanical test specimen composites and manufacture the mechanical parts by pouring the mixture of Epoxy–DPF into different silicone molds.

2.1.1. Epoxy as a Matrix. Generally, Epoxy is produced from petroleum or plants. The Epoxy is made of resin and hardener with the following specifications: (1) the density of resin and hardener is 1.22 and 0.96 g/ml, respectively, (2) the viscosity of the resin and hardener at room temperature is 800 and 400 mPa, respectively, and (3) curing time at room temperature is 24 hours. Epoxy has high solvent resistance, adhesion to different materials, shrinkage on cure, and low fracture toughness. Epoxy is widely used as a matrix for natural and synthetic fibers, especially in some applications where metals are replaced by Epoxy-based composites [31–33]. In the current study, Epoxy–DPF composite specimens were prepared using commercial Erco Epoxy (made in Turkey) with a 2 : 1 resin to hardener ratio.

2.1.2. DPF as a Reinforcement. As demonstrated in Figure 1, DPF from the leaf sheath serves as the reinforcing material in the current investigation. The chemical makeup is

Table 2: Mechanical results of epoxy–DPF composites in the literature featuring different fiber types and chemical composition.

Type of fibers	Chemical composition of date palm	Mechanical properties: Tensile strength (MPa)	Elongation (%)	Young's modulus (GPa)	References
Date palm fibers	Cellulose wt% = 45–46 Lignin wt% = 22–26 Hemi-cellulose = 28–30	30–203	5–10	2–7.5	[22–26]
Date palm tree lignocellulosic fibers (from leaves)	Cellulose wt% = 35.00–50 Lignin wt% = 27–29 Hemi-cellulose = 20–27	100.12 ± 43.87	2.68 ± 0.49	4.00 ± 1.33	[14, 27, 28]
Trunk fibers of date palm tree	Cellulose wt% = 34–40 Lignin wt% = 30–36 Hemi-cellulose = 29–31	170–300	Not mentioned	15.60	[29–31]
Fruit bunch stalk	Cellulose wt% = 39–44 Lignin wt% = 11–30 Hemi-cellulose = 20–27	51–114	4–12 2.88	4.33–2.67 1–19	[14, 28, 32]
Leaf stalk	Cellulose wt% = 35.00 Lignin wt% = 20.10 Hemi-cellulose wt% = 15.40	26.45	Not mentioned	1.42	[17, 27, 28]
Date palm meshes or leaf sheath fiber	Cellulose wt% = 43–46.00 Lignin wt% = 20–28 Hemi-cellulose wt% = 18–22	36.17	Not mentioned	Not mentioned	[17, 18, 27]
Date palm petiole fibers	Cellulose wt% = 33–34 Lignin wt% = 26–28 Hemi-cellulose wt% = 20–21	90 ± 8.87	0.95 ± 0.42	7.00 ± 2.00	[27, 28]
Date palm textile	Cellulose wt% = 46 Lignin wt% = 20 Hemi-cellulose wt% = 28	453 MPa (vascular bundle) and 531 MPa (arch)	Not mentioned	5.88–13.3 GPa (vascular bundle) and 22 GPa (arch)	[21]

generally 43–46 wt% cellulose, 18–24 wt% hemi-cellulose, 20–28 wt% lignin, 5–10 wt% ash, and 2–11 wt% moisture content [12]. The mechanical properties of natural fibers are affected by the degree of polymerization, crystal structure, crystallinity, porosity content, and cavity size [34–36].

2.2. Silicone Mold Fabrication. Silicone rubber molds are commonly used to cast polyurethane, polyester resins, polyurethane foam, and Epoxy resins because they (1) can be used repeatedly, (2) have a high level of flexibility, (3) are lightweight, (4) have no shrink on cure, (5) have resistance to other chemicals, and (6) are low cost in comparison with stiffer molds. Three patterns for creep, tensile, and impact testing were created for this investigation with standard dimensions following ASTM D2990, D638, and D6110 [37] (as in Figure 2). It should be noted that a pattern is a part made of wood, metal, or even wax. This part forms the cavities to shape the sample.

