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Research Article

Study on Nanomaterials Coated Natural Coir Fibers as Crack Arrestor in Cement Composite

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The process of inclusion of carbon nanotubes as fibers in cement paste has been proved to have optimistic effect as it enhances the tensile property of cement paste composite. Coir fibers have exceptional mechanical qualities and are thus employed as reinforcement in cement composites. Epoxy resin, which has a high Young's modulus, is an ideal component for bonding carbon nanotubes (CNTs) to coir fiber. This paper describes a novel kind of nanocomposite made of L-12 epoxy resin and CNTs at the nanolevel, along with coir fibers at the microlevel which operate as crack arrestors. To remove surface contaminants, coir fibers are first treated with sodium hydroxide (NaOH). Epoxy/CNTs polymer coatings were developed at varying CNTs fractions (0.05, 0.1, 0.15, and 0.2 wt.% of cement). Multiwalled CNTs were combined in distilled water, followed by epoxy resin and hardener (9 : 1 v/v) polymer in an ultrasonic sonicator for 90 min to ensure full dispersion of CNTs within the epoxy polymer. This blend is now coated on the treated clustered coir fiber (length 10 cm, 10 strands) and reinforced along the length of a cement composite beam 20 mm × 20 mm × 80 mm in size. Tensile and three-point tests were performed to evaluate the mechanical characteristics of the hybrid composite. The linear elastic finite element analysis is employed to distinguish their failure phenomena via fatigue or fracture behavior. The microstructure behavior and the effect of coating material on the coir fibers were investigated using scanning electron microscope and EDX analysis. The reinforcing impact of nanopolymer coated coir fiber in cement composite diminished the tensile and flexural strength after 0.1 wt.% of CNT fraction but increased the composite's durability and Young's modulus. Fourier transform infrared spectroscopy analysis was carried out to assess the chemical interaction between the epoxy/CNTs and the coir fibers. The simulation was performed using ANSYS workbench, and the modeling results were within an acceptable 10% range of the experimental data. Nevertheless, it can be concluded that the hybrid composite is capable of enhancing the composite's stress and strain capacity by regulating the fracture propagation process at the crack's end.

1. Introduction

Development of polymer-based cement composites using different fibers at the nanoscale and combination of both micro- and nano-scales has opened a new field of research for engineering applications. In a broad view, cementitious materials are very brittle in nature and pervaded by inadequate strain and tensile strength. This inadequate tensile strength integrated with brittle behavior accompanies instantaneous collapse of structures without any warning. Consequently, tensile strength and ductility of cement-based substances are imparted through steel reinforced bars. These bars must be meticulously affixed in the tension zones to enhance the tensile strength and ductility.

A couple of decades ago, researchers started victimization distinct macro–microfibers to regulate crack growth within the building material [1–3]. In contrast to normal reinforcing bars, these are precisely defined and placed within the tension zone. The fiber reinforced concrete is drastically transformed by increasing the strength capacity from several discrete fibers instead of couple of steel section [1]. Hence, the utilization of discrete fibers reverberates in equal stress distribution inside the matrix. Fibers perform as bridging components by clenching the cracks together and disperse the energy liberated at the crack end. As a consequence, incorporation of the fibers governs the expansion of cracks which sequentially leads to augmentation in pre- and post-peak mechanical performance. Many articles have focused on conductive concrete with various nanomaterials such as nanographite–cupric nickel sulfate ore [4], performance of hospital waste ash modified asphalt mixtures [5], an unique form of styrene–butadiene–styrene was used as a modifier for a low viscosity asphalt binder G80/100 (PG 58-22) [6], natural aggregates and ferro slag as alternative replacements for traditional aggregates have gained attention as a sustainable alternative [6], sisal fibers considered as reinforcement in concrete matrices subjected for alkali treatment with NaOH solutions [7] and influence of water content on the strength characteristics, and brittle–plastic failure process of Xiashu loess [8] were some of works carried out.

Carbon nanotube (CNT) robustness mechanisms are predominantly based upon fiber bridging (fiber pull-out and fracture). Because of their efficient surface area, CNTs can enhance interfacial adhesion when used as traditional fiber reinforcements [9]. Epoxy resins are particularly adopted among the cluster of the polymers accessible for high-performance cement composites applications because of their satisfactory mechanical performance, process potentiality and compatibility with majority of the fibers, chemical and wear resistance, economical, and easily curable at laboratory scale [10, 11]. Coir fiber is considerably higher than most other natural fibers because of its hard-wearing quality and sturdiness. Coir fibers are ductile and energy absorbent and have a high tensile strength [12]. Study of failure mechanism is another aspect of new age composites, and there are several methods established such as pull-off test [13] was performed to explore the aging effect on different failure mechanisms (cohesion and adhesion), and the indirect tensile stiffness modulus test was conducted to study the asphalt mixture's performance against moisture damage.

In comparison with conventional microfibers, inclusion of CNTs as fibers into cement matrix is quite taxing [14–16]. One of the foremost challenges of CNTs is its proper dispersal in cement matrix. It gets tougher due to their increased hydrophobicity and high van der Waals forces which causes the CNTs to be more prone to agglomeration (bundling). CNTs must be efficiently and effectively infused in cement matrix by thoroughly isolating the discrete fibers and evenly distributing in the matrix [17]. Several analysis investigations were according within the literature with relevance use of various natural fibers in cement primarily based systems with various reinforcements in small, nano, and combination of micro–nanofillers to develop cement-based composites [18–22]. However, coating the reinforcement with multi-walled carbon nanotubes (MWCNTs) (nano) on natural fiber (micro) in cement-based matrix for structural applications has been less investigated. Crack arrestors by using coir fiber have been scantily reported in the literature survey [23, 24]. The significance of work is to introduce coir fiber as a crack arrestor and study the before and after effects of the same via simulation study using ANSYS workbench and correlate it with experimental work to realize the error percentage. Further, the work validated for convergence of simulation with alternative options such as H-type and P-type methods by altering the element size and element order, respectively. As it is mandatory to verify the feasibility of coir in concrete mix as crack arrestor, and further micro characterization study was carried out to realize the importance of fracture analysis based on the intergranular and trans granular grain boundary study. Coir is abundantly available in every part of globe, and it does not require much cost for harvesting or after harvesting process. As per the properties of coir, it acts like a natural crack arrestor. It has unique properties such as holding the material together with the coir filament leading to less scope of air pocket developments. The other aspect of coir is that it is cost effective and easily degradable.

The topic "Study on MWCNTs coated natural coir fiber as crack arrestor in cement composite" is significant as it addresses the need for durable and strong cement composites that can resist cracks and increase the lifespan of construction materials. The study explores the use of MWCNTs to coat natural coir fibers, which are then used as an additive in cement composites for crack arrestment. The real-world applications of this study are immense, as cement composites are widely used in construction materials, such as bridges, buildings, and roads. The addition of MWCNTs coated natural coir fiber as crack arrestors in cement composites can provide superior mechanical properties, increase durability, and longevity of the material. The use of this composite material can lead to reduced maintenance costs and improved safety of structures.

