Original Article

Date palm reinforced epoxy composites: tensile, impact and morphological properties

N. Saba a, Othman Y. Alothman b, Zeyad Almutairi c, M. Jawaid a,b,*, Waheedullah Ghori d

a Laboratory of Biocomposite Technology, Institute of Tropical Forestry and Forest Products (INTROP), Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia
b Department of Chemical Engineering, College of Engineering, King Saud University, Riyadh, 11421 Saudi Arabia
C Department of Mechanical Engineering, College of Engineering, King Saud University, Riyadh, 11421 Saudi Arabia
d College of Engineering, King Khalid University, Abha, Saudi Arabia

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ABSTRACT

In this study date palm stem fibers (DPF)/epoxy composites at different loading (40, 50 and 60 wt.%) were fabricated and their tensile, impact and morphological properties are characterized. The interfacial bonding in tensile fractured samples of composites was examined by scanning electron microscopy (SEM). Tensile and impact results revealed that increase in DPF loading until 50% improved the mechanical strength, modulus, impact strength and elongation at break with respect to pure epoxy resin. Tensile strength, modulus, impact strength and elongation at break of pure epoxy resin increases from 20.5 to 25.7657 MPa, 0.5123 to 1.546 GPa, 45.81 to 98.71 J/m and 0.91 to 1.412% respectively while, energy absorption decreases drastically from 50 to 32% with the incorporation of DPF filler. SEM microstructure displayed good interfacial bonding in 50% DPF epoxy however the addition of more DPF loading reduces the interfacial strength due to poor wettability. Overall test results declared that 50% DPF loading is ideal to enhance tensile, impact strengths and morphological properties of epoxy.

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1. Introduction

Polymer composites are regarded as advanced engineered materials having chemically different constituents, as continuous matrix and reinforced material like nano fillers, synthetic and natural fibers [1]. However, the growing consciousness of sustainable environment, govern the profound interest among researchers to explicitly utilize natural fibers such as kenaf, hemp, flax, jute, banana, bamboo, coir, pineapple leaf, oil palm, sisal, among many others, as green reinforcements in polymer composites in order to minimize the usage of synthetic fibers like carbon, glass and Kevlar [2–4]. Until now many research studies reviewed that cellulosic fibers are biodegradable, renewable, nonabrasive and exhibits perfect mechanical
properties [5–7]. Moreover, the mechanical properties of natural fibers reinforced polymer composites greatly depend on individual properties of their components and interfacial interaction (adhesion) between hydrophobic polymeric matrix and hydrophilic reinforcements [8,9]. Reduction in the composites strength and modulus are usually governed by fiber pullout, fibers wettabillity (insufficient wetting), fiber breakage, fiber debonding and the poor tendency of stress transfer from polymer matrix to stiff fibers through shear stresses at the interface [10–12], results poor surface adhesion.

Epoxies are the versatile and established thermoset resin having epoxide groups as the representative unit in their polymeric backbone structure [13,14], which comprised of two carbon atoms bonded to an oxygen atom [15]. The diverse characteristic of epoxies enables them for versatile engineered and industrial applications including encapsulations of electronic component, lightweight construction materials, laminated circuit board, surface coatings, potting, automobile, adhesives and maritime structure as well as other advanced composites on a worldwide scale. However, the wide and high performance field pervasive applications of the epoxies such as aerospace structural components, get limited owing to their delamination, fracture toughness, inherent brittleness (due to the presence of polymerization-induced microcracks/microvoids [16]) and low impact resistance behavior [17]. These drawbacks can be overcome by the addition of additives, fibers and nano fillers (<10 wt.%) that can certainly amend the epoxies, with improved thermal and dynamic along with mechanical, morphological and electrical properties [14,18,19]. Presently, the cellulosic fibers and biomass based wastes material are the most suitable, promising, effective and inexpensive reinforcing agent to enhance the properties of epoxies [8]. Among many bio-based materials and natural fibers like coconut shells, saw dust, rice husk, oil palm, kenaf, jute, banana and sisal fibers, the date palm fibers from date palm tree are receiving great attention from researchers as green, renewable and biodegradable reinforcing agent. The date palm (Phoenix dactylifera L.) tree is the widely cultivated flowering plant species of the palm family [20] for its edible sweet fruit, around the world including arid and semi-arid regions. Interestingly there are beyond 100 million date palm trees widely spread in the Middle East, Arabian Peninsula, Northern Africa, the United States (California), Canary Islands, India and Pakistan [20,21]. Date palm trees possess better resistance for both cold and dry hot climates. In the harsh climatic conditions of Tunisia, oases cover almost 40,000 ha representing limited human development [22]. However, like other natural fibers, date palm stem fibers (DPF) also possess certain disadvantages like low compression strength, poor thermal resistance, moisture absorption and high anisotropic properties [23]. Mechanical and thermal stability of raw DPF used in this study are listed in Table 1 [24]. Remarkably, the extracted stem fibers obtained from decomposed palm trees possess low tensile strength, elasticity modulus and are brittle with high water absorption tendency [25].