After designing the patterns, they were anchored inside a frame, and then, the silicone mixture was poured into the frame mold. The patterns were then removed from the silicone mold after it dries, and then, a mold powder was added. When the cavities (i.e., mechanical tests cavities and mechanical applications parts cavities) were ready to be used, the mixture of Epoxy–DPF was poured into them. After that, the mixture is allowed to be cured, and then, when the samples are formed, they were removed. Three cavities are prepared using silicone molds (refer to Figure 3) to fabricate specimens for mechanical testing (i.e., creep, impact, and tensile).

2.3. Preparation and Characterization of Composites. Epoxy–DPF composites were prepared according to the wt% ratio and lengths of 2.5–10 mm, as shown in Table 3. The process of preparing Epoxy–DPF composites is divided into two parts: the first is the preparation of the fibers and the second is the preparation of the Epoxy mixture. The fibers were prepared according to the following steps: (1) DPF was washed with water and treated with 5 wt% NaOH for 30 minutes to improve the interfacial adhesion between the DPF and the Epoxy, (2) fibers with a diameter of 0.3 mm were selected, (3) the DPF was dried in a vacuum oven to get rid of the air trapped in the upper layers of the fiber, (4) the fibers were dried at 40 degrees Celsius for 12 hours to get rid of moisture, and (5) the fibers were cut to the required lengths (i.e., 2.5–10 mm) and then collect the prepared fibers in bags

Figure 1: DPF from leaf sheath.

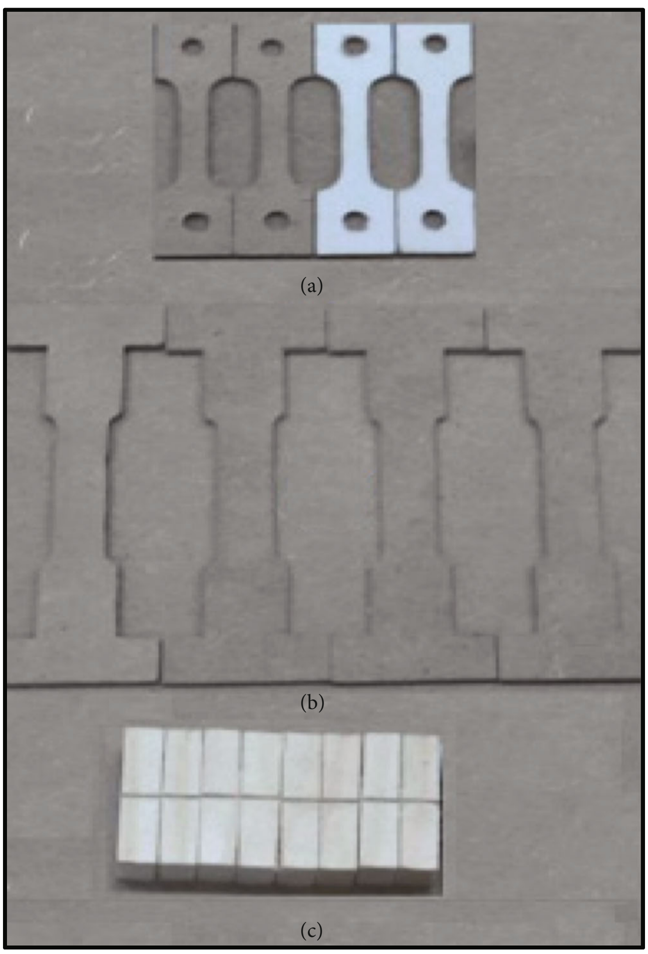


Figure 2: Patterns for (a) creep, (b) tensile, and (c) impact tests.

sealed plastic until ready. As for the preparation of the Epoxy, the Epoxy resin and hardener were mixed in a ratio of 2 : 1 (recommended by the manufacturer) in a plastic container. Then, DPF in different ratios were gradually added to the Epoxy and mixed with a stirring rod. The stirring rod motion was regular and slow in order to (i) reduce gas formation (i.e., porosity) throughout the mixture, (ii) increase homogeneity, and (iii) increase the wettability between the Epoxy and the DPF. After mixing the Epoxy and the fibers, the mixture was poured into the pre-prepared molds.

Following the previous steps, specimens of Epoxy-DPF composites with different ratios of DPF were synthesized as shown in Figure 4.