The paper's contribution is significant as it presents a novel method to improve the properties of cement composites. It highlights the potential of using natural fibers as a sustainable and economical alternative to synthetic fibers. The use of MWCNTs enhances the cohesion between the fibers and cement matrix, resulting in improved strength and durability of the material. This study also opens avenues for further research and development in the field of composite materials. It provides a new approach to utilize natural fibers in combination with nanotechnology to develop high-performance materials. In conclusion, the study on MWCNTs coated natural coir fiber as a crack arrestor in cement composite has significant implications for the construction industry. The development of high-performance sustainable composite materials can lead to reduced maintenance costs, improved safety of structures, and longevity of construction materials. The contributions of paper to the industry are essential,

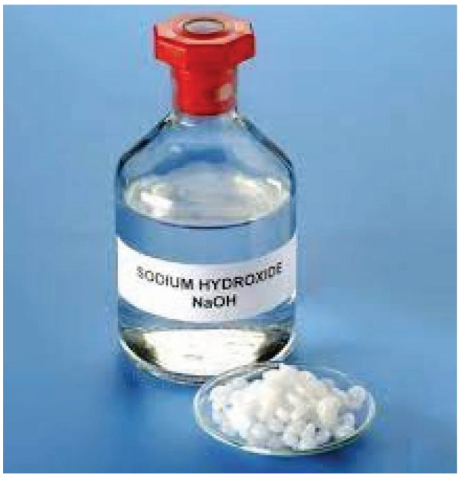


FIGURE 1: Sodium hydroxide.

as they demonstrate a new approach to enhance the properties of cement composites, which can benefit the construction industry and society as a whole in the long run.

The essential point of this task is to direct exploratory examination for upgrade of properties of concrete glue by fortifying it with epoxy and MWCNT's surface coated coconut coir fibers and study the mechanical performance of cement beam bolstered with the nano coated material on natural coir fibers so that they are aligned along the length of the fiber. As the coir fibers are coated with epoxy resin, which forms as a film on discrete fibers and hence there is improved degree of activation and a good wetting on the surface of the fibers. Development of epoxy resin-MWCNT's surface coated coconut coir fibers composite leads to invention of low cost, high strength, lightweight, and eco-friendly materials.

2. Experimental Investigation

2.1. Materials. The materials used were sodium hydroxide (NaOH), epoxy resin (L-12) and hardener (K-6), MWCNTs (functionalized and unfunctionalized), and coir fibers and cement (Ultratech 43 grade).

2.1.1. Sodium Hydroxide. Spectrum Reagents and Chemicals Pvt. Ltd. used as a surface treatment of coir fibers, as shown in Figure 1. In total, 5% of NaOH at room temperature kept for 72 hr had the highest shear strength.

2.1.2. Epoxy Resin and Hardener. Atul Ltd. is particularly used since it has distinctive nature of exceptional bonding to fibers, apart from which the modified samples provide better mechanical and electrical properties at elevated temperatures, and they are dimensionally steady for all chemical reactions. The details of each have been depicted in Figure 2. Table 1 illustrates the epoxy resin and hardener.

2.1.3. Multiwalled Carbon Nanotubes. MWCNTs were used as a coating material. In Figure 3, it can be inferred that MWCNT's usage and dispersion method are shown along with magnetic stirrer. Properties of MWCNTs as per suppliers (United Biotech, Bangalore) specifications are displayed in Table 2.

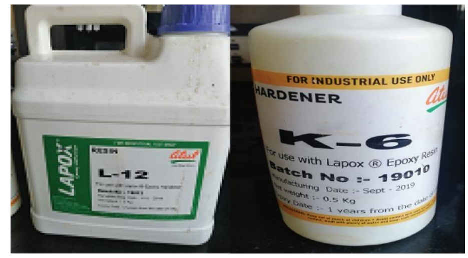


FIGURE 2: Epoxy resin and hardener.

TABLE 1: Properties of epoxy resin as per supplier (Atul Ltd.) specifications.

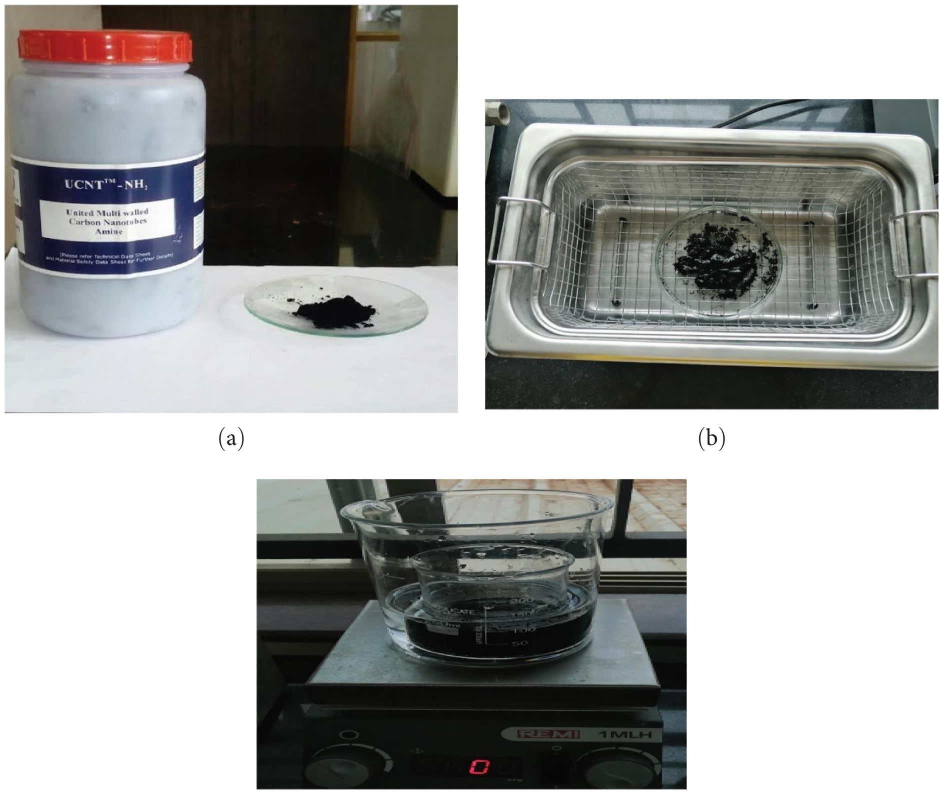
Character property	Inferences
Product type	Epoxy resin and hardener
Model no.	L-12 and K-6
SNS part number	31200000LPX0002
Brand	Lapox
Curing time (minimum)	15–30 min at 100°C
Pot life	1/2 to 1 hr at 20°C
Viscosity	9,000–12,000 m Pa.s. at 25°C
Temperature (°C)	100°C
Shear strength	1.4 kg mm/min

2.1.4. Coir Fibers. Locally available coir fiber of length 10 cm is clustered in a count of 10 numbers (strands). Each cluster is tied together and used as reinforcement. The natural coir fiber is shown in Figure 4 and with properties mentioned in Table 3.

2.1.5. Cement. Ordinary Portland cement, Grade 43 is utilized in this experiment. It is utilized as a building material in construction because of its effective binding qualities. Cement has a density of 1,440 kg/m^3. The details are discussed in Table 4. The cement is tested as per IS: 4031, and the properties are listed in the table.

2.2. Methodology. Coir fibers of 10 cm long are treated by washing with 5% of NaOH and kept in the solution for 72 hr and then washed again with distilled water and dried. Surface treated coir fibers are clustered together in a count of 10 numbers, and epoxy (9 : 1) and MWCNTs (0.05%, 0.1%, 0.15%, and 0.2%) are used as coating material. This coating material (epoxy/CNT) is applied on clustered coir fiber with hand lay-up technique. The coated coir fibers are now elevated to a temperature of 200°C for 5 hr to eliminate any contaminants. Tensile test was carried out on the clustered coated coir fiber.

Molds of size 20 mm × 20 mm × 80 mm are greased. Clustered coated coir fibers are laid at the bottom of the mold as reinforcement (like steel in RCC). Cement paste is filled in the mold, vibrated, and demolded after 24 hr and cured for 28 days. Three-point test was carried out for the cement beam reinforced with coated coir fibers. This work emphasizes the use of surfactant (NaOH) on coir fibers to



(a) (b)

(c)

Figure 3: (a) MWCNTs used as coating material, (b) dispersion of MWCNTs, and (c) epoxy and MWCNTs in magnetic stirrer.

Table 2: Properties of MWCNTs as per supplier (United Biotech, Bangalore) specifications.

