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Research Article

Effect of Mechanical Properties on Fibre Addition of Flax and Graphene-Based Bionanocomposites

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Natural fibre-based polymer nanocomposites have played an essential role in many industry domains for four to five years because of their strong mechanical and physical qualities. The primary goal of this research is to establish the mechanical and morphological properties of nanocomposite materials in natural environments. Flax fibre was employed as a reinforcement, nanographene powder was used as a filler, and epoxy resin was used as a matrix material to achieve the goals above, keeping the following restrictions in mind: (i) fibre length (15, 30 and 45 mm), (ii) fibre content (10, 15 and 20 mm), and (iii) wt.% of nanofiller (2.5, 5 and 7.5 wt.%). The composite materials were laminated using the compression moulding process per the Taguchi L_9 design. The mechanical characteristics of the material, such as flexural, tensile, and impact properties, were examined according to ASTM standards. The mechanical characteristics of combinations A2, B2, and C2 are the best when compared to other combinations. The graphene-based nanocomposites revealed that 2.5 wt.% graphene contributes 33.08% of mechanical properties, the 5 wt.% graphene contributes 36.4%, and the 7.5 wt.% graphene contributes 30.53%. Including 5 wt.% graphene content provides the highest mean values of mechanical strength like 36.59 MPa tensile, 40.25 MPa flexural, and 31.68 kg/m^2 of impact. Scanning electron microscopy (SEM) images of the cracked specimens were used better to understand the failure process of composites during mechanical testing.

1. Introduction

The modern world and its changing needs have enabled the development of a pollution-free and environmentally healthy civilization. This can be done partly or entirely by altering the materials used in building structures, industries, and materials utilized in various applications. Traditional materials are treated or degraded; they constitute the principal source of carbon dioxide emissions. Furthermore, environmentally friendly biomaterials are required in today's society. As a result, scientists are concentrating their efforts on developing a new biologically degradable material [1, 2]. In this case, natural polymers are one of the best options for overcoming the metal and alloy shortage. Biocomposite components are lightweight, have unique mechanical properties, and are both cost-effective and ecofriendly. Ceramics and alloy steels cannot provide the unique combination of material properties necessary for current advancements, especially in aeroplanes, submarines, and transportation. Materials in aviation usually fail to meet engineering structure's high fracture toughness and relative stiffness [3, 4]. The composite material aids in achieving the appropriate quality by carefully mixing several components. These materials are excellent for a wide range of technical applications since they are typically tough and rigid. Polymer composite materials have surged in popularity as the most popular new materials in recent history, with applications in project management and other structural aspects. Natural fibres provide several benefits over synthetic materials in terms of material preparation, including being recyclable, having the lowest density, being less expensive, having more flexibility, and giving longer durability. Natural fibres are also readily accessible and have good mechanical properties. Natural fibres are utilized to create a wide range of textiles, cables, canvases, and sheets. Plant parts such as stem, leaf, kernels, and fruits have all been identified as possible natural fibre sources [5, 6].

Vakka and date fibre excavation and tensile properties were investigated, which led to the potential of employing these fibre-reinforced composites in composite materials. On the other hand, fibre-reinforced composites are the most important component and bear most of the load. As a result, the appropriate choice of fibre reinforcement, fibre length, and fibre weight concentration influence the composite's mechanical properties [7]. Flax (Linum usitatissimum L.) belongs to the *Linaceae* family, which contains thirteen families and 300 species, and is the sole agriculturally important genus. Around 4000 B.C., flax, the earliest cloth made from crops and stiffened into a matrix, was farmed and discovered in Egyptian tombs. It is one of the most widely utilized biofibres. Flax is a significant product that has been grown for generations because of its fibres and oil. Flax has been the subject of intensive study and the adoption of beneficial traits such as glyphosate tolerance, abiotic stress resistance, and better oil and fibre grades. Flax is an evergreen shrub with 16–32 mm stems that grow to a height of 0.5–1.25 m [8, 9]. On poor soils, where environmental abiotic variables cause greater mortality, phytoemployees in flax production are more successful than in rich soils. The study aimed to see how successful acetylsalicylic and salicylic chemicals were in developing fibre flax in two distinct soil types in 2020 and 2021. Salicylic acid did not affect the number of flax outputs during the testing. Although natural fibres are never a problem-free option to synthetic fibres, they have certain advantages. Low surface qualities among fibres and polymer matrices sometimes restrict their efficacy as reinforcing materials due to the deterioration of natural materials [10, 11].