To study the influence of different DPF ratios in Epoxy–DPF composites, mechanical properties (hardness, impact, creep, and tensile) have been conducted. To reduce any errors, the average value of five replicas of Epoxy–DPF composites specimens is taken for each test. According to the American Society for Testing and Materials (ASTM), the specimens' dimensions for the hardness, impact, creep, and tensile tests were E10–18, D6110, D2990, and D638, respectively. GUNT WP 410, WP 600, and WP 300 machines were used for impact, creep, and tensile testing, respectively. On the surface of the sample whose hardness is to be determined, the Brinell hardness test is carried out using a hardness machine with a weight of 60 kg for 5 seconds. The dimensions of the Charpy impact test specimen were 55 mm in length with a 10×10 mm section having a V-notch: 2 mm deep, with a 45° angle. In the Charpy impact test, the fixed specimens are struck against the notch with a pendulum hammer. The amount of energy absorbed by the sample was measured by observing the change in pendulum arm motion. Temperature, the elasticity of the specimens, cracks, and voids inside the specimens all influence the impact test. Creep properties were determined by a WP 600 machine, in which samples of Epoxy–DPF composites were subjected to a prolonged static tension load (25 N) at room temperature. During the test, the deformation of the DPF–Epoxy samples was recorded at different times (1, 2, 3, and 4 minutes). A universal testing machine (WP 300) was used based on the electric motor that moves the cross head up or down. Generally, the results of tensile tests are used to ensure the quality of the materials used for some engineering applications.

3. Results and Discussions

3.1. Hardness Testing. Hardness is a material's resistance to permanent surface deformation (i.e., dent). Hardness values can be determined by Vickers, Knoop, Brinell, and Rockwell tests. From the hardness results, it is possible to deduce most mechanical properties of composites (e.g., yield and ultimate tensile strengths, impact, fatigue strength, creep, and wear) [36–39]. A higher hardness was also associated with a lower porosity [40]. Depending on the quantity, length, and distribution of DPF, the hardness may be improved (Figure 5). Results for the average hardness values of several Epoxy–DPF composites are displayed. Furthermore, surface conditions of Epoxy–DPF composites specimens (e.g., smoothness and flatness) have a role in the hardness value results.

In general, the hardness of Epoxy–DPF composites with a 15 wt% ratio is higher than the other Epoxy–DPF composites that have weight ratios of 5, 10, and 20 wt%. The harnesses of Epoxy–DPF composites with ratios (5, 10, 15, and 20 wt%) are 28.2, 35.7, 38.4, and 35.2 HB, respectively.

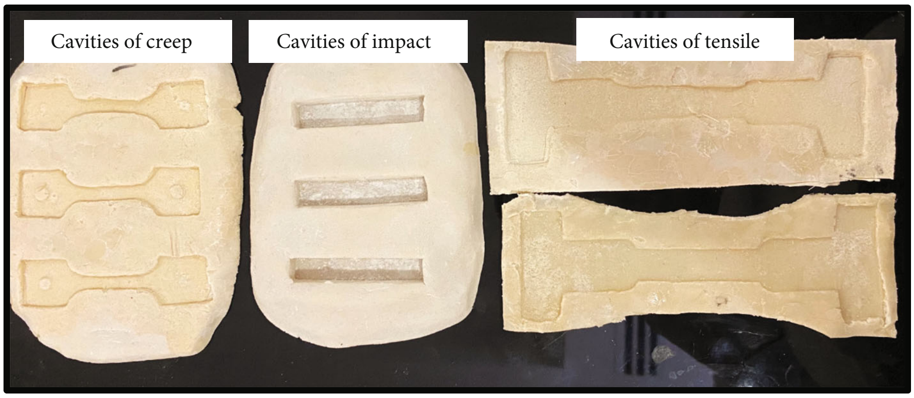


Figure 3: Silicone molds cavities used to fabricate specimens (i.e., creep, impact, and tensile).

Table 3: The raw materials, which are used to prepare the specimens.