Material	Multiwalled carbon nanotubes (MWCNTs)
Diameter	10–30 nm
Length	1–2 microns
Purity	>95% (MWCNT)
Special surface area	>350 m^2/g
Bulk density	0.05–0.17 g/cm^3

Figure 4: Coir fibers.

Table 3: Properties of coir fibers [18].

Density	1,200 kg/m^3
Cellulose	32–43%
Hemicellulose	0.15–0.2%
Pectin	3–4%
Lignin	41–45%
Ash	2%

Table 4: Properties of cement.

Density	1,440 kg/m^3
Grade	43 grades
Color	Dark gray
Specific gravity	2.7
Specific area	3,250 cm^2/g

increase its mechanical properties. The idea of using clustered coated coir fiber as reinforcement in cement was to align the CNTs along the length of the beam in order to escalate the strength of the coir fiber.

The decision to use epoxy (9 : 1) and MWCNTs (0.05, 0.1, 0.15, and 0.2 wt.%) as coating materials in the study on MWCNTs coated natural coir fiber as crack arrestor in cement composite was likely based on previous research and a trial-and-error approach. The specific concentrations of MWCNTs (0.05, 0.1, 0.15, and 0.2 wt.%) were likely chosen based on previous studies that found these concentrations to be effective in improving the properties of similar composite materials. The concentrations of 0.03% can still be used. But values of 0.3 wt.% or 3 wt.% cannot be used because as these concentrations increase the load-carrying capacity

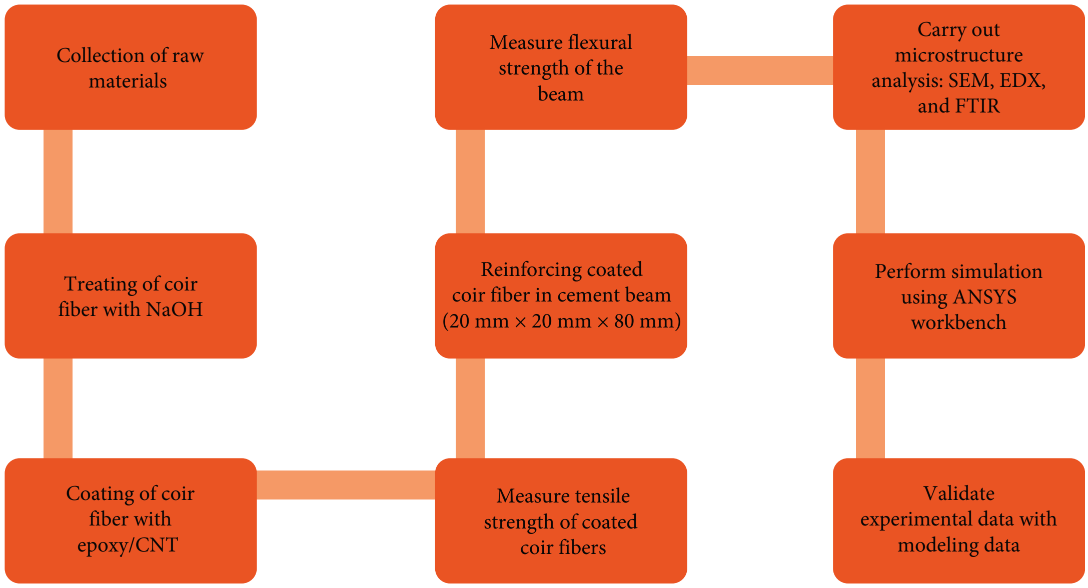


Figure 5: Flowchart of methodology.

and strength decreases due to the fact that more the concentration of MWCNTs, more will be the agglomeration, and hence their full strength will not be utilized thus adversely affecting the properties of the cement composite.

The use of epoxy resin in a proportion 9 : 1 (epoxy to hardener) is a common practice in composite material manufacturing. The reason for this is that the 9 : 1 ratio provides a good balance between curing time, mechanical properties, and cost-effectiveness. In this study, the researchers used the 9 : 1 ratio of epoxy resin to hardener to ensure the proper curing of the epoxy matrix and to improve its adhesion to the natural coir fibers and the MWCNTs.

Figure 5 depicts the entire methodology of experimental, simulation, and analytical works carried out mentioned in the process map form. Further, Figure 6 illustrates the specimen dimensions along with coir.

2.3. Testing

2.3.1. Tensile Test of the Specimen. ASTM A370 specimen characteristics were used for tensile testing. Tensile strength was measured on coated and uncoated coir fibers, as well as twisted steel fibers of length 10 cm. The machine was tested using a load cell frame with a strain rate of 0.125 mm/min and a capacity of 10 kN. The test setup is shown in Figure 7.

2.3.2. Three-Point Test of the Specimen. The flexural characteristics of epoxy–MWCNT-coated coir fiber composite materials were estimated using a single-point load. The machine was tested using a load cell frame with a strain rate of 0.125 mm/min and a capacity of 10 kN. Deflections were recorded at regular intervals of load, and load-deflection graphs were generated for each sample. The loading equipment as per ASTM requirements is depicted in Figure 8. Based on three-point loading test results, the optimal proportion of coated coir fiber with epoxy and MWCNTs as reinforcement in beams was calculated. As a result, the flexural behavior of coated reinforced beams was studied.

2.4. Mechanical Strength and Characterization Study

2.4.1. SEM Study. Scanning electron microscope (SEM), JSM-IT300 instrument from JEOL, Japan, is considered from Polymer Science and Technology Department in Sri Jayachamarajendra College of Engineering, Mysore. The specimens subjected to testing were three samples per study for SEM.

2.4.2. EDX Study. Energy dispersive X-ray diffractometer (EDX), Proto instrument from Canada, is considered from Polymer Science and Technology Department in Sri Jayachamarajendra College of Engineering, Mysore. The specimens subjected to testing were three samples per study for EDX.

2.4.3. Mechanical Strength Study. Universal testing machine, Tinius Olsen instrument from India, is considered from Centre for Material Science in School of Mechanical Engineering from KLE Technological University.

3. Results and Discussion

The experimental work is categorized into mechanical property study and characterization study. The detailed discussion is in the following section.

3.1. Tensile Strength. There were in total eight samples tested for tensile, and each sample acronym is shown in Table 5. Further, load vs. deflection for each of the cases is depicted in Figure 9. For 80 N load, the sample yielded 0.42 mm deflection. Till 0.1% MWCNT coated coir fiber, the deflection value is 62 microns with 24.8 N but after that addition of MWCNT coated coir fiber resulted in decline of load bearing capacity.

In Table 6, it is clear that among eight samples, CF5 emerged as the highest strength attained coupon, showing

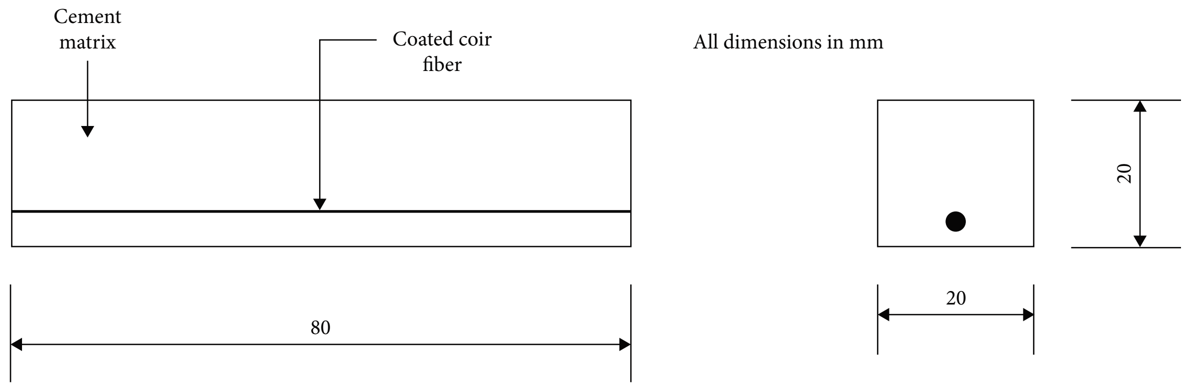


Figure 6: Specimen reinforced with epoxy/CNT coated coir fiber.

