Effect of nanoclay on mechanical, flammability, and water absorption properties of glass fiber-epoxy composite

Suhas Kowshik¹, Manjunath Shettar¹, Nikhil Rangaswamy², Ganesh Chate³ and Patcharapon Somdee⁴

Abstract: Automobile bodywork, wall insulation, bridges, and ship hulls, to name a few, are among the many applications for glass fiber-epoxy composites. To manufacture lightweight products for aforesaid applications, the properties of glass fiber-epoxy composites must be improved. The present work aims to fabricate and characterize nanoclay epoxy composites (NECs) and nanoclay glass fiber epoxy composites (NGFEC) by varying nanoclay weight percentages (i.e., 0, 2, and 4 wt.%). NECs are fabricated by a general-casting technique, and NGFECs are fabricated by hand layup technique. Flexural, impact, flammability, and water absorption tests are conducted to evaluate the properties of NECs and NGFECs in accordance with ASTM standards. The addition of nanoclay increases the flexural and impact strengths of NECs and NGFECs by 8 to 14% and 16 to 29%, respectively. Also, nanoclay additions decline the burning rate and water uptake (%) of NECs and NGFECs by 6 to 23% and 6 to 30%, respectively. The impact strength of pure epoxy, NECs, GFEc, and NGFEC is diminished by 7 to 25% at the end of 70 days of water absorption. Scanning electron microscopy images are employed to learn the causes of specimen failure under an impact load for as-made and water absorbed conditions. Crack deflection, pinning, and arresting, fiber pull-out, crazing and matrix rupturing, shear leaps are observed in the SEM images.

Subjects: Composites; Materials Processing; Polymers & Plastics
Keywords: Nano clay; epoxy; glass fiber; impact strength; burning rate; SEM

1. Introduction
“Fiber-reinforced polymer” (FRP) composites have sparked considerable interest in academia and industry. FRPs have better properties and are simple to process. The type of polymer resin, fiber, additives, and fabrication technique utilized all have an influence on the properties of FRP composites (Annappa et al., 2021), (Alberto, 2013).

Epoxy resin offers a number of distinguishing characteristics, including relatively higher strength and modulus, slight shrinkage, and exceptional resistance to chemicals and heat. Epoxy is used in various applications, including adhesives, metal coatings, and matrix constituents for composite, due to its outstanding characteristics (Shettar, Kowshik et al., 2020), (Shettar, Kini et al., 2020). (Nando et al., 2019), reported that cured epoxy has poor impact strength. Also, the authors stated that SEM images of pristine epoxy specimens displayed lower tolerance to crack inception and propagation and minimal fracture toughness. Epoxy resins are used in a wide range of applications that are subjected to damp service conditions. Epoxies suffer permanent damage when exposed to water over long periods of time due to their vulnerability to hydrolysis, swelling, crazing, plasticization, oxidation, and a drop in the effective average crosslinked molecular weight (Dogan & Arman, 2019). As a result, the absorbed water molecules have a negative impact on the epoxy’s physical properties, which has a major effect on its performance. Water absorption by the polymer causes irreversible damage, such as microcavities, which decreases the polymer’s strength. (Shettar et al., 2022) reported that tensile and flexural strengths of epoxy are diminished by 25 and 23%, respectively, under water absorption conditions because of its “hydrophilic nature”.

To increase the applicability of epoxy, a new strategy has been proposed by incorporating fillers into the epoxy. The nanoparticle-reinforced epoxy has improved interest compared to pristine polymers due to their superior properties (Hanemann & Szabó, 2010). One of the most studied and researched nanoparticles in polymer composites is nano clay. Nano clay has become eminent among nanoparticles owing to its easiness in usage, environmental advantages, and exact chemistry (Guo et al., 2018). Nano clay has a higher modulus, is more affordable, has a lower density, and has a more extensive surface area. Nano clay in small amounts (less than 5% by weight) can improve a wide range of properties (A. Kini et al., 2022). The use of nano clay in polymers can improve fracture toughness while preserving other properties, viz., strength, module, thermal stability, and flame retardancy (Chan et al., 2011). Many studies on nano clay-epoxy composites have been conducted, with researchers reporting that adding nano clay improves the properties of epoxy resin (Kusmono & Mohd Ishak, 2013), (Krushnamurty et al., 2015), (A. Kini et al., 2022), investigated the influence of nano clay on water soaking and the mechanical properties of nano clay-polyester nanocomposites. The results revealed that nano clay addition reduces the total water uptake percentage of polyester by 5–11% and enhances both tensile strength by 12–15% and flexural strength by 4–10%.