DPF extensively being used for tertiary domestic wastewater treatment, besides these the leaves, wasted dates and floral stems supporting date regimes are explicitly used in animal feeding or as a bio-monitor of high metals in arid environments, offering a noticeable environmental and economic potential [22]. Despite the immense socio-cultural and economic values of date palm round the globe from past decades (fruit production, medical uses, religious, feed, brooms and wood), its production generates huge amounts of agro-industrial by products and residues including leaves and DPF [20]. A huge quantities of DPF wastes are thrown away after each annual trimming procedure presenting troublesome environmental and waste disposal problems, except usage as artisan products in small scale [22]. Noticeably, wood, leaves and stem fibers of date palm, which now were considered as an agro wastes or used in low value products, are widely been used as potential reinforcement material in several thermostes and recycle thermoplastic composite industries [26], leading to open a broader platform [21]. Several studies have been reported in the literature where DPF materials are incorporated in thermostes, thermoplastics and biodegradable polymer matrix. Table 2 clarifies the reported work on the date palm fiber materials reinforced polymer matrix for certain applications.

From the Table 2 it is clear that until now study has been carried on the DPF reinforced epoxy composites in order to modify its mechanical and morphological properties at different filler loadings. Present work is an extension of our previous published work in which we deals about flexural, thermal and dynamic mechanical properties of DPF/epoxy composites [52]. This study deals the fabrication of DPF/epoxy composites at different loading (40, 50 and 60 wt.%). Effect of DPF loading as filler on mechanical and morphological properties were examined and compared with respect to pure epoxy resin to determine the perfect loading. Success of this study will deliver one step progress towards the proper utilization of DPF wastes deposition in the Saudi Arabian region. Also, it is an attempt to support the environmental efforts such as replacement of synthetic fiber by DPF to find its applications in various industrial sectors.

### Table 1 – Properties of raw DPF.

<table>
<thead>
<tr>
<th>Properties of raw date palm stem fiber</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignin content</td>
<td>Approx. 20%</td>
</tr>
<tr>
<td>Density</td>
<td>Approx. 0.917 g/cm³ [3]</td>
</tr>
<tr>
<td>Thermal stability</td>
<td>200–250 ºC</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>60–275 MPa</td>
</tr>
<tr>
<td>Young’s modulus</td>
<td>2–12 GPa</td>
</tr>
</tbody>
</table>

2. Materials and method

The epoxy resin D.E.R 331 used in this research study is a general purpose clear liquid resin based on diglycidyl ether of bisphenol A (DGEB), procured from Dow Chemical Pacific Singapore, Singapore. The epoxy hardener (curing agent) Jointmine 905-35 is a clear, less toxic and transparent colour liquid. It is a modified cycloaliphatic amine, supplied by Tazdiq Engineering Sdn. Bhd., Malaysia. Silicone spray and Teflon sheets used in this research work were also procured from Tazdiq Engineering Sdn. Bhd., Malaysia and NR Medicare Sdn. Bhd., Selangor, Malaysia, respectively. The purchased chemicals
were used without any further purification. DPF was imported from the streets of Riyadh city (Kingdom of Saudi Arabia).