Two or more fillers are contained in the same matrix in hybrid composites. Hybridization improves the mechanical properties of natural fibre reinforced plastic composites by removing the flaws that single composites have [12]. However, the impact of mixing fibres in matrices on improving mechanical characteristics has reached its limit. Nanoparticles are employed to strengthen the bond between the matrix and the fibre, resulting in even better characteristics. As a result, using nanoparticles in polyester is gaining popularity [13]. Nanoparticles have unique properties due to their nanometer size, which may be used to develop new goods or improve the efficiency of existing ones. Nanoparticles have wide applications in water purification, energy generation, and contaminant detection. Much research focuses on how new nanoparticles might be used to address pressing environmental challenges. The most recent material to pique scientists' curiosity is graphene, a two-dimensional sheet of carbon molecules organized in a crystalline hexagon structure [14]. The amazing physicochemical properties of graphene have attracted interest, notably its exceptionally high surface area, electron and heat mobility, and mechanical properties [15, 16]. These extraordinary properties have inspired significant efforts to incorporate graphene into various technological applications, from electrical systems to biomaterials. In the field of environment, graphene and graphene-based materials have been used to develop novel sorbate or photocatalysts equipment for ecologic disinfection, as building blocks for the next water purification membrane surface, and as electrocatalysts for pollutant tracking or expulsion [17, 18]. The adhesion of epoxy resin and flax fibre can be improved using various chemical treatments. Bast fibres, like flax, can provide thermal comfort. After assessing them under loading conditions and recurrent packing trials, it was determined that the elastic modulus of flax fibres is controlled by the size and orientation of a tensile strength [19, 20]. The efficacy of the fibre-reinforced nanocomposite material is improved by establishing interfacial coherence adhesion between the fibre and matrix. On the other hand, surface modification of nanocomposites has unintended effects such as mechanical degradation, extreme swell renegotiation, and external damage [21].

In the literature review, thus far, just a few research publications on nanocomposite reinforced with flax-based natural fibres have been uncovered. On the other hand, graphene and epoxy is a potential nanofiller and biocomposite polymer resin that has gotten the least amount of research. Even though biocomposite has a wide variety of applications, such as assisting in reducing negative environmental consequences, it must still be tested for the target use. Researchers have started developing biocomposite materials using natural fibre reinforcement and evaluating their mechanical properties. This study looks at graphene-based epoxy nanocomposites' flexural, tensile, and impact strengths. The characterization of the tested biocomposites was also looked into, and the results are documented in this study. Table 1 shows the mechanical and physical properties of flax and epoxy matrix.

2. Investigational Resources and Methods

2.1. Flax Fibre. Flax that had not been processed was utilized in this investigation. Flax fibres have a strong tensile strength and are easy to extend when broken. The chemical structure has a significant impact on the features of the fibres, as well as the attributes of the composite generated as a result. The water content is approximately 12%. To use a fabric cutting

Table 1: Mechanical properties of the flax fibre and matrix.

Sl. No	Properties	Flax fFibre	Epoxy resin
1	Cellulose (%)	64.57–75.38	—
2	Hemicellulose (%)	12.96–26.07	—
3	Lignin (%)	4.78–7.44	—
4	Density (g/cm^3)	1.4	1.15
5	Tensile strength (MPa)	500–1500	29.5–31.25
6	Young's modulus (GPa)	50–70	3.1
7	Elongation (%)	1.8-2.1	1.6

equipment, filaments were cut to a different length. The flax fibres were procured from the GVR fibre industry in Madurai, Tamilnadu, India. Figure 1 shows the flax fibre extraction from the flax plant.