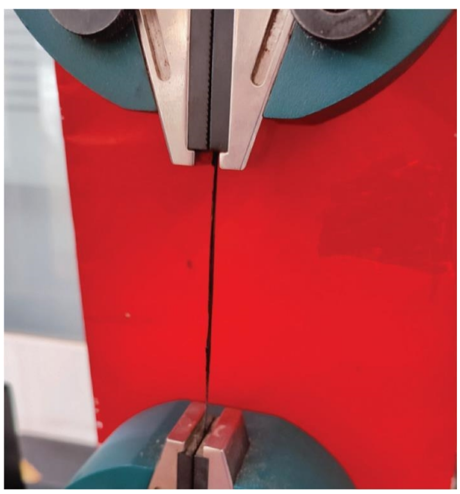


Figure 7: Tensile test of specimen.

Figure 8: Three-point test of the specimen.

deflection value of 62 μm. Sample SF8 has steel wires included in the composite showing 2,080 MPa with deflection value of 0.42 mm. The inclusion of 0.1% MWCNT has shown optimal outcomes with CF5 sample as highest value after SF8, the reason for highest strength is due to the addition of brittleness in the form of CNTs. The data are quite comparable with earlier literatures and having good agreement with observed outcomes.

3.2. Flexural Strength. Table 7 shows the three-point bending test samples. In Table 8 and Figure 10, it can be understood that under flexural strength test results show better compatibility for sample D with load of 1,021 N deflection of 0.47 mm with stress value of 30.63 MPa. For ease of understanding, Figure 10 has been included with pictorial representation.

Figure 11 infers that stress versus strain curve for sample D is far better than pristine form of sample (PC). The reason it has got higher strain rate and shows low stress before yielding gives an impression that pristine form transforming from brittle material behavior to ductile material behavior. Higher strain rate of 0.06 shows better proof stress value in comparison to pristine form composite.

4. Microstructural Analysis

Physical characterization is one such information required in detail for samples characteristic realization. Out of the eight samples denoted as “CF and SF,” among them, cement mix composites with 0.1 wt.% (CF5) inclusion were subjected to microstructural study and revealed that uniform agglomeration of MWCNT on coir fiber. Figure 12(a) shows the area where the MWCNTs and the coir fiber have bonded, and Figure 12(b) shows the microcracks that were found in the area where the epoxy and MWCNTs had been separated from the surface of coir fiber. Figures 12(c) and 12(d) show that despite using epoxy–MWCNTs coated coir fiber clustered along the length, there was a good reaction and hydration product viz., C–S–H gel was formed. This proves the fact that the strength of the composite increases [25–29]. Because of this, air pockets formed in the vicinity of the bond between the coated coir fibers and the cement paste. Because cement always shrank in volume during curing, it continued to adhere even after 28 days.

In Figure 12(a)–12(d), the FESEM images show an enlarged sketch of the internal formation of the CF5 and cement composites. Using the linear intercept method and the formula [8], the grain size can be determined. Even though CF5 is hydrophobic as a parent material, it degraded after being combined with cement and coir fiber, cast, and allowed to cure for 28 days (as depicted in Figure 12(e)–12(h)). The bead-like structure is shown in Figures 12(f) and 12(g). The lengths of these flakes are not uniform, showing peaks and valleys, which leaves more room for the penetration of water and air particles, leading to early degradation of the member. MWCNT’s and epoxy [30, 31]

Table 5: Tensile test samples.

Sample constitution	Sample
UCF—untreated coir fiber	CF1
TCF—treated coir fiber	CF2
ECCF—epoxy coated coir fiber	CF3
EC_CF_CNT—epoxy and 0.05% MWCNT coated coir fiber clustered	CF4
EC_CF_CNT—epoxy and 0.1% MWCNT coated coir fiber clustered	CF5
EC_CF_CNT—epoxy and 0.15% MWCNT coated coir fiber clustered	CF6
EC_CF_CNT—epoxy and 0.2% MWCNT coated coir fiber clustered	CF7
TSF—twisted steel fibers	SF8

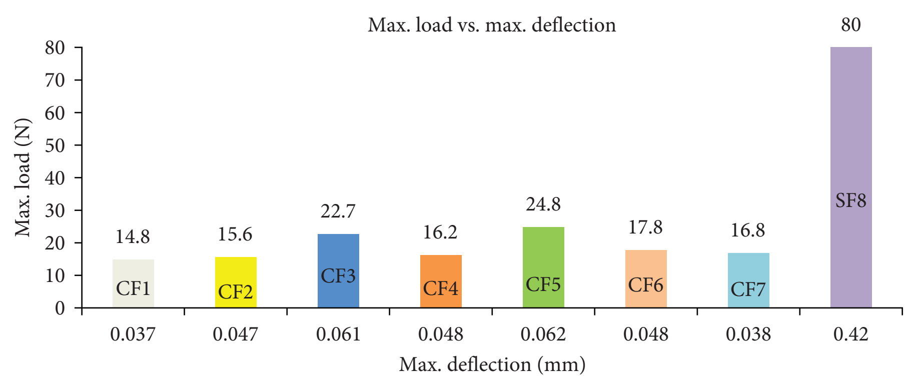


Figure 9: Tensile test results of the specimen.

Table 6: Tensile test results.

Sample	Ultimate load (N)	Ultimate strength (N/mm^2)	Deflection (mm)
CF1	14.8	29.6	0.037
CF2	15.6	31.2	0.047
CF3	22.7	45.4	0.061
CF4	16.2	32.4	0.048
CF5	24.8	49.6	0.062
CF6	17.8	35.6	0.048
CF7	16.8	33.6	0.038
SF8	80	40	0.42

Table 7: Three-point bending test samples.

Sample constitution	Sample
PC—plain cement	PC
PC_E—(PC + epoxy)	A
PC_E_0.1CNT—(PC + epoxy + 0.1 CNT_C)	B
PC_CF—(PC + coir fiber)	C
PC_ SF—(PC + steel wire)	D

in the composites showed higher load-carrying capacity and higher deflection and this could be due to the reinforcement offered by the filler materials at both micro and nano levels. The grain size is computed by the linear intercept method using the equation [8] for the composite specimen.

The ITZ between cement paste and MWCNT is depicted in Figure 12(h). Even from the SEM's Back Scattered Image, the ITZ can be retrieved [9]. In this case, the only goal was to pinpoint the ITZ in SEM photos. Since pristine MWCNT samples do not break easily, transgranular failure behavior must begin at the nanotubes' periphery. The debonding region must have improved, as a result. Figure 12(h) interprets the inflation of cracks, which originated in Figure 12(e), where stresses provoked at the intermediate part due to continuous loading led to microcrack commencement at the grain boundary zones. As a result of this behavior, brittle fracture occurred, and scanning electron microscopy images revealed numerous weak zones. Large pockets and fiber channels were noticeable as a result of debonding. Everywhere you looked, pullouts could be seen [19, 20].

4.1. Energy Dispersive X-Ray Spectroscopy (EDX). EDX analyses were done to verify the elemental composition of the composite specimen of nanopolymer-based composite that may alter the mechanical properties of the polymer

Table 8: Three-point bending test results.