### 2.1 Fabrication of composites

In this study DPF (Phoenix Dactylifera L.) is used as filler for the fabrication of DPF/epoxy composites at different loading (40, 50 and 60 wt.%). Prior to this received DPF were manually separated into single fibers and washed in distilled water to remove sand, dust and other impurities attached to its surface. DPF was then ground into 0.8–1 mm by using grinding machine having an average of 6–8% moisture content and dried in oven at 60 °C. Dried DPF was added into the epoxy resin using a high speed mechanical stirrer. The stoichiometric ratio (2:1) of the epoxy and hardener was maintained. The mixture was mechanically stirred for at least 20 min at room temperature. The mixture was then poured into a stainless steel mould and cured for 24 h at room temperature. Silicone spray release agent was used in the mould to facilitate the removal of the composite samples. Fabricated composites were cut and characterized as per ASTM standard. The weight fractions of DPF and epoxy in DPF/epoxy composites are listed in Table 3.

### 2.2 Characterization

#### 2.2.1 Tensile tests

Mechanical strength, modulus properties and elongation at break of DPF/epoxy composites at different loading were measured through Universal Testing Machine (Instron 5567, Shokopee, USA). The composite samples were cut to rectangular shape of dimension 120 × 20 × 3 mm with a band saw machine prior to commence tensile testing. The mechanical characterization were performed in accordance with the ASTM D 3039 (2014) standard having the crosshead speed 5 mm/min and gauge length of 50 mm. The tensile tests were performed using maximum load cell of 5 kN, the temperature was set at 22 °C and the humidity at 50%. All data (load, displacement and strains) were acquired. Stress-strain curves were obtained from these tests; tensile strength and modulus were evaluated and discussed for seven replicate specimens of each DPF/epoxy composites.

#### 2.2.2 Impact test

The impact strength of DPF/epoxy composites at different loading was measured with a CEAST 9050 impact testing machine (Instron, Norwood, USA). The composite samples were cut to rectangular shape of dimension 70 × 15 × 3 mm with a band saw machine. Before impact testing, V-notch were made on all seven replicates of each DPF/epoxy composites (7 × 4 = 28) by using NOTCHVIS. The V-notched specimens

### Table 2 – Exclusively reported research studies on date palm fiber reinforced polymer composites.

<table>
<thead>
<tr>
<th>Reinforcements</th>
<th>Polymer matrix</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>DPF</td>
<td>Polyester</td>
<td>[27]</td>
</tr>
<tr>
<td>DPF</td>
<td>Epoxy</td>
<td>[28]</td>
</tr>
<tr>
<td>Date palm wood fronds</td>
<td>Polyester</td>
<td>[29]</td>
</tr>
<tr>
<td>DPF</td>
<td>PP</td>
<td>[30]</td>
</tr>
<tr>
<td>DPF</td>
<td>HDPE</td>
<td>[31]</td>
</tr>
<tr>
<td>Short DPF</td>
<td>Poly-epoxy thermostet</td>
<td>[32]</td>
</tr>
<tr>
<td>DPF</td>
<td>Polyester</td>
<td>[33]</td>
</tr>
<tr>
<td>Date palm seed particles</td>
<td>Polyester</td>
<td>[34]</td>
</tr>
<tr>
<td>Date seeds powder</td>
<td>Polyester</td>
<td>[35]</td>
</tr>
<tr>
<td>DPF</td>
<td>PP</td>
<td>[36]</td>
</tr>
<tr>
<td>Rice husk and DPF</td>
<td>Unsaturated polyester</td>
<td>[37]</td>
</tr>
<tr>
<td>Date palm leaves and wood flour</td>
<td>Polyester</td>
<td>[38]</td>
</tr>
<tr>
<td>Glass fibers/DPF</td>
<td>Epoxy</td>
<td>[39]</td>
</tr>
<tr>
<td>Date palm frond fibers</td>
<td>PP and LDPE</td>
<td>[40]</td>
</tr>
<tr>
<td>Aligned date palm frond fibers</td>
<td>LDPE</td>
<td>[41]</td>
</tr>
<tr>
<td>Untreated and silane treated oil and date palm frond fibers</td>
<td>Polyester</td>
<td>[42]</td>
</tr>
<tr>
<td>DPF and jute fibers</td>
<td>Poly-epoxy thermostet</td>
<td>[43]</td>
</tr>
<tr>
<td>DPF</td>
<td>PP/EPM thermoplastic elastomers</td>
<td>[44]</td>
</tr>
<tr>
<td>DPF</td>
<td>Recycled HDPE</td>
<td>[45]</td>
</tr>
<tr>
<td>DPF</td>
<td>PP</td>
<td>[46]</td>
</tr>
<tr>
<td>Coir and wild DPF</td>
<td>Epoxy</td>
<td>[47]</td>
</tr>
<tr>
<td>DPF and flax fibers</td>
<td>Starch</td>
<td>[24]</td>
</tr>
<tr>
<td>Alkali treatment of date palm fibers</td>
<td>Epoxy</td>
<td>[21]</td>
</tr>
<tr>
<td>Date palm leaf fibers</td>
<td>PVA</td>
<td>[48]</td>
</tr>
<tr>
<td>Alkali treated date palm leaf fibers</td>
<td>PETr</td>
<td>[49]</td>
</tr>
<tr>
<td>DPF and graphite filler</td>
<td>Epoxy</td>
<td>[50]</td>
</tr>
<tr>
<td>DPF</td>
<td>Thermoplastic corn starch</td>
<td>[51]</td>
</tr>
</tbody>
</table>