2.2. Graphene. The graphene used in this study was of commercial quality, with a quality of 95%. Different concentrations of 2.5 to 7.5 percent of the epoxy matrix were utilized in progressive increments of 0.1 percent by the weight percent of the polyester matrix to make an altered nanocomposite. The photographic image of graphene powder employed in this investigation is shown in Figure 2(a). The graphene powder used in the current research is blocked in colour with a formula weight of 12.01 g/mol and iron content of ≤100 ppm. Figure 2(b) reveals the chemical structure of graphene powder.

2.3. NaOH Processing. NaOH processing is among the most popular treatments for natural fibres used in composite materials. The -OH group in sodium hypochlorite is ionized and converted to aldehyde. The chemical treatment causes hydrogen atoms on the interface system structure to be disrupted, resulting in increased surface quality. It also aids in the depolymerization of cellulose and the exposure of a shorter crystalline phase. To some extent, the quantity of lignin, a wax that coats the majority of hemp's exterior surface, is eliminated.

Fresh flax was obtained and carefully washed for alkalization. The flax was hand-chopped into 5 to 8 mm lengths. According to the literature, a 5% NaOH solution with maximal strength was created, and the flax fibres were soaked in it for 4 hours. The modified flax was then neutralized with acetic acid until the pH reached 7, which was determined using a litmus paper. The balanced solutions were rinsed with distilled water to eliminate surplus chemicals. It would bring the alkali process to a close.

2.4. Fabrication of Hybrid Composites. The graphene used in this study was of commercial quality, with a quality of 95%. Different concentrations of 2.5 to 7.5 percent of the epoxy matrix were utilized in progressive increments of 0.1 percent by the weight percent of the epoxy matrix to make an altered Nanocomposite. The specimens were under research at 90 : 10 stochiometric ratio of resin and hardener. The sonication process was used to disperse graphene and flax in epoxy. A three-roll shearing mixed procedure was employed further to disperse the graphene and flax, and the combination was continuously blended. This mechanical blending is carried out for a set period until the mixture is homogenous. Gas bubbles become retained throughout mechanical stirring and must be eliminated using the degasification procedure. The combination is dried for 2 hours at 600 degrees Celsius, then for 4 hours at 1000 degrees Celsius. The resin and curing agent mixture was put into a 300 mm × 300 mm × 3 mm aluminium mould to make laminates. The composite fabrication was done based on the constraint's levels; it is revealed in Table 2. The desiccators were used to keep the hybrid composite samples from absorbing additional moisture. Table 3 shows the L_9 orthogonal array with ILSS outcomes of the hybrid composite.

2.5. Testing of the Composite Specimen. The fabricated composite specimens were cut to the ASTM standard of D 638-03 replicas with a dimension of 150 × 15 × 3 mm for tensile testing, ASTM D-790 (width 10 mm, length 125 mm, and thickness 3 mm) for flexural testing, and ASTM D-256 (width 12.7 mm, length 64 mm, and thickness 3 mm) for impact testing.

2.6. Scanning Electron Microscopy (SEM). SEM was utilized to conduct microscopic investigations into fractured composite samples. The specimens were laved, dehydrated, and surface coated with 10 nm of gold before SEM clarity to increase the composites' electrical conductivity.

3. Result and Discussion

The following session discusses the effectiveness of fibre content and its length and graphene concentrations on the mechanical properties such as tensile, flexural, and impact properties.

3.1. Effect of Fibre Content. The influence of fibre weight (wt.%) on mechanical characteristics such as tensile, flexural, and impact strength of flax-based epoxy composites is shown in Figure 3. The maximum tensile strength is 32.9 MPa, flexural strength is 36.93 MPa, and impact strength is 28.57 Kg/m^2. The flax fibre content of 15 wt. % offers the best mechanical qualities when compared to 10 wt. % and 20 wt. % fibre content. The low performance at 10% composite construction is due to inadequate load transmission due to the uneven distribution of fibres across the matrix. As a result, the composite developed a matrix-rich region with weak fibre-to-fibre interaction [22].