Glass fiber-epoxy composites are extensively used in different applications, comprising automobile bodywork, wall insulation, bridges, and ship hulls, to name a few (Naveen et al., 2019), (Ismail et al., 2019). One major issue that hinders the extensive use of composite structures in aforesaid applications is their fire and moisture absorption resistance performance. It is needed to improve the glass fiber-epoxy composites properties in order to produce lightweight products for domestic applications. Many studies show that nano clay addition to epoxy improves mechanical, thermal, tribology, and water absorption properties dramatically (U. A. Kini et al., 2018) - (Jeyakumar et al., 2017). (Wang et al., 2019), explored the influence of nano clay on the tensile strength of glass fiber-epoxy composites. Results revealed that nano clay addition improved the tensile
strength by 3–20%. Higher tensile strength is witnessed at 3 wt.% of nanoclay with a 20% increase compared to pristine composites.

The improvement in tensile and flexural properties of nano-clay reinforced epoxy-based nanocomposites has been extensively studied in the literature. However, there is insufficient research in the literature on the effect of nanoclay addition on the impact strength of epoxy and glass fiber-epoxy composites. The knowledge of the effects of water soaking conditions on impact strength is not certainly observed in the literature on nanoclay reinforced epoxy and glass fiber-epoxy composites, including a varying weight percentage of nanoclay. This appears crucial in broadening the spectrum of uses for these composites, especially in the automotive, marine, construction, and domestic sectors. This work aims to study whether the addition of nanoclay can improve the flexural and impact strengths and flammability properties and reduce the water degradation effect caused by water uptake on the impact strength of nanoclay reinforced epoxy and glass fiber-epoxy composites.

This research aims to manufacture and characterize two different types of composite materials, viz., nanoclay epoxy composite (NEC) and nanoclay glass fiber epoxy composite (NGFEC), with varying weight percentages (wt.%) of nanoclay. It also targets the influence of different nanoclay wt.% on flexural and impact strengths, flammability, and water absorption properties of NEC and NGFEC. In addition, fracture surfaces under impact load are investigated in order to establish the causes of specimen failure.

2. Methodology

2.1. Materials used
Epoxy resin (Lapox (L-12)) and hardener (K-6) with a mixing ratio of 10:1, obtained from “Atul Polymers”. L-12 is an unmodified liquid epoxy of intermediate viscosity (9000–12,000 mPa.s). K-6 hardener is a room temperature curing liquid hardener with a low viscosity. Epoxy and hardener can be mixed effortlessly at ambient temperature, and the mixture gives a short pot life and rapid curing. The bi-directional plain-woven E-glass fiber reel (360 GSM) is used as a reinforcement and obtained from “Yuje Enterprises, Bengaluru”. Nanoclay (“Surface modified contains 15–35 wt. % octadecylamine, 0.5–5 wt. % aminopropyltriethoxysilane”) is used as a filler and purchased from “Sigma Aldrich”. Nanoclay has a sheet-like structure with a density of 0.2 to 0.5 g/cm³. Each nanoclay sheet has crosswise sizes of 200–600 nanometers and is just a few nanometers thick.

2.2. Preparation of composite
Nanoclay epoxy composite (NEC) and nanoclay glass fiber epoxy composite (NGFEC) with varying wt.% of nanoclay (i.e., 2 and 4) are prepared for the investigation. The nanoclay wt.% percentages are selected as 2 and 4 wt.% based on our previous work (Shettar, Kowshik et al., 2020). Initially, nanoclay and epoxy are mixed meticulously using a magnetic stirrer and sonicator for 2.5 hours. Later, the epoxy-nanoclay mixture is allowed to cool down for an hour. The known quantity of hardener is mixed manually with the epoxy-nanoclay mixture before pouring the mixture into the mould. The moulds for pure epoxy and NEC specimens are prepared as per ASTM standards’ dimensions. NGFEC laminates are prepared by hand layup technique followed by compression moulding. The glass fiber weight percentage is maintained at 50 wt.%. The specimens are cut from the prepared laminates as per the dimensions of ASTM standards. Detailed flowchart for preparation of composites is presented in figure 1. The designated codes for prepared composites are reported in Table 1.
2.3. Testing

2.3.1. Flexural test
Under standard operating conditions, the 3-point flexural test is carried out as per the ASTM D790-10. The specimens are prepared with dimensions of 127 mm (L) × 13 mm (W) × 3.2 mm (T; Figure 2 (a)). A span-to-thickness ratio of 20:1 is maintained during testing. Flexural strength is tested on a minimum of 5 specimens of each type using “ZWICK-ROELL Z020, LOADCELL 20 kN” equipment; the test speed is maintained at 1.0 mm/min with pre-load of 0.1 MPa.