DPF, date palm stem fibers; PP, polypropylene; HDPE, high density polyethylene; LDPE, low density polyethylene; EPM, polyethylene–propylene–diene–monomer; PVA, polyvinyl alcohol; PETr, recycled poly (ethylene terephthalate).

### Table 3 – Formulation of DPF/epoxy composites.

<table>
<thead>
<tr>
<th>Composites</th>
<th>Epoxy resin in wt.%</th>
<th>DPF in wt.%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure epoxy resin</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>40% DPF</td>
<td>60</td>
<td>40</td>
</tr>
<tr>
<td>50% DPF</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>60% DPF</td>
<td>40</td>
<td>60</td>
</tr>
</tbody>
</table>
were then tested according to the ASTM D256 (2010) specifications. Appropriate 10 kJ pendulum hammers were mounted. The machine was calibrated for energy and accurate determination of the exact amount of impact energy (J/m) involved in the tests. The energy needed to break the composite specimen, its toughness and average impact energy was then analysed.

2.2.3. Scanning electron microscopy (SEM)
Morphology of the tensile fractured sample of each DPF/epoxy composites were carried out by Hitachi S-3400 N SEM. Prior to SEM examinations, the samples were coated with gold on fractured end and mounted onto SEM holder.

3. Results and discussion

3.1. Tensile strength and modulus

Tensile strength (mechanical resistant) determined the ability of composite materials to refute failure under longitudinal tensile stress [8]. Fig. 1 displays the change in the tensile strength and modulus respectively with the addition of DPF variable (40, 50 and 60 wt.%) loading reinforced in epoxy resin. From Fig. 1 it is clear that the incorporation of hard and stiff DPF filler explicitly improved the tensile strength of the pure epoxy resin. Thus the fabricated DPF/epoxy composites became stiffer and tougher with respect to pure epoxy resin. Although, a minimal increase in the tensile strength by the addition of DPF filler up to 40% (21.432 MPa), are observed. The minimal increment might be explained on account of the presence of small content of reinforced DPF (fibers dispersion) to allow effective applied loads transfer and poor mechanical interlocking within the composites that results interfacial adhesion of the reinforced fibers to the epoxy, to withstand the stress build-up during investigation [53,54].

Interestingly, the further addition of DPF up to 50% loading shows better and smooth transfer of the applied longitudinal stress between filler and the epoxy matrix having good enough mechanical interlocking, thereby allowing an enhancement in the tensile strength (25.7657 MPa) of the pure epoxy resin. However, with a further increase of the DPF filler loading from 50 to 60% a slight decrease in tensile strength is noticed. Mechanism of failure in 60% DPF/epoxy composites might be attributed due to the fiber fracture failure, which gets more predominant compared to fiber-matrix interfacial failure. Analogous statement are observed by other researchers [24]. This behavior might be explained on accounts of poor wetting, improper mixing, agglomeration and cloudiness of the stifed DPF filler, resulting a notable decrease in the fiber and matrix adhesion. The formation of DPF agglomerated structures ultimately improves the density and later results in the formation of microvoids, thus minimize the reinforcing effectiveness of DPF in the epoxy matrix. All these results in an early failure followed by the relatively poor tensile strength of the developed epoxy composites. A relatively comparable results are reported were total 50 wt. % of natural fibers (25% flax and 25% DPF) loading in biodegradable starch, displayed higher tensile strength and have lower void fractions [24].