The fibre reinforcement was easily taken out of the matrix when loaded in this configuration. It shows that the flax composite's 10% reinforcing effect cannot withstand the mechanical load. When the fibre content of the composite is raised from 10% to 15%, the mechanical properties of the composite improve. This is mostly due to the establishment of strong bonds between the fibres and the matrix, which resulted from the fibres' ability to fill up gaps in the composite by admitting additional short filaments and providing good load distribution [23]. The mechanical strength of the composite is lowered when 20 wt. % fibre loading is utilized.

Figure 1: Extraction of the flax fibre from the flax plant.

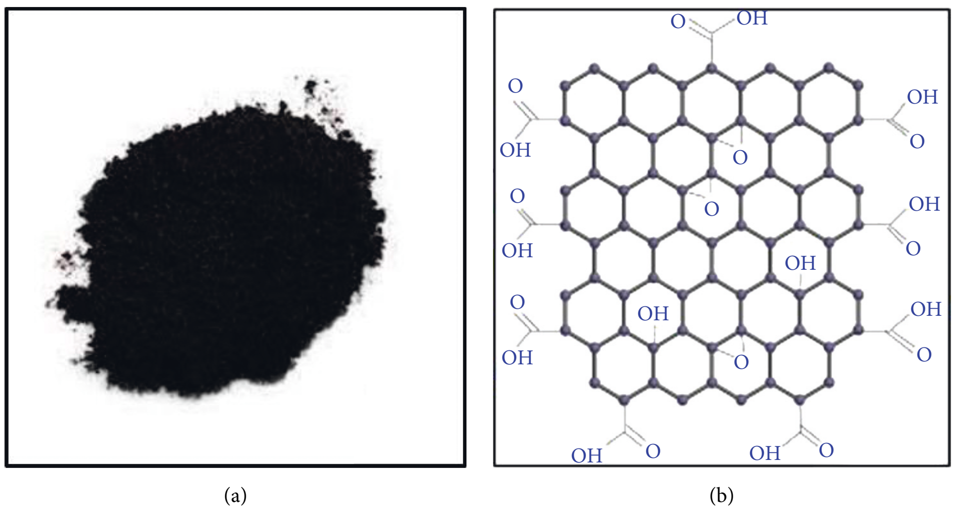

Figure 2: (a) Photographic image of graphene powder; (b) chemical structure of graphene powder.

Table 2: Constrains and their stages for nanocomposites.

Sl. No	Constrains	Symbols	Stages		
			S1	S2	S3
1	Flax fibre content (wt.%)	A	10	15	20
2	Flax fibre length (mm)	B	15	30	45
3	Graphene concentration (wt.%)	C	2.5	5	7.5

Table 3: L_9 orthogonal array with ILSS outcomes of hybrid composite.

Trail no	Fibre content (wt.%) A	Fibre length (mm) B	Graphene concentration (wt.%) C
1	10	15	2.5
2	10	30	5
3	10	45	7.5
4	15	15	5
5	15	30	7.5
6	15	45	2.5
7	20	15	7.5
8	20	30	2.5
9	20	45	5