Table 1. Codes for prepared composites

| Code  | Composite Name                              |
|-------|---------------------------------------------|
| E     | Pure Epoxy                                  |
| 2NEC  | 2 wt.% Nanoclay Epoxy Composite             |
| 4NEC  | 4 wt.% Nanoclay Epoxy Composite             |
| GFEC  | Glass Fiber Epoxy Composite                 |
| 2NGFEC| 2 wt.% Nanoclay Glass Fiber Epoxy Composite |
| 4NGFEC| 4 wt.% Nanoclay Glass Fiber Epoxy Composite |

Figure 1. Detailed flowchart for preparation of composites.
2.3.2. Impact test
The impact test is conducted as per ASTM D4812 standard. The specimens are prepared with dimensions of 65 mm (L) × 12.7 mm (W) × 3.2 mm (T; Figures 2 (b)). The impact test is tested on a minimum of 5 specimens of each type using “ZWICK /ROELL HIT 50P” equipment. During testing, theoretical impact velocity is maintained at 3.458 m/s.

2.3.3. Flammability test
The ASTM D635 (Horizontal burning) standard is used to conduct the flammability tests. The “ATLAS HVUL2” equipment is used to evaluate a minimum of 5 specimens of each type for burning
Figure 3. Flexural strength of pure epoxy and different composites.

Figure 4. Impact strength of pure epoxy different composites.
tests. The specimens are prepared with dimensions of 127 mm (L) × 13 mm (W) × 3.2 mm (T; Figure 2 (a)).

2.3.4. Water absorption test
The prepared impact test specimens (Figure 2 (b)) are kept in the tap water at room temperature for 10 weeks for a water absorption test. The specimens are weighed weekly during the water
soaking tests (ASTM D570-98 standard) using a digital weighing apparatus to find the difference in weight and water absorb percentage.

The water uptake (%) is determined by using the following equation:

Water uptake (%) = \((W_s - W_a) \times 100 \div W_a\)

Where \(W_s\)—Weight after soaked; \(W_a\)—Weight of as made specimen
Figure 10. Water uptake by different composites.

Figure 11. Impact strength of different composites under as-made and water absorbed conditions.
2.4. **SEM analysis**

Images of the morphology at the fractured surface of specimens are captured with the help of a “Scanning Electron Microscope (ZEISS, Model: EVO18)”. Specimens are diced to the necessary dimensions in order to equip them in the specimen holder of the microscope. The specimen surface should be electrically conductive to produce effective imaging. A very-thin conductive material is deposited on the surface of the specimen using a mini sputter coater machine (Model: SC7620) for 10 mins. The sputter coater machine uses a gold-palladium (80:20) sputtering target.

3. **Results and discussion**

3.1. **Flexural strength**

The flexural strength of pure epoxy and different composites is demonstrated in Figure 3. Five specimens are tested for each composite, and average flexural strength values are presented in the current study to avoid instrumentation errors. The figure and discussions show the experimental results of flexural strength of pure epoxy and GFECs with and without nanoclay. The effect of nanoclay in the epoxy matrix on flexural strength can clearly be seen. The flexural strength value of pure epoxy is 127 MPa. As the nanoclay wt.% is increased, the flexural strength increases. 2NEC and 4NEC exhibit improvement in flexural strength as compared to pure epoxy. The flexural strength of 2NEC and 4NEC increased by 8 and 10%, respectively, compared to pure epoxy. (Arulmurugan & Venkateshwaran, 2016) reported improvements in this property by 6 and 9% by nanoclay addition (1 and 3 wt.%) to a polyester resin. The enhancement in the flexural strength is attributed to the
improved interfacial bonding liable for the stress transfer and elastic deformation in the presence of nanoclay particles. The surrounding matrix is strengthened and stiffened using nanoclay. Nanoclay can also offer physical crosslinks between epoxy chains, resulting in stronger localized areas (Sand Chee & Jawaid, 2019). The nanoclay’s sheet-like structure allows for the rearrangement of clay layers in the stress direction, resulting in a stronger reinforcing effect (Hamim & Singh, 2014).