Similar argument of low mechanical properties at higher fiber loading were reported by the researchers where date palm leaflets at different loading (70, 75 and 80 wt.%) are reinforced in polystyrene wastes [55]. They claimed that the poor coating or wetting by the matrix and the adhesion state possess many defects and voids, favouring the creation of early fiber fractures. Fig. 1 also reflects the variations in the tensile modulus of pure epoxy resin by incorporating DPF filler. Fig. 1 clearly revealed that a similar trend is followed by tensile modulus to tensile strength of pure epoxy resin, as it also increases with the DPF filler loading. It has been observed that commencing from 40 to 60% loading, tensile modulus achieved maximum at 50% loading. Obtained higher tensile modulus value, determined the perfect distribution along with better interfacial adhesion among the incorporated DPF filler and the epoxy. However beyond 50% the formation of microvoids due to the fiber pull out, acts as the favoured sites for the crack initiation and results pre-rupture thus lowered the tensile modulus for 60% DPF/epoxy (1.324 GPa) as compared to the 50% DPF/epoxy composites. Overall 50% DPF loading in epoxy displays higher tensile modulus (1.546 GPa), as the epoxy matrix is sufficient to cover the surfaces of the
incorporated DPF among the rest and hence it can endure more loads efficiently [24].

Furthermore, the decrease in tensile strength and modulus of epoxy composites having 60% DPF loading is greatly attributed to the increased porosity, poor incorporated DPF wetting and their non-uniform distribution within epoxy matrix. In more simplified words, the amount of epoxy is probably insufficient to wet out the fiber and fully transfer the stress effectively at such high fiber loadings. Furthermore, it might be due to high fiber–fiber interaction and agglomeration of fibers within the epoxy matrix. Similar justifications were presented by other researchers where 40 wt.% of kenaf fiber and up to 10% (w/w) of thymol are incorporated in poly (lactic acid) through melt blending and compression moulding techniques [56]. Comparable justifications were also reported by the other researchers where the tensile modulus get improved by the reinforcement of date palm leaf fibers (10–30 phr) in recycled polyolefin ternary blend consisting of low density polyethylene, high density polyethylene and polypropylene, due to the improvement in the stiffness of the composites [57]. Analogous justifications also found in literature where tensile modulus increases progressively with the increase of the fiber loading, affecting the stiffness of the composites and improves the stress-strain properties of DPF reinforced in gypsum, thus minimize the brittle fracture of gypsum matrix [58]. In other study, the reinforcement of treated 50 wt.% DPF in biodegradable corn starch improved the tensile strength, modulus and impact strength of starch composites by 7, 12.5 and 4.3 times respectively [51] while considerable reduction in mechanical properties are noted at higher DPF loading.

3.2. Elongation at break

Fig. 2 illustrates the elongation at break values of all composites. It is observed from the Fig. 2 that the trends for the elongation at break are quite similar to that obtained for both tensile strength and modulus (Fig. 1). Results analysis shows that the elongation at break values increases from 40 to 50% by the addition of DPF filler, while further addition to 60% decreased the elongation at break values.

Improved tensile strength and elongation at break is chiefly attributed by the fiber stiffness which prohibits the segmental polymer chain mobility within the matrix. Thus at 50% DPF loading, the stress transfer becomes more effective due to the uniform fiber distribution, mixing and its remarkable reinforcing effect with relative to higher fibers loading. This shows that the elongation at break of 50% DPF/epoxy sample can withstands more strain before failure, and it is relatively more ductile compared to rest composites. Similar arguments are presented by other researchers, where abaca/jute/glass fibers are reinforced in epoxy [59]. Thus it can be concluded that when the loads transferred in a better way between the DPF filler and the epoxy matrix, it delivers a positive effect on both mechanical resistant (tensile strength) and ductile (elongation at break) properties as both them are highly sensitive to cohesion [60]. Comparable improvements in the tensile strength and elongation at break were also reported for DPF reinforced recycled PP/LDPE/HDPE ternary blends [23]. Lowering in the elongation at break (%) also observed where date palm leaf fibers was incorporated in recycled ternary polyolefin blend composites [57].