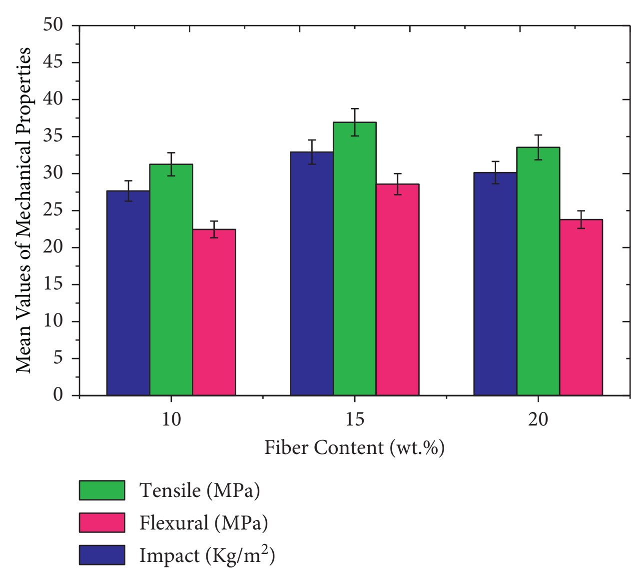

Figure 3: Mean values of tensile, flexural, and impact properties of hybrid composites based on the fibre wt.%.

This might be due to a lack of matrix volume % to provide effective bonding, resulting in inadequate wettability between the matrix and reinforcements [24].

3.2. Results of the Fibre Length. Figures 4(a)–4(c) show the effect of fibre length on the mechanical characteristics (tensile, flexural, and impact) of flax-based nanocomposites. Joseph et al. [25] investigated the mechanical properties of tiny sisal fibre/polyethylene composites and the effects of fibre amount, length, and orientation on processing stages. The chopped fibre dispersion in epoxy was random in this study. Therefore, the fibre could not withstand the stress when the matrices were shifted. The length of the fibres

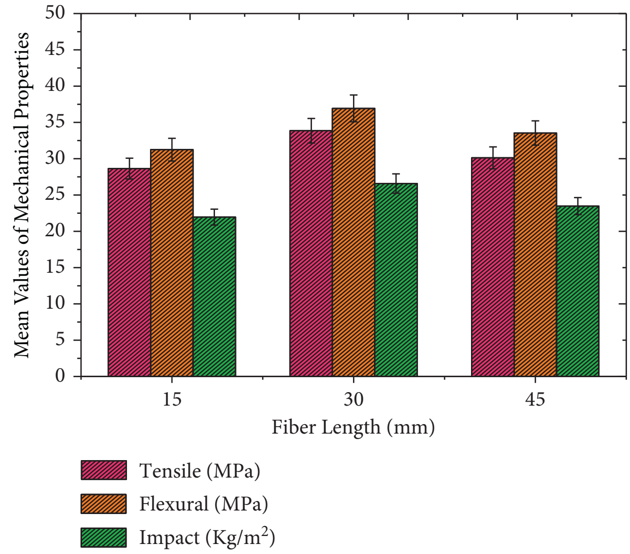

Figure 4: Mean values of tensile, flexural and impact properties of hybrid composites based on the fibre length in mm.

influences the mechanical characteristics of fibre-reinforced composites, according to Doan et al. [6] and Arib et al. [24] analyzed the experimental and theoretical values of tensile characteristics for pineapple fibre-based composites, finding that the formula for the rule of mixing fails to provide a good match, and the difference develops as the fibre content % increases [19, 26]. The presence of voids in the composites and the fact that the fibres are not perfectly aligned may have contributed to the poor testing results.

Mechanical properties improved with fibre length, reaching a maximum of 33.86 MPa tensile, 37.69 MPa flexural, and 26.58 Kg/m^2 impact strength at 20 mm. The chemical reaction at the fibre-matrix interface is likely too strong to convey the load, causing the mechanical properties of these composites to improve. As the threads' length increases, the fibres' mechanical strength diminishes. This might be because the minor gap was most likely caused by a lack of bonding between the resin and the fibre during composite manufacture. It was also noticed by Arib et al. [24]. Matrix fracture, matrix and fibre debonding, and fibre pull-out are the causes of impact failure in composites. Even though fibre pull-out has been established as the main failure mechanism in fibre reinforced composites, delamination between the fibre and the matrix happens whenever the applied load is surpassed. The composite's interfacial bond strength was weakened due to this. When the stress levels exceed the fibre strength, a fibre strength fracture occurs. The fragmented fibres may be drawn out of the resin, resulting in energy loss.