Figure 13. SEM image of impact tested NEC’s fracture surface under water absorbed condition.

Figure 14. SEM image of impact tested GFEC’s fracture surface under water absorbed condition.

Figure 15. SEM image of impact tested NGFEC’s fracture surface under water absorbed condition.
The flexural strength of GFEC is increased by 173% compared to pure epoxy. The main load-bearing components are glass fiber, with epoxy acting as a stress transmission medium. Reinforcing glass fibers increase the flexural strength of epoxy owing to the improved composite stiffness. Also, glass fibers are lighter and stiffer, making them more resistant to bending loads (Safri et al., 2018). As presented in Figure 2, 2NGFEC and 4NGFEC show improvement in the flexural strength compared to GFEC. The flexural strength of 2NGFEC and 4NGFEC increased by 8 and 14%, respectively, compared to GFEC. Similar results are reported by (Rafiq & Merah, 2019) and (Nemati Giv et al., 2020), i.e., the addition of nanoclay to glass fiber polymer composites enhances the flexural strength by 6 to 16%. The presence of nanoclay enhances the interfacial bonding among glass fibers and epoxy, resulting in a greater surface area for nanoclay–matrix interaction, leading to superior stress transfer from epoxy to nanoclay and glass fiber combined improving flexural strength (Rafiq et al., 2014), (Dorigato et al., 2012).

### 3.2. Impact strength

Impact resistance is a critical attribute for any material that must absorb energy when subjected to a quick impact load. Generally, impact strength refers to a material’s capacity to withstand fracture under higher-velocity stress. When the stress is equally distributed throughout the material, it has higher impact resistance (Mysamy et al., 2019). Pure epoxy and GFEC’s impact strengths are compared to nanoclay added composites. The impact strength of pure epoxy and GFEC composites with and without nanoclay is shown in Figure 4. The impact strength of the pure epoxy composite is 16 kJ/m². It is increased to 21 and 23 kJ/m² for 2NEC and 4NEC, respectively. (Nanda et al., 2019) reported that adding 1.5 wt.% nanoclay enhances the impact strength by 22%. Improved impact strength is supposed to be achieved through nanoclay intercalation. Nanoclay layers function as crack inhibitors, creating a tortuous path for crack propagation, resulting in greater impact strength values (Nanda et al., 2019).

The impact strength of GFEC is about 6 times higher than that of pure epoxy. Further addition of nanoclay shows the improved impact strength of GFEC. As shown in Figure 4, the impact strength of 2NGFEC and 4NGFEC increased by 16 and 29%, respectively, compared to GFEC. Nanoclay prevents microcracks from forming and propagating in the epoxy matrix. The use of a nanoclay-filled epoxy matrix improves stress transfer, lowering local stress concentrations along the interlayer of glass fibers and epoxy matrix (Tian et al., 2017). As a result, NGFEC’s interfacial adhesion and impact strength improve.

#### 3.2.1. SEM analysis

SEM images provide comprehensive information pertaining to the fracture surface of different composite specimens. The surface of pure epoxy (Figure 5) is smooth, flat, and has some river-like patterns that indicate brittle fracture behavior, indicating inferior impact strength. The fracture propagation lines are nearly parallel to each other, representing that the cracks propagated quickly and straightly (Figure 5; arrow in white-colored indicating crack propagation direction). Though there is some deviation in the cracks, they mostly ran in one direction. Pure epoxy’s plane, glassy, and monotonous fracture surface represent minor matrix displacement, characteristic of a homogeneous brittle material (Lim et al., 2010) with lower impact strength.

NEC’s fracture surface has a tortuous path and increased surface roughness (Figure 6). This indicated that the crack front is difficult to propagate and so has a higher impact strength. The nanoclay in NEC is effective in preventing fracture front progression. Various energy absorption mechanisms are discovered in these NECs, resulting in increased impact strength. Crack deflection, pinning, and arresting are among the mechanisms included. These fractographic characteristics resulted in a tortuous path for the propagation of crack before failure, which increased the absorbed energy to fail and improved impact strength (Nanda et al., 2019).
The SEM images of the fractured impact test GFEC and NGFEC specimens are shown in Figures 7 and 8. Figure 7 shows the specimen failure is because of matrix rupture, fiber breakage, fiber-matrix delamination, and fiber pull-out under impact load. The glass fibers appear clean, and no residue matrix. Figure 6 shows a broken fiber end, revealing the debonding of fiber and epoxy.