Sample	Load (N)	Deflection (mm)	Flexural stress (N/mm²)
PC	1,415	0.12	42.88
A	945	0.23	28.35
B	835	0.17	28.35
C	781	0.11	23.42
D	1,021	0.47	30.63

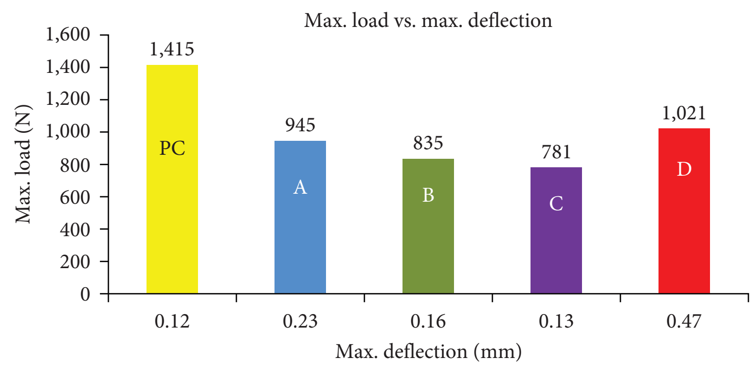


Figure 10: Maximum load vs. maximum deflection.

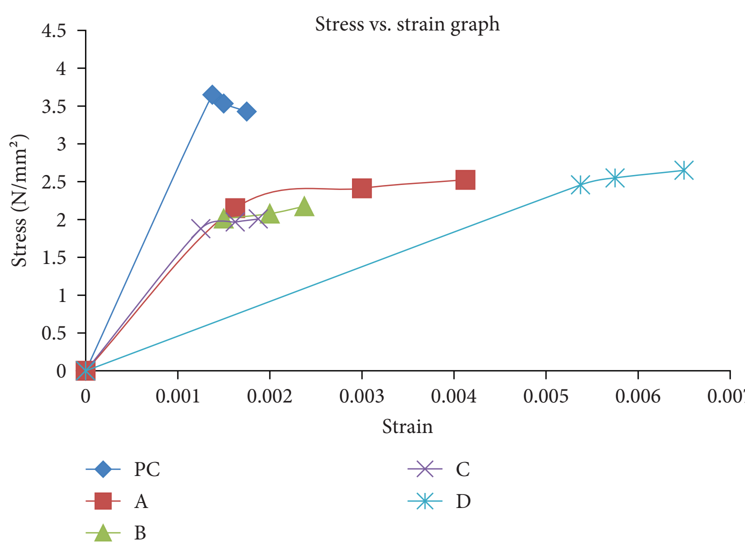


Figure 11: Stress and strain curve.

composites under study. The elemental composition of the specimen can be measured and studied with EDS. For more comprehensive line profiles or critical distribution maps, the EDX system can also be used to operate the SEM scanning system. The cement composite samples used in the FESEM and EDS analyses here were allowed to cure for 28 days. The levels of coatings on coir fiber varied from 0.05% to 2% in increments of 0.05%. Subsequently, curing for 28 days, the bonded area between MWCNTs coated coir fiber, and the cement matrix has been the focus of microscopy observations on the fractured and flat surfaces of paste samples [6]. Figure 13 demonstrates different elements present in nano coated CF composite. Table 9 displays the elemental analysis of a sample, which includes compounds and elements like $CaCO_3$, MgO, SiO_2, Al_2O_3, FeS_2, albite (Na), wollastonite (Ca), SiO_2, Mn, KCl, Ti, and Fe. Each element's atomic structure has its own distinct pattern of peaks. Table 9 shows that Ca is more prevalent at higher altitudes. Possible explanation: SiO_2 particles speed up the formation of C–S–H gels. There are also hints of Si and O peaks [32–35]. MWCNTs' inert behavior with cement matrix causes the amounts of Fe, Al_2O_3, MAD-10 Feldspar, and FeS_2 to decrease proportionally as the percentage of coating rises. The EDX spectrum shows a small sulfur peak, suggesting the tiny crystals could be calcium sulfoaluminate [7]. Table 9 shows that

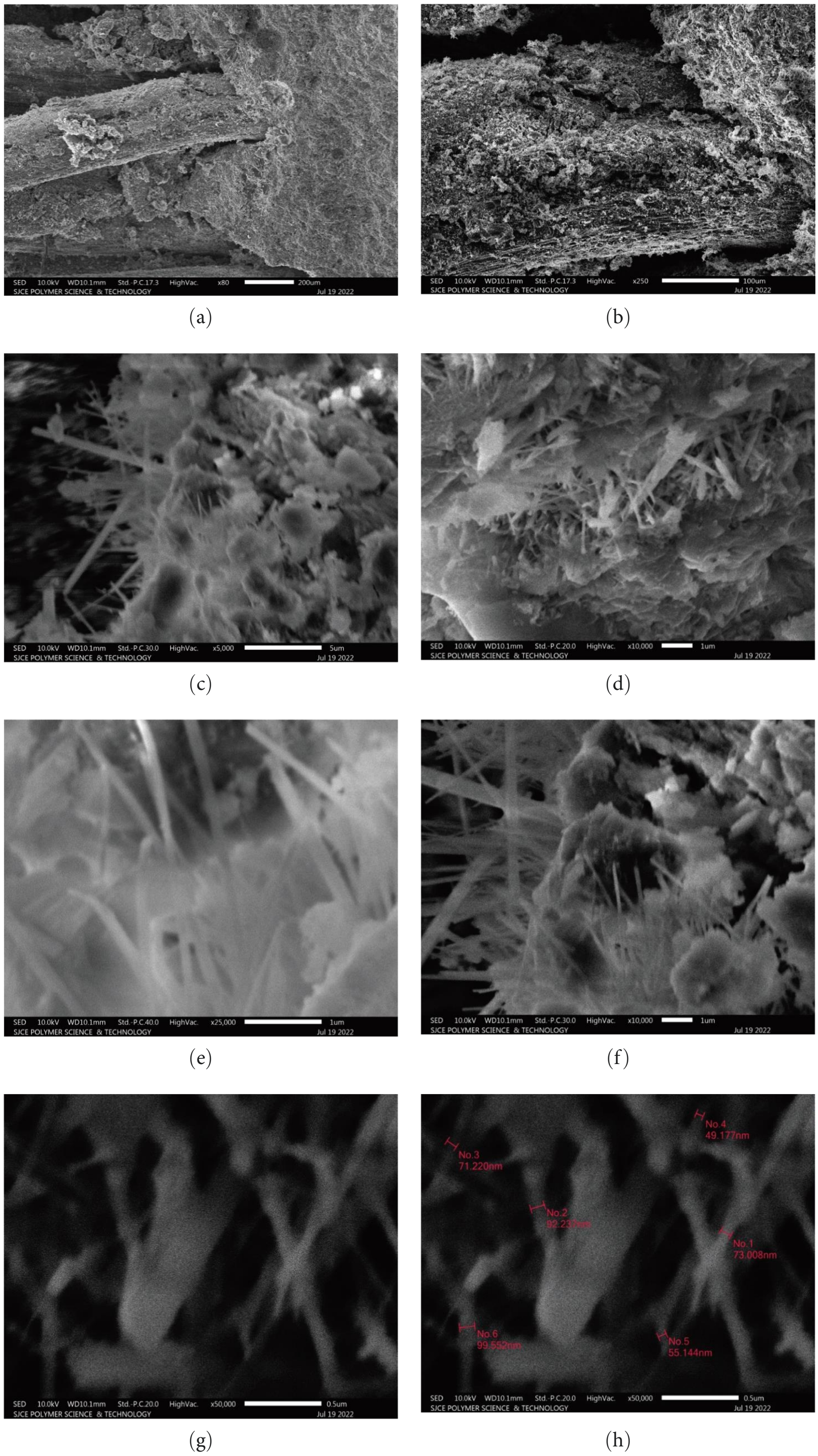


Figure 12: (a–h) SEM image extraction.