3.3. Effect of Graphene Fibre Additions. The efficacy of graphene filler additions in terms of tensile, flexural, and impact characteristics is shown in Figure 5(a). In comparison to 2.5 and 7.5% graphene additions, 5% graphene additions showed superior mechanical strength (36.59 MPa tensile, 40.25 MPa flexural and 31.68 kg/m^2 impact). Better stress distribution and transmission may account for the improved mechanical properties of graphene in resin at a concentration of 5 Wt.% [27, 28]. Adding more filled graphene to the polymer matrix influenced the decohesion bonding between the fibre and the matrix by increasing the conveyance and size of holes [29]. As a result, at a 5 wt. % concentration, the epoxy, flax, and graphene formulations provide good adhesion binding among surface adhesions [30]. In contrast, adding 2.5 and 7.5 weight % graphene resulted in a negative outcome, indicating a reduction in mechanical strength [31].

Furthermore, in flax and epoxy, heavier and lighter loadings of 2.5 wt% and 7.5 wt% have been shown to have poor boundary adherence of fibre and matrix, resulting in aggregation due to poor adhesion and inferior composite strength qualities [32]. Figure 5(b) demonstrates the percentage contributions of graphene nanofiller on the mechanical properties. The 2.5 wt.% graphene contributes 33.08% of mechanical properties, the 5 wt.% graphene contributes 36.4%, and the 7.5 wt.% graphene contributes 30.53%.

4. Microstructural Examinations

The broken interfaces of the flax fibre reinforced epoxy composite after flexural, tensile, and impact testing are shown in Figures 6(a)–6(c). An SEM picture of the cross-sections of the flax fibre reinforced epoxy composite following mechanical (tensile) failure is shown in Figure 6(a). Figure 6(a) shows that the fibres are removed from the polymer interface due to lower interfacial adhesion. The fibre's exterior is rough, indicating that there is not much contact between the fibres and the epoxy frameworks [33]. The flax fibre slipping from the matrix is seen in Figure 6(a) (for a 10 mm fibre length) [34, 35].

Furthermore, increasing the fibre length to 20 mm may improve compatibility [36]. The increased fibre length from 10 to 20 mm results in less surface breakage 6(b) [37]. As a

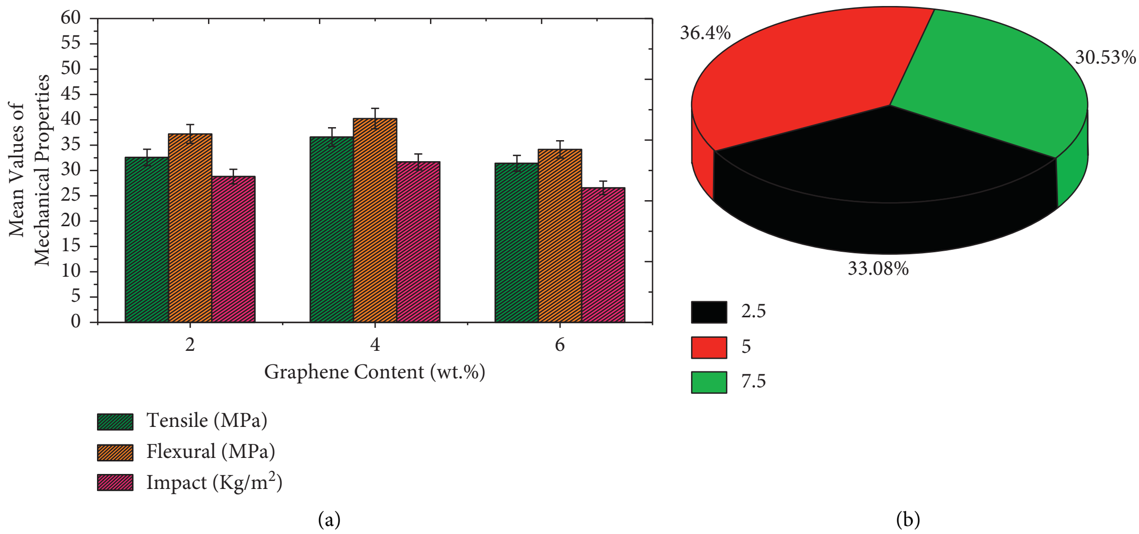

Figure 5: (a) Mean values of tensile, flexural, and impact properties of hybrid composites based on the graphene filler content in mm; (b) % contributions of graphene filler.