3.3. Impact properties

Impact strength is the defined as the tendency of composites to endure high energy impact without fracturing [61] and is greatly depend on the individual fiber properties and interfacial adhesion between the fibers and the matrix [4]. Comparative impact strength of the epoxy and DPF/epoxy composites at different loading are illustrated in Fig. 3.

It is crystal clear from Fig. 3 that the lowest impact properties of pure epoxy resin shows noticeable improvement with the addition of DPF filler due to improved stiffness of the pure epoxy resin. Considerable improvement in the impact strength of 50% DPF/epoxy composites with respect to 40 and 60% loadings are realized, that can be primarily account due to the better adhesion of the DPF with the epoxy matrix to overcome the applied high impact stress/load. Moreover, the increase in impact strength can be related to an improved stress capability that will minimize the contribution of fiber-related mechanism such as fiber pull out.

Fig. 3 also illustrates the energy absorption (%) along with impact strength of composites. Energy absorption regarded as different means to evaluate toughness as it is the area under a stress-strain curve and thus highly depends on the tensile strength of a material [62]. Interestingly, energy absorption mainly occurs during deformation and fracture processes [60]. Besides increase in impact strength by addition of DPF
filler to the epoxy, a remarkable decrease in energy absorption (Fig. 3) during izod impact test was also observed for all DPF/epoxy composites. However it is more pronounced for 50% DPF/epoxy with respect to other composites. Thus lower energy absorption and higher damage resistance tendency are realized for 50% DPF/epoxy with relative to the rest composites, are more likely associated with the amount of internal damage during impact load. This statement and justifications are in complete agreement with reported literature where impact strength and toughness increases with the increase in fiber loading for DPF/recycled poly (ethylene terephthalate) composites from 11.3 to 12.5 and 13.8 kJ/m \(^2\) for 5, 10 and 15 wt.% fiber loadings respectively due to strong interfacial adhesions [63].

### 3.4 Scanning electron microscopy (SEM)

The surface characteristics and the distribution of the filler within the matrix were investigated through SEM. SEM micrographs of 40, 50 and 60 wt.\% DPF/epoxy composites are illustrated in Figs. 4–7. Fig. 4 shows the micrograph of pure epoxy resin, presenting brittle plastic nature with a glassy and smooth exterior having several stream-like cracks [6].

Remarkably wavy cracks (marked by red colour) depict its high tendency at markedly less energy consumptions towards tensile fracturing, rupturing and its propagation [64]. Analogous SEM images were noticed for pure epoxy resin by other researchers [1,8].

In first sight SEM morphology (Figs. 5–7) of all DPF/epoxy composites observed alike, but relatively different from pure epoxy resin. As is evident from Figs. (5–7), epoxy surface becomes more jagged and irregular by adding DPF indicating marked reduction in brittleness and ductile nature. Fig. 5 shows that the addition of 40% DPF filler makes surface slightly coarser and rougher, with relative to pure epoxy resin (Fig. 4). As the incorporated DPF filler hindered the crack deflection and crack initiations mechanism thus delays the early rupture of the composites under examination.

Addition of 50% DPF filler to the epoxy (Fig. 6) makes the surface more rougher and coarser with respect to 40% loading (Fig. 5) but reasonably lesser in comparison with 60%...
Fig. 5 – SEM images of tensile fractured sample of 40% DPF/epoxy composites.

DPF/epoxy composites (Fig. 7). Moreover, the SEM micrograph of 50% DPF/epoxy composites also displayed relatively lesser clumping, aggregations, fiber pull outs and voids formation compared to rest composites (Fig. 6). Hence relatively huge amounts of energy were required to break the 50% DPF/epoxy composites as these filler hindered the crack propagation path and divert it from straight way to the highly complicated and twisted path. All these improved the resistance tendency to pre-rupture and eventually enhanced the tensile and impact properties.