Figure 8 confirms that adding nanoclay enhanced the interfacial bonding between fiber and matrix, indicating an improvement in impact strength. In SEM images of NGFEC, large resin clusters can be seen, indicating strong matrix adhesion to fiber. Even after the fracture, there is only a little degree of relative debonding among the fibers and matrix. This signifies a stronger bond due to the addition of nanoclay in the NGFEC s at the fiber and matrix interface.

3.3. Flammability tests
The horizontal burning rate of different composites is demonstrated in Figure 9. The addition of nanoclay and glass fibers prevents dripping, while only the pure epoxy specimens showed dripping without considerable char formation. Dripping flaming polymer during combustion accelerates the spread of fire in general. In contrast, the formation of the stable char surface layer obstructs further ignition by restraining the heat and mass transfer from the flame to polymer and polymer to flame, respectively (Riahipour et al., 2018), (Azeez et al., 2013).

The nanoclay addition to the epoxy decreases the burning rate by 6% for 2NEC and 13% for 4NEC. (V T. Nguyen et al., 2020) reported that adding 2 wt.% of nanoclay to epoxy reduces the burning rate up to 10%. A sheet-like barrier is formed by nanoclay, i.e., heat-resistant and retaining, which delays the oxygen diffusion and stops flammable ingredients from burning in the epoxy (T. A. Nguyen et al., 2019), (Nguyen & Pham, 2020). The flammability resistance of the composite displays remarkable enhancement when reinforced with glass fiber. The burning rate of GFEC is reduced by 20% compared to pure epoxy. Nanoclay addition to GFEC further reduces the burning rate by 23% for 2NGFEC and 25% for 4NGFEC.

3.4. Water absorption
Figure 10 shows that increasing nanoclay wt.% decreases different composites’ overall water uptake (%). All composites are reported to have the normal polymer water uptake behavior. The nanoclay addition to the epoxy declines the epoxy’s water uptake (%) by 6% for 2NEC and 11% for 4NEC. A similar trend is observed by (A. Kini et al., 2022), i.e., the addition of nanoclay decreases water uptake (%) of the polymer by 5 to 10%. Water uptake could be owing to the ability of molecules of water to penetrate within the epoxy’s network. Water molecules in epoxy form a strong bond with “hydrophilic functional groups,” viz., hydroxyl or amine. Nanoclay in the epoxy network limits the mean free path for water molecules to cross, resulting in lesser water uptake. The higher aspect ratio of nanoclay produces “tortuous pathways” for molecules of water, which is the prime reason for the better water absorption resistance(Al-Qadhi et al., 2013), (Rull et al., 2015).

As shown in Figure 9, GFEC shows lesser water uptake (%) because water is absorbed by epoxy only because of “no water-absorption property” of glass fiber. Reinforcing glass fiber reduces the water uptake of epoxy by 50%. Further addition of nanoclay to GFEC decreases the water uptake by 20% for 2NGFEC and 30% for 4NGFEC. The effect of nanoclay addition on the water uptake (%) (Figure 10) is similar to that observed for ENCs and what has been reported by (Rafiq & Merah, 2019). The lowest water uptake (%) is found for 4NGFEC, i.e., 0.59% at the end of 70 days, because of an increase in the tortuous path for the water molecules movement by the glass fiber and nanoclay.
3.5. Effect of water uptake on impact strength

The impact strength of pure epoxy and NECs is diminished at the end of 70 days of water absorption, as shown in Figure 11, because of its “hydrophilic nature”. The maximum impact strength is decreased by 25% for pure epoxy. Due to the dissociation of hydrogen bonds among polymer chains, the presence of water in the epoxy network increases free volume, which enhances chain mobility and reduces segmental motion when the load is applied to the epoxy and composites. These physical alterations may account for the reduced impact strength found in water-absorbed specimens (Silva et al., 2016). The effect of water absorption is more severe in pure epoxy than in the NECs. The impact strength of NECs is decreased by 19% for 2NEC and 13% for 4NECs. Because of the extraordinary barrier property of nanoclay, the addition of nanoclay in NECs has minimized the influence of water absorption conditions on impact strength, as shown in Figure 11. Nanoclay creates a “tortuous path” for water molecules to penetrate in NECs, delaying the overall effect of the water absorption condition (Hamim & Singh, 2014), (Alamri & Low, 2012). Furthermore, when compared to pure epoxy, the nanoclay’s larger aspect ratio provides resistance to polymer chain agility in water-absorbing polymers, resulting in a decreased impact strength reduction for NECs.