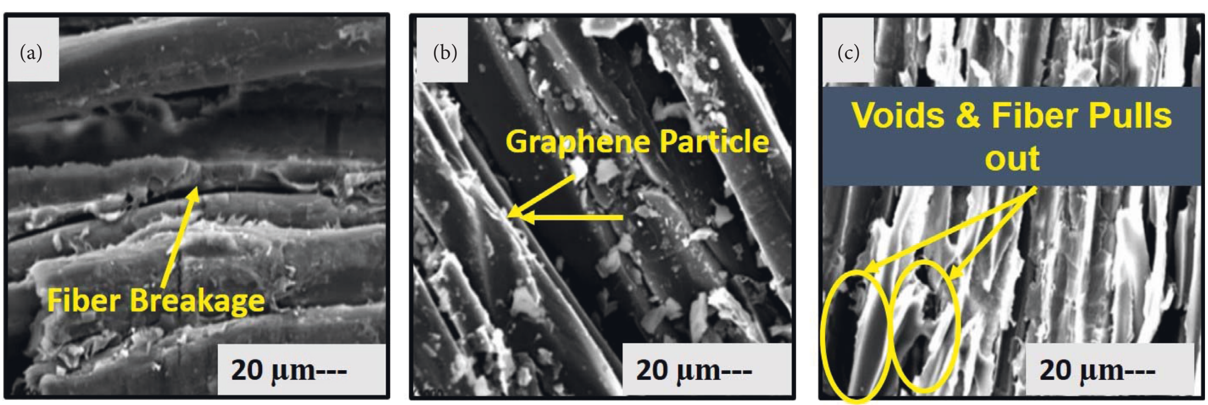

Figure 6: Microstructural analysis of graphene and flax-based bio nanocomposites.

result, at a 5% weight % concentration, the epoxy, flax, and graphene formulations provide good adhesion binding among surface adhesions [38]. In contrast, adding 2.5 and 7.5 weight % graphene resulted in a negative outcome [39], indicating a reduction in mechanical strength [40]. Furthermore, in flax and epoxy, heavier and lighter loadings of 2.5 wt% [41] and 7.5 wt% have been shown to have poor boundary adherence of the fibre and matrix [42], resulting in aggregation due to poor adhesion and inferior composite strength qualities [43]. It is demonstrated in the SEM image in Figure 6(c).

5. Conclusion

The flax and graphene-based epoxy natural nanocomposites were successfully fabricated through the compression moulding method and the mechanical belongings like flexural, tensile, and impact properties were found. The following conclusion was obtained:

(i) The mechanical belongings of flax and graphene-based epoxy composites were increased when the fibre weightage was increased by up to15 wt.%. It shows the highest tensile strength of 32.89 MPa, 36.93 MPa of flexural strength, and 28.57 kg/m^2 of impact strength.

(ii) Compared to 15 mm and 45 mm, the 30 mm fibre length shows the highest mechanical properties (33.86 MPa of tensile, 37.69 MPa of flexural, and 26.58 Kg/m^2 of impact). Because 30 mm of flax fibre is distributed evenly to the epoxy matrix, it reduced the formation of voids in the composite materials.

(iii) Compared to 2.5 wt.% and 7.5 wt.%, the 5 wt.% of graphene revealed improved mechanical strength; this is because the effects of voids are balanced by the incidence of controlled filler additions (36.59 MPa of tensile, 40.25 MPa of flexural, and 31.68 Kg/m^2 of impact)

(iv) The morphological analysis of flax-based composites reveals that poor adhesion is the main reason for lowering the mechanical properties.

Data Availability

The data used to support the findings of this study are included within the article. Should further data or information be required, these are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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