Specimens no.	Epoxy (%)	DPF content (wt%) with lengths from 2.5 to 10 mm (%)
1	95	5
2	90	10
3	85	15
4	80	20

When the weight ratio increases, the hardness increases. Note that the DPF with a weight ratio of 5 wt% has the lowest value of hardness. The hardness increases with increasing the content of DPF until it reaches 15 wt%, due to the fiber structure (i.e., irregular polymer chain by a high content of lignin ranging from 20 wt% to 28 wt%), good distribution of fibers, and good interfacial bonding between the Epoxy and DPF [41–43]. In general, lignin content affects the structure and properties of the fiber [44]. Despite the use of a stirrer rod with appropriate speed, some level of agglomeration and porosity are randomly generated during preparing 20 wt% Epoxy–DPF composites, which causes a decrease in the hardness value in the prepared specimens. Additionally, the Epoxy–DPF composites with 20 wt% DPF have weak mechanical characteristics because of the disappearance of the Epoxy matrix between the fibers, poor wettability, and weak interfacial bonding between the Epoxy and DPF in some areas.

3.2. Impact Testing. The mechanical properties of the Epoxy–DPF composites are taken from the properties of its matrix and fibers. The impact test is one of the tests that indicate to what extent Epoxy–DPF composites can absorb shocks before breaking. It is known that brittle materials have very little energy absorption compared to ductile materials. Cross-links in the structure of Epoxy resin increase strength and at the same time make it a brittle material. Brittle materials generally allow cracks to spread and cause sudden breakage. The propagation and distribution of microcracks depend directly on the type of matrix and fibers that are used in the composites. The toughness of Epoxy–DPF composites is directly affected by toughness properties, a weight ratio of DPF, interfacial adhesion between Epoxy and DPF, and the amount of pulled DPF from the matrix [45, 46]. Increasing the weight ratios of DPF increases the impact strength as shown in Figure 6. Good stress transfer from the matrix to the fibers is needed to improve the mechanical properties such as increased impact strength. To obtain a good stress transfer, the interfacial adhesion must be at an appropriate level, except that the mechanical properties of the Epoxy–DPF composites will be lower. The poor interfacial adhesion between Epoxy and DPF is often because raw natural fibers are hydrophilic and normally contain a high amount of impurities on the surface [47]. However, in this research study, the DPF is washed with water and treated with 5 wt% NaOH for 30 minutes to improve the interfacial adhesion between the Epoxy and DPF. In addition, the interfacial adhesion affects the stress transfer, which leads to increasing the impact strength. Other factors have a significant effect such as weight ratios and DPF lengths. The increase in the weight ratio of the fibers and the closeness of the fibers without forming agglomeration or the existence of small air bubbles contribute to improving stress transfer. It is also worth noting that the length of the fibers should not be less than a specified value. The failure of specimens is certain even at low loads if they contain fiber lengths that are less than the critical value. On the other hand, for specimens reinforced with fiber lengths greater than the critical length, stress is transferred between the matrix and the fibers effectively and easily [48].

The impact strength for Epoxy–DPF composites with ratio fibers: 5, 10, 15, and 20 wt% are 0.1, 0.11, 0.12, and 0.13 J/mm^2, respectively. The maximum impact strength is obtained using 20 wt% DPF due to the toughness of DPF with suitable lengths, and strong interfacial adhesion between Epoxy and DPF with a good random distribution of DPF that leads to crack propagation resistance. The high rate of fiber withdrawal for some specimens is due to the low adhesion between the matrix and fibers. A good interfacial adhesion leads to absorbing higher fractions of the total energy [49].

3.3. Creep Testing. Creep results from continuous stress on the Epoxy–DPF composites for specific periods. Creep is

Figure 4: Different types of specimens with different ratios of DPF in Epoxy–DPF composites: (a) 5 wt%, (b) 10 wt%, (c) 15 wt%, and (d) 20 wt%.