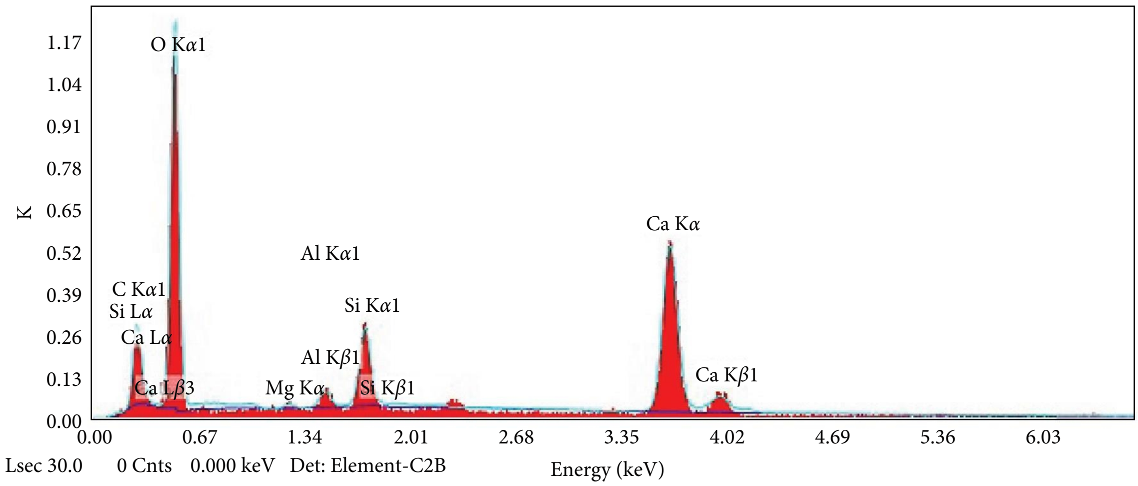


Figure 13: Different elements present in nano coated CF composite. Lsec, live time in seconds.

Table 9: EDX elemental composition.

Element	Weight (%)	Atom (%)	Net int.	Wt.% error	K ratio
CK	3.55	6.95	39.02	11.42	0.0214
OK	39.32	57.80	267.23	10.56	0.1211
MgK	0.24	0.23	3.31	70.08	0.0018
AlK	1.08	0.94	15.28	16.82	0.0087
SiK	5.29	4.43	76.47	7.26	0.0468
CaK	50.52	29.66	218.97	5.12	0.4599
Total	100.00	100.00			

the calcium carbonate and silica content, as well as the amount of wollastonite (CaK), increased dramatically as the percentage of inclusion of MWCNTs increased from 0.05% to 2% in steps of 0.05% [34, 36].

The metallic traces present in the composite fillers are shown in Table 9. The existence of components such as traces of oxygen, carbon, silica, and calcium are identified as main elements in cement composites. Hence, it becomes obvious that the sample contains silica, calcium, alumina, and oxides [37].

4.2. Fourier Transform Infrared Spectroscopy (FTIR). In Figure 14, it can be understood that three samples such as coated coir, plain coir, and cemented coir were subjected for Fourier transform infrared spectroscopy (FTIR) study. The investigation of functional clusters, like MWCNT inclusion at varying weight percentages, is dealt with via FTIR spectroscopy in all circumstances. Any chemical alterations taking place in the area of bonding and the effect of coated MWCNT on coir fiber reinforced with cement composite have a favorable effect. Figure 14 implies that a large peak of 3,316 cm^{-1} was seen indicating a hydroxyl group, with a pure sample tested that included less lignin and hemicellulose than plain coir fiber. Plain coir fiber showed 3,350.55 cm^{-1} as peak value. When treated 2,884 cm^{-1}, the result is seen in comparison to plain cement powder [38]. Further, the characteristics were compared with MWCNT percentage variations [38]. However, all three

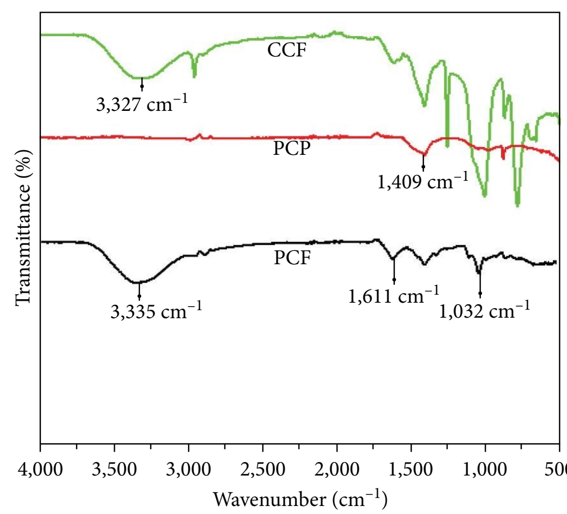


Figure 14: FTIR outcomes of coated coir fiber (CCF), plain cement powder (PCP), and plain coir fiber (PCF).

samples—aside from MWCNTs—had wavelengths that were roughly comparable to those of the pristine form model, with the exception of MWCNTs, which had a different peak intensity for the C = O and CO stretching [39–42].

5. Simulation

Wang et al. [43] modeling is commonly used to create finite element (FE) models for MWCNTs. This model depicts the component tubes of MWCNTs using solid parts. The solid element (SOLID187) was used with the midside node retained condition to improve precision, indicating the second-order element [44–47].

5.1. Material Properties. Table 10 describes the properties of the materials used in the experiments. These parameters are fed into ANSYS Workbench, which generates the various boundary conditions and their outcomes. The figures depict the specimen's geometric modeling.

Table 10: Mechanical properties details.

S. no.	Description	Density (kg/m^3)	Youngs modulus (MPa)	Poisson's ratio
1	MWCNT	2,600	4,800	0.3
2	Hardener	1,280	2,250	0.3
3	Epoxy resin	1,162	30,790	0.35–0.5
4	Coir	1,200	5,000	—

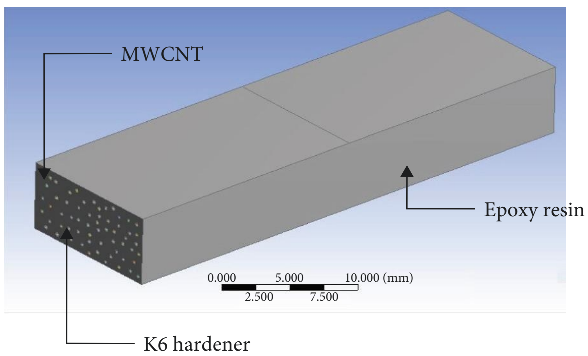


Figure 15: Geometrical modeling of 20 mm × 20 mm × 80 mm size specimen.

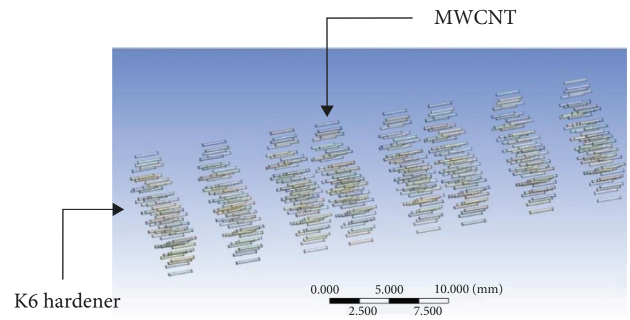


Figure 16: Arrangement of MWCNT in uniformly aligned condition.

In the process of modeling the specimen, careful consideration is given to achieving a homogeneous distribution and alignment of MWCNTs within the epoxy resin. The assumption is made that both MWCNTs and the hardener exhibit uniform distribution throughout the matrix. Various techniques are employed to determine the inclination of MWCNTs with respect to the abscissa. Figure 15 illustrates a specimen with dimensions of 80 mm × 20 mm × 20 mm, wherein MWCNTs of 0.3 nm diameter and 5 mm length are generated using ANSYS Design Modeler [48]. During the alignment of MWCNTs, a uniform direction with dispersion conditions is considered, as depicted in Figure 16, showing a unidirectional pattern of MWCNTs of consistent size. Solid modeling is utilized to examine the directional orientation of MWCNTs, considering the distinct mechanical properties of K6 hardener and L-12 in terms of density, Young's modulus, and Poisson's ratio. To accurately represent the interaction, K6 and epoxy resin are modeled separately, with a bonded contact assumption to ensure cohesive behavior [49]. Figure 16 illustrates the arrangement of CNTs alongside the hardener. This approach in the ANSYS Workbench analysis successfully replicates the observed behavior in the experimental analysis. Treating K6 as a distinct entity in the polymer matrix design enhances sensitivity and realism in the results, acknowledging its independence within the studied polymers [50–53].