The situation is however quite different for 60% DPF/epoxy composites due to the accumulation of DPF filler and microvoids within matrix due to the lack of sufficient epoxy matrix to provide effective wettability of DPF. All this favour the formation of weak interface or stress concentration sites to initiate and propagate crack for easy failure of composites under applied tensile stress (Fig. 7). These factors are govern by the poor dispersion of incompatible DPF filler and their minimal adhesion, resulting reduction in the value of mechanical properties especially the tensile strength and modulus for 60% DPF/epoxy, as illustrated in the Fig. 1. The statements are also in line where alkali treated date palm fibers are reinforced in polyurethane matrix [10]. Analogous results were also reported where the existence of voids and aggregates in the matrix directs the early rupture of the pure epoxy resin at high filler loadings of glass fibers/nanoclay/epoxy composites [65]. Interestingly reasonable arguments for date palm fibers extracted from the mesh part in the palm at different loading (20, 50 and 70 wt.%) reinforced in biodegradable thermoplastic starch (TPS) are also presented [66]. Researchers observed that 50% fibers loading shows similar SEM micrograph indicating better adhesion between the matrix and the fibers due to good wettability and have more fractured fibers than pull outs. However increasing fiber content beyond 50% increases the value of the applied load that causes fatigue damage initiation to the composites under stress.
Fig. 6 – SEM images of tensile fractured sample of 50% DPF/epoxy composites.

4. Potential applications of DPF/epoxy composites

Comparable and satisfactory mechanical properties and moderate value of elongation at break of 50% DPF/epoxy composites with respect to kenaf/epoxy, pineapple/phenolics, oil palm/epoxy and hemp/epoxy composites governs its probable applications with the prime benefits of renewability, sustainability and economical issues besides as lightweight structural material. Remarkably the 50% DPF/epoxy formulation can be used in secondary structural applications in housing, aircraft components like blades, other machinery parts and in certain non-structural applications like consumer products, sports items, backrests, roof tiles, cabin linings and exterior designing with minimal repairing costs. Obtained acceptable mechanical and morphological results also suggest that, it can be used as substitute for glass reinforced polymer composites in automobile interior linings (rear wall, side panel lining, roof), shipping pallets, sustainable construction material (including roofing tiles, partitioning boards, ropes), furniture and household products (window, toys, flower pots picture frames and storage containers). Overall we can conclude that the fabricated composites can be considered as suitable for a wide range of industrial applications from mechanical performance standpoint.

5. Conclusion

In this study an effort has been made to reinforce stiffer DPF (40, 50 and 60 wt.%) as filler in order to modify the mechanical (tensile and impact strength) and microstructure properties of pure epoxy resin. Result analysis revealed that DPF incorporation improves the tensile properties, impact strength and presents marked effect on energy absorption tendency. However noticeable enhancements were realized for 50% DPF/epoxy composites due to fine distribution and
Fig. 7 – SEM images of tensile fractured sample of 60% DPF/epoxy composites.

perfect mixing and dispersion of DPF filler without any prominent sign of aggregations and microvoids formation. Addition of 50% DPF improves the tensile strength, tensile modulus, elongation at break (%), impact strength and energy absorption (%) of pure epoxy resin from 20.5 to 25.7657 MPa, 0.5123 to 1.546 GPa, 0.91 to 1.412%, 45.81 to 98.71 J/m and 50–34%. Although at higher fiber content (beyond 50%) the epoxy was insufficient to cover the DPF, causing the mechanical properties to deteriorate and to initiate the failure mechanism within composites. SEM micrographs also explain the stiffer nature and toughening mechanisms for 50% DPF/epoxy composites among the 40 and 60% DPF/epoxy composites.

It is anticipated from the previous and current work that 50% DPF reinforcement have the highest mechanical and thermal stability and these studies will motivate the introduction of sustainable and huge deposits of DPF wastes as filler in thermosets. Furthermore this study might contribute to the optimized used of DPF in the development of advance and cost effective materials for engineering mechanical based applications. It will also help to avoid or minimize the use of synthetic fibers like carbon, glass and Kevlar or exclusive fillers like graphene, carbon nano fibers, metal oxides, carbon nanotubes and modified nanoclay.

Conflicts of interest

The authors declare no conflicts of interest.

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