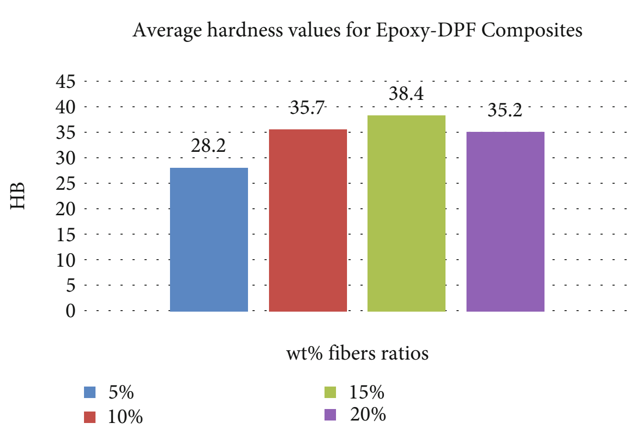


Figure 5: Average hardness values for Epoxy–DPF composites for different DPF weight ratios.

divided into three stages, where the first stage and the last stage are fast, but in the second stage, creep decreases with time [50]. There are several factors that affect creep, and the effect of each factor differs from the other. For example, increasing the DPF weight ratio and interacting with the matrix inside the composites increase creep strain. The weight percentage of DPF may have a greater effect than fiber length, temperature, humidity, and level of pressure applied to the composites. In order to replace such composites and use them practically as mechanical parts in equipment or structures, the properties must be improved and that includes reducing the rate of creep [51–53]. Creep strain values for Epoxy–DPF composites, as shown in Figure 7, confirm the results in the previous studies, that if the stress is optimally transferred between the DPF and Epoxy matrix, it will increase the mechanical resistance (i.e., tensile strength) and improve the ductile properties (i.e., elongation at break) [54]. Thus, at 20 wt% DPF, the stress transfer is larger due to the number of stiff fibers, the uniform distribution of the fibers, and interfacial adhesion. This demonstrates that the creep strain for 20 wt% Epoxy–DPF can bear higher strain before failure and is substantially more ductile in comparison to low-weight percent DPF composites. During creeping, many micro-failure modes are occurred such as: fibers pulled

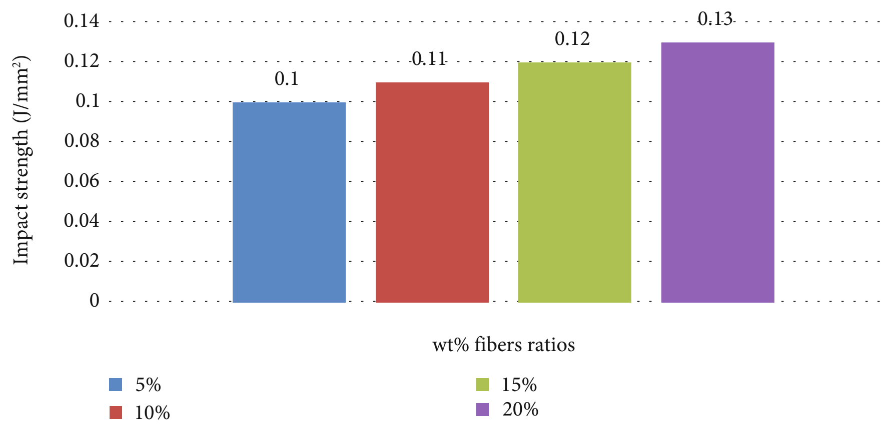
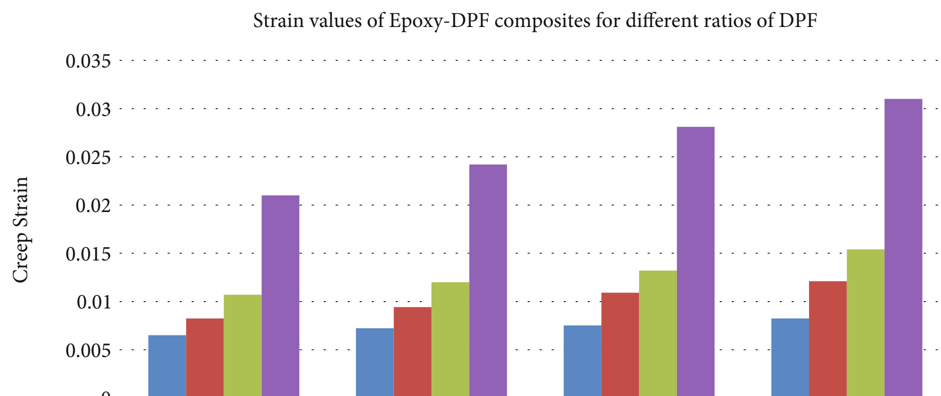


FIGURE 6: Impact strength results for different weight ratios (i.e., 5, 10, 15, and 20 wt%) of DPF in the tested notched specimens.