5.2. Contact Generation. The "Bonded" contact behavior is implemented to establish interfacial adhesion between the epoxy resin and MWCNTs. This implies that the two entities remain in constant contact, akin to a welding scenario. As illustrated in Figure 17, the bonding behavior is represented by assigning a bonded contact, wherein the MWCNT is given a "contact surface," and the epoxy resin is assigned a "target surface." The default contact formulation, termed "program controlled," utilizes the penalty method in finite element analysis (FEA) [54–57]. The contact between MWCNT and epoxy resin is deemed bonded because both are treated as independent entities in geometrical modeling, interconnected through a pure penalty contact mechanism. The pure penalty technique is preferred over augmented Lagrange and normal Lagrange methods as it ensures that the contact surface (MWCNT) does not penetrate the target surface (epoxy resin).

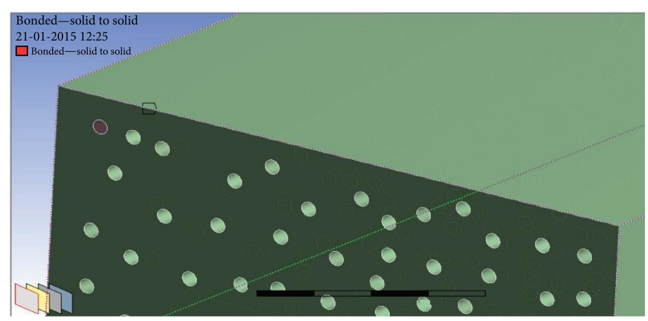


Figure 17: Bonded contact assigned between the epoxy resin and MWCNT.

Table 11: Mesh generation details along with nodes and elements.

Statistics	
Nodes	856,686
Elements	326,070

5.3. Mesh Generation. The manual mapped face meshing' approach is used for mesh creation to ensure that MWCNTs are properly meshed. Table 11 contains node and element

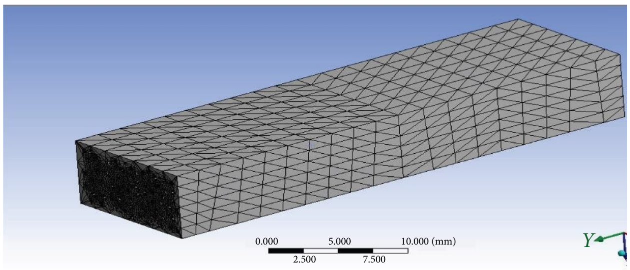


Figure 18: Mesh generation with coarse mesh.

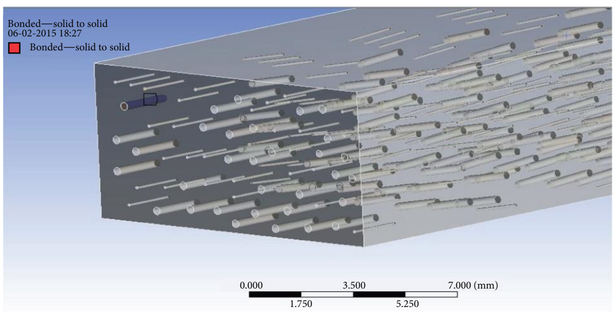


Figure 19: Bonded contact with epoxy resin and MWCNT.

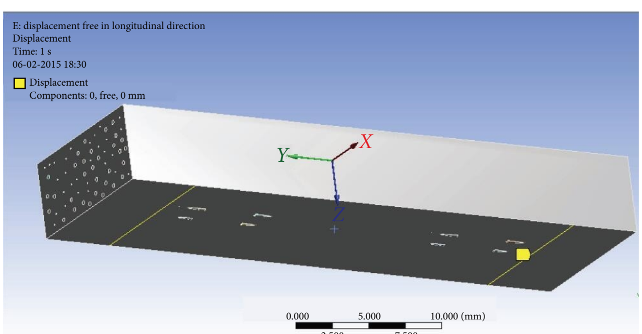


Figure 20: Two-point roller support for the specimen.

information. Meshes are created with "tetrahedron midside node retained elements" (second-order elements), as illustrated in Figure 18.

Figure 19 refers to contact generation between MWCNTs and cement particles; typically the "bonded" contact is assigned with formulation method considered as "pure penalty" because of zero penetration between contact and target surfaces. Figure 20 illustrates the displacement support free in "Y-direction" equivalent to simply supported boundary condition.

Figure 21 infers a total deformation of 0.038 mm in comparison to 0.037 mm for Sample 1 in experimentation. The observed error percentage between experimental and simulation work is 2.6. For a typical condition of composite material, the error percentage is acceptable up to 20%. In Figure 22, the von Mises stress observed is 11.73 MPa.

This section deals with clarification on the results mechanical properties such as tensile and flexural strength test, physical characterization study of Fourier transforms infrared along with simulation study results of ANSYS Workbench.

5.4. Simulation in ANSYS Workbench. This section unveils the outcomes derived from a three-point bending test, conforming to the boundary conditions specified by the ASTM D2344 standard, considering both scenarios with and without the reorientation of CNTs [58, 59]. To ensure a comprehensive analysis of trends and prevent deviation from the actual trajectory, experimental results were cross-verified using the FEA tool. The modeling outcomes demonstrated a favorable alignment with the experimental results, falling within an acceptable range of 20%.

6. Comparison Study

The work is incomplete if a comparison between the predecessor work and current has not been discussed. Table 12 infers that the total deformation observed is 2.6%, and von Mises stress is 16.36%. It can be understood that both the parameters are still well within the design acceptable criteria limit of 20% [60, 61].

The current research on "Study on epoxy and MWCNTs coated and aligned along the natural coir fiber as crack arrestor in cement composite" is focused on using natural coir fiber coated with MWCNTs and epoxy as a crack arrestor in cement composites. This study is a new approach to strengthening cement composites and preventing crack propagation, which is different from previous research. Unlike these previous studies, the current study incorporates natural coir fiber, which is a biodegradable and renewable resource, coated with MWCNTs and epoxy. This approach not only reinforces the cement composites but also enhances their durability and sustainability. The results of the study demonstrate that the addition of MWCNTs and epoxy to natural coir fiber enhances the tensile strength and provides better crack arrestment capabilities in cement composites. Overall, the current study is a unique approach to strengthening cement composites compared to previous research that has focused on aligning MWCNTs on coir fibers.

Furthermore, the epoxy resin provides excellent resistance to water, chemical, and UV degradation, enhancing the durability of the cement composite. The addition of MWCNTs helped to improve the mechanical properties of the composite as well as its crack arrest capabilities. Moreover, the alignment and coating of MWCNTs on natural coir fibers led to the formation of a network structure that helps in redistributing the stress and hence preventing the propagation of cracks in the composite. This phenomenon is known as crack arrest and is highly desirable for composite materials used in structural applications. One of the main benefits of using epoxy resin and MWCNTs in this study is that it can potentially lead to the development of sustainable and cost-effective crack arrestors in cement composites. This is essential in the construction industry, where durability and resilience are key factors in ensuring the safety and longevity of buildings and infrastructures.