As shown in Figure 11, GFEC displays lesser impact strength reduction (10%) compared to pure epoxy at the end of 70 days of water absorption. Further addition of nanoclay to GFEC decreases the overall decrease in impact strength by 8% for 2NGFEC and 7% for 4NGFEC. At the end of 70 days of water absorption, a minor reduction in impact strength is observed in 4NGFEC. The incorporation of both glass fiber and nanoclay improves epoxy’s resistance to water absorption. This is because of an enhancement in the tortuous path via which water molecules infiltrate (Rafiq & Merah, 2019).

3.5.1. SEM analysis

The fracture surface of water absorbed pure epoxy displays a complex surface (Figure 12) compared to the as-made specimen’s fracture surface (Figure 5). In water-absorbed conditioned pure epoxy specimens, a complex linkage of micro-cracks on the surface of the fracture is discovered, boosting craze inception and propagation in the epoxy and endorsing the plasticization effect of absorbed water. Stress is high enough to generate secondary local cracks at various phases of crack growth, causing the rougher area next to the crack front to develop. The crack propagates quickly that the crazes initiated near the crack front do not have enough time to expand.

Compared to the as-made specimen (Figure 6), the water-absorbed conditioned NEC specimen (Figure 13) shows the presence of shear leaps and a lesser rough surface on the fracture surface, indicating lesser fracture toughness. The water absorption condition had a substantial effect on the pure epoxy resin, as demonstrated in SEM images, in comparison to NEC. This could explain why epoxy has a higher impact strength reduction than NEC. The addition of nanoclay to epoxy increases crosslinking density and makes water molecules difficult to migrate. Nanoclay addition to epoxy (NEC) decreases the effect of water absorption in comparison to pure epoxy, resulting in a lower percentage reduction in impact strength.

The interface area of the fiber and matrix of composite specimens under water absorbed conditions are shown in Figures 14 and 15. SEM images of GFEC are presented in Figure 14. The failure of GFECs under water absorbed conditions is due to pull-out of fiber, matrix rupturing, or degradation and debonding of fiber-matrix. The degradation of the fiber-matrix interface and matrix properties are the main reasons for the reduction of impact strength of GFEC.

From Figure 15, it is obvious that nanoclay addition in NGFECs reduced the effect of water absorption conditions. The addition of nanoclay enhanced the fiber-matrix bonding, crack arresting, and diversion of crack propagation in NGFEC, which delayed the water absorption effect and declined the percentage of reduction in NGFEC strength.
4. Conclusion
Adding different wt.% of nanoclay on mechanical, flammability, and water absorption properties of epoxy and glass fiber-epoxy composites are investigated. The results revealed that nanoclay addition to epoxy and GFEC enhances the flexural and impact strength, and 4NGFEC displays maximum flexural and impact strengths, i.e., 399 MPa and 119 kJ/m². The burning rate of epoxy and GFEC declines up to 13 and 25%, respectively, with the addition of nanoclay. The water uptake (%) of epoxy decreases with the addition of nanoclay and glass fiber, and the lowest water uptake (%) is found for 4NGFEC, i.e., 0.59% at the end of 70 days. The impact strength of pure epoxy, NECs, GFEC, and NGFEC is diminished at the end of 70 days of water absorption. Overall, from the impact test results, it can be concluded that the addition of nanoclay has declined the percentage of reduction in impact strength of epoxy and GFEC. SEM analysis of the fracture surface reveals the reasons for specimen failure under impact load. Crack deflection, pinning, and arresting, fiber pull-out, crazing and matrix rupturing, shear leaps are observed in the SEM images. Hence, based on the results and discussions, the applications of epoxy and glass fiber-epoxy composites could be increased in the field of automotive, marine, construction, and domestic sectors. In the future, the study related to the wear and ballistic properties of aforesaid composites is crucial to increase the applications.

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Author details
Suhas Kowshik
Manjunath Shettar
E-mail: manjunath.shettar@manipal.edu
ORCID ID: http://orcid.org/0000-0003-4318-3129
Nikhil Rangaswamy
Ganesh Chate
Patcharapon Somdee
1 Department of Mechanical and Industrial Engineering, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal, India.
2 School of Mechanical Engineering, Reva University, Bangalore, India.
3 Department of Mechanical Engineering, KLS Gogte Institute of Technology, Belagavi, India.
4 School of Materials Engineering, Rajamangala University of Technology Isan, Muang, Nakhon Ratchasima, Thailand.

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