	1 min	2 min	3 min	4 min
5 wt%	0.00661	0.00733	0.00762	0.00833
10 wt%	0.00833	0.00952	0.011	0.0122
15 wt%	0.0108	0.0121	0.0133	0.0155
20 wt%	0.0211	0.0243	0.0282	0.0311

FIGURE 7: Strain values of Epoxy–DPF composites for different ratios of DPF (i.e., 5, 10, 15, and 20 wt%) with constant applied load of 25 N for different strain times (i.e., 1, 2, 3, and 4 minutes).

out, fibers breakage, interfacial debonding, and cracking brittle Epoxy matrix, which leads to rapid failure. Hence, by improving these modes, the creep strain rate will decrease and delay the failure [55].

From Figure 7, the strains increase with increasing the DPF contents. The maximum strain is obtained using the ratio 20 wt% DPF due to the reduced rigidity of the brittle Epoxy matrix. The creep strain after 4 minutes for ratio fibers of 5, 10, 15, and 20 wt% is 0.00833, 0.0122, 0.0155, and 0.03112, respectively. The minimum creep strain is obtained using 5 wt% DPF due to the brittleness Epoxy matrix. The results show that the creep strain of 20% Epoxy–DPF specimen can exhibit more stress resistance with creep strain, and is relatively more flexible in comparison with the low ratio reinforcement composites. Many researchers have discussed such a case related to the increase of creep strain with the increase of the amount of the reinforcing substance inside the Epoxy matrix [56-58].

3.4. Tensile Test. Tensile strength is an important property to determine the mechanical performance of Epoxy–DPF composites in some mechanical applications. Figure 8 shows the tensile strength of Epoxy–DPF composites for different ratios of DPF (i.e., 5, 10, 15, and 20 **wt%**). Figure 8 shows that increasing the stiff DPF as reinforcement improves the tensile strength of the Epoxy. Thus, Epoxy–DPF composites are stiffer and tougher, making them more suitable for a variety of mechanical applications than non-fiber–reinforced Epoxy composites.

From Figure 8, the tensile strength of 5, 10, 15, and 20 wt% DPF content is 18.5, 19.7, 21.3, and 23.4 N/mm^2, respectively. A low value in tensile strength for Epoxy–DPF composites with 5 wt% DPF content is due to the presence of a small content of reinforced DPF, which does not achieve a good and easy transfer of the applied stress inside the composite between the fibers and the matrix. On the other hand, tensile strength for the Epoxy–DPF composites

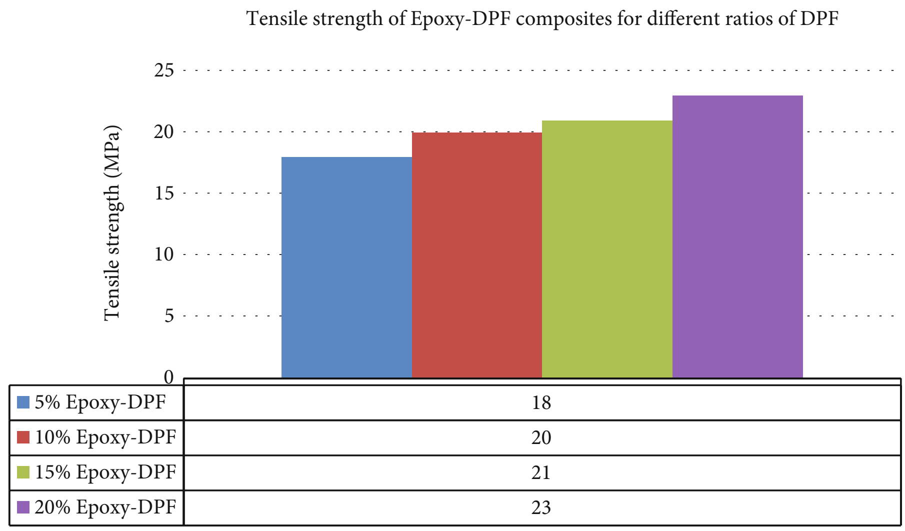


Figure 8: Tensile strength of Epoxy–DPF composites for different ratios of DPF (i.e., 5, 10, 15, and 20 wt%).