7. Discussion on the Innovation

The topic "Study on epoxy and MWCNTs aligned and coated on natural coir fiber as crack arrestor in cement

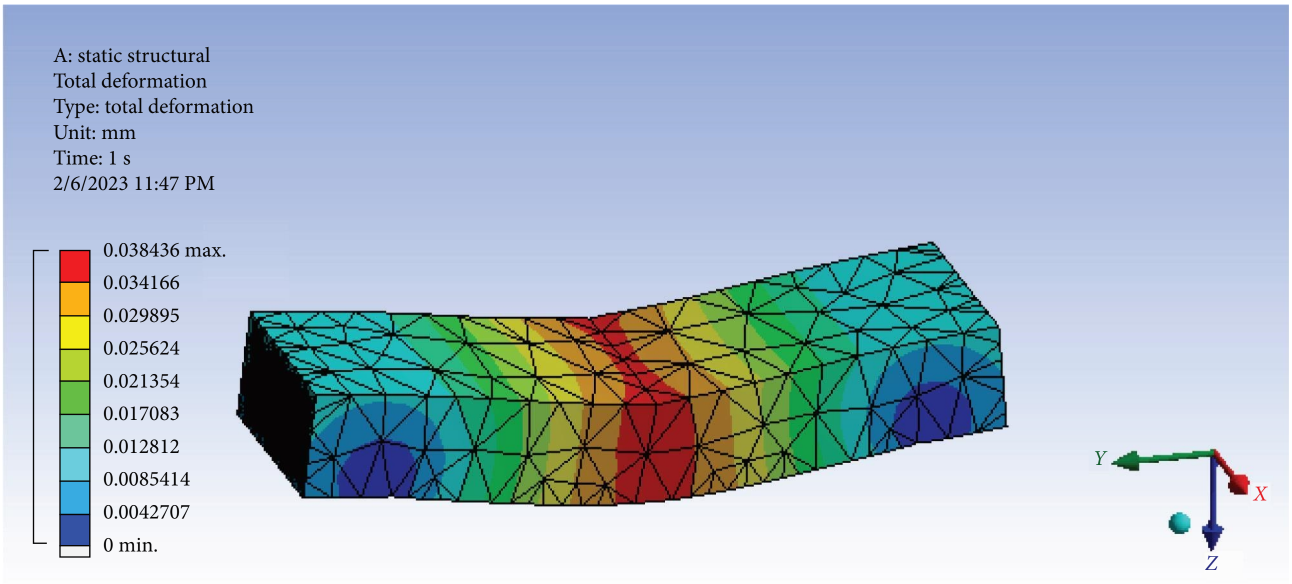


Figure 21: Total deformation.

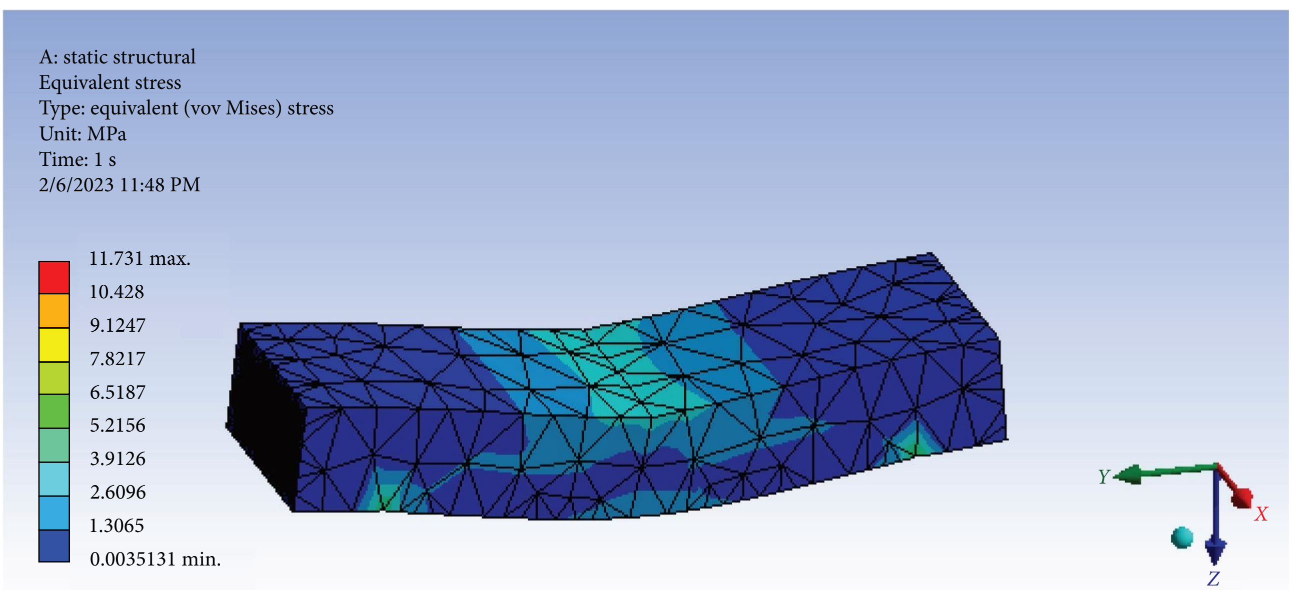


Figure 22: von Mises stress.

Table 12: Comparative study.

S. no.	Description	Experimental	Simulation	Percentage error
1.	Total deformation (in mm)	0.037	0.038	2.6
2.	von Mises stress (in MPa)	13.65	11.73	16.36

composite" is an innovative research study that aims to develop a new type of sustainable and composite material that can prevent or arrest cracks in cement composite structures. The study utilizes the combination of naturally available coir fibers, epoxy, and MWCNTs to enhance the mechanical and physical properties of the cement composite material. The micro-, macro-, and nano-scale studies enable researchers to analyze the chemical, mechanical, and physical properties of the composite material at different scales, providing comprehensive insights into its effectiveness as a crack arrestor in cement composite.

Through the innovative experiment, the focus was on optimizing the alignment and coating of the coir fibers with MWCNTs [62]. It was observed that the tensile strength, flexural strength, and energy dissipation capabilities improved significantly with the addition of the aligned and coated coir fibers in cement composite. This led to an extension in the time required to develop microcracks and an overall delay of macrocrack propagation and fracture. It also opens potential applications for the construction industry to produce more durable and longer lasting structures, reducing maintenance costs, and the environmental impact of construction waste. The research also promotes the introduction of eco-friendly and easily available materials in material engineering, highlighting the importance of sustainability in the development of composite materials.

In conclusion, the study on epoxy and MWCNTs aligned [63] and coated on natural coir fiber as crack arrestor in cement composite represents an innovative and eco-friendly solution to address the issues of cracking in composite materials and brings broader prospects for sustainable material engineering in construction.

8. Conclusion

Coupling agents improved the compatibility of polymer matrices with natural fibers. One approach for dealing with the moisture absorption qualities of coir fiber is to apply surface treatment. The NaOH treatment on coir fiber minimizes the risk of moisture and increases the chemical bonding of the fiber, resulting in better mechanical characteristics than raw fiber and a rougher fiber surface posttreatment. This improved the coir fiber's adhesion ability with the matrix in the developed composite, resulting in a high tensile strength. Up to 0.1 wt.% epoxy/CNTs coated coir fiber has increased flexural strength and deformations, but it subsequently decreases due to agglomeration of the higher CNT dosages. SEM images demonstrated a brief interaction between the nanotubes, epoxy, and C–S–H gel, strengthening the hybrid composite's Young's modulus. The chemical interaction between the epoxy/CNTs and the coir fibers was determined by FTIR measurement. The simulation was executed using ANSYS workbench, and the modeling outcomes were within 20% of the experimental data. As per the standards of design criteria for composite modeling, error percentage expected to be less than 20%. Considering eligibility criteria, the results are well within the acceptable range. Thus, a coating material on coir fibers was proficiently developed using epoxy resin and MWCNTs.

Data Availability

Data supporting this reasearch article are available on request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Supplementary Materials

Results. (*Supplementary Materials*)

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