with 20 wt% and specified length of DPF is relatively high due to the presence of a sufficient DPF in addition to the easy and smooth transfer of the applied longitudinal stress between DPF and the matrix. Also, high tensile strength for composites with 20 wt% DPF is observed due to the fiber structure by a high content of lignin (i.e., 20–28 wt%), good distribution of fibers, and good interfacial bonding between the Epoxy and DPF. The poor interfacial adhesion between Epoxy and DPF is often because the natural fibers contain a high amount of impurities on the surface [47]. However, interfacial adhesion between Epoxy and DPF can be improved by washing the DPF with water and treating it with 5 wt% NaOH. In general, the tensile strength increases with increasing the DPF weight ratios as long as the Epoxy–DPF composites are fabricated with minimum agglomeration and porosity [48]. A high increase in the weight ratios of the fibers causes DPF agglomeration, porosity formation from the stirring process, and lack of the matrix in covering the fiber perfectly, which reduces the strength dramatically because of the minimized reinforcing effectiveness of DPF in the matrix. Thus, the Epoxy–DPF composites specimen cannot withstand more loads efficiently. The formation of small voids due to fiber withdrawal (i.e., pull out) serves as preferred sites for cracking propagation, thus reducing the tensile strength. Many studies [58–61] have confirmed that DPF reinforcement improves the tensile and impact strengths while the considerable reduction in mechanical properties is noted at higher wt% of DPF.

4. Conclusions

Epoxy–DPF composites have been synthesized and characterized successfully with various reinforced ratios of DPF (i.e., 5, 10, 15, and 20 wt%). Epoxy–DPF composites were prepared by silicone molds after pouring the mixture into the cavities (i.e., mechanical tests cavities and mechanical parts cavities). The results of mechanical tests like impact, creep, and tensile were improved by increasing the DPF ratio in the Epoxy matrix. Due to the high concentration of lignin (20–28 wt%) in the fiber structure, excellent fiber dispersion, and strong interfacial bonding between the Epoxy and DPF, the hardness increases with increasing the content of DPF up to 15 wt%. Due to agglomeration, porosity, weak interfacial bonding, poor wettability, and disappearance of the Epoxy matrix between fibers, the hardness of the Epoxy–DPF composites with 20 wt% DPF was reduced, which resulted in poor mechanical test results. The impact strength for Epoxy–DPF composites with ratio fibers of 5, 10, 15, and 20 wt% was observed to be 0.1, 0.11, 0.12, and 0.13 J/mm^2, respectively. The maximum impact strength is obtained using a suitable DPF length and 20 wt% of tough DPF. In addition, effective stress transfer, due to the strong interfacial adhesion between Epoxy and DPF, and the good random distribution of DPF, which leads to crack propagation resistance, contributes to the maximum impact strength. In comparison to low ratio wt% DPF composites, a creep strain of 20% Epoxy–DPF can bear higher strain before failure and is considerably more ductile. The tensile strength of 5, 10, 15, and 20 wt% DPF content is observed to be 18.5, 19.7, 21.3, and 23.4 N/mm^2, respectively. The presence of a small amount of reinforced DPF prevents a good and simple transmission of the applied stress inside the composite between the fibers and the matrix, leading to low values of tensile strength for Epoxy–DPF composites with 5 wt% DPF concentration. On the other hand, tensile strength for Epoxy–DPF composites with 20 wt% and specified length of DPF is relatively high because of the existence of a sufficient DPF, which results in easy and smooth transmission of the applied longitudinal stress between DPF and the matrix.

Data Availability

The [hardness, impact, creep, and tensile strength] data used to support the findings of this study are included within the article. Through the article, the others can directly access the data that supports the conclusions of the study. The nature of the data in this article is collecting the results from hardness, impact, creep, and tensile strength machines and analyzing the results which included within the article.

Conflicts of Interest

The author(s) declare that they have no conflicts of interest.

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