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Research Article

An Experimental Study of the Properties of Carbon Fiber/Epoxy Composites Mixed with Rubber Granules

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In this research work, the mechanical properties of hybrid composites reinforced with woven carbon fiber mats particulated with natural rubber powders as fillers in the epoxy resin matrix were investigated. The specimens were prepared by the hand-layup process followed by a vacuum bag moulding process. The vacuum moulding reduces the voids or cavities in the hybrid composites. The natural rubber powder was added in different weight proportions (5%, 10%, 15%, and 20%), and carbon fiber is added in 20% for all the specimens. Experiments such as tension testing, flexural testing, water absorption/acid corrosion/base corrosion tests, dynamic mechanical analysis (DMA), and scanning electron microscopic (SEM) analysis were conducted to evaluate the epoxy carbon rubber (ECR) composites. The tensile and flexural test findings demonstrated that the addition of 10% natural rubber particles gave better results as compared with other proportions. The water/acid/base absorption test findings reveal that the ECR composites are not affected by water/acid/base. The DMA teat findings show that ECR composites having 10% natural rubber have higher damping factor, storage, and loss modulus. The SEM analysis shows that ECR hybrid composites with 10% rubber particles contained a uniform distribution of rubber particles over reinforcement, and also, there were no cracks and voids. According to this research findings, ECR hybrid composites with 10% natural rubber particles prepared during the vacuum bag moulding process can be used to prepare aerospace interior components.

1. Introduction

Polymer composites are used as an important engineering material from the 19^{th} century onwards. They gain attention in the defence and aerospace sector due to their high strength-to-weight ratio and tailor-made property [1]. Polymer composites possess long life and are not affected by environmental conditions [2]. Nowadays, metallic materials are replaced by polymer composites to reduce cost and time of the production process [3]. Newer reinforcements, particulates, and newer material preparation techniques have brought improvements in hybrid composites [4]. Carbon fiber reinforcements have higher strength than aramid/glass fibers and are suitable for high-temperature applications [5]. Carbon fibers possess good tribological characteristics and can be used as mechanical elements [6]. Carbon fibers in powder form are used to make autoclave unidirectional composites and have good fracture toughness [7]. Carbon fibers and carbon nanotube-reinforced epoxy composites are used to make wing turbine blades [8]. When particulates are added to composites, mechanical properties are much improved. Carbon fibers with biochar-particulated composites presented better viscoelastic behavior and improved flexural strength [9]. The addition of fillers to the hybrid composites added improved mechanical properties. Lignite fly ash was used as filler in the *Sansevieria roxburghiana* fiber-reinforced epoxy composites, and tensile, flexural, and impact strength was increased in the ratios 38.33%, 41.34%, and 33.56% [10]. SiC was used as filler material in hybrid fiber-reinforced composites, and it provided a strong effect on various properties [11]. Red mud, an industrial waste, was added with coconut sheath fiber, and this

Figure 1: (a) Mixing rubber with resin. (b) Spreading carbon fiber over the mixed resin. (c) Alternate layers of mixed resin and carbon fiber. (d) Vacuum bag moulding process.

polymer composite possesses superior flexural, tensile, and impact strength [12]. SiO_2 nanofiller was added in jute and polypropylene fiber composites and has good viscoelastic and fire characteristics [13]. Coconut shell and palm powders as fillers and Kevlar/hemp fiber-reinforced composites have superior hardness, impact, and flexural strength [14]. Liquid natural rubber with kenaf fiber-reinforced composite has better flexural and impact strength and can be used for automotive applications [15]. Epoxidised natural rubber with flax fiber-reinforced composites can act as an alternative for petroleum-based composites [16]. A vacuum bag moulding process was used to fabricate epoxy glass-reinforced carbon nanotube composites to produce defect-free components for aerospace applications [17]. Further, very few research works have been carried out in the hybrid composites with carbon fiber as reinforcement and natural rubber as particulates in the epoxy resin matrix. This research work is aimed at the experimental study of mechanical and viscoelastic properties of ECR hybrid composites comprising 10% carbon fiber and varying proportions of 5%, 10%, 15%, and 20% natural rubber in the epoxy matrix using the vacuum moulding process.

Table 1: Designation and composition of ECR hybrid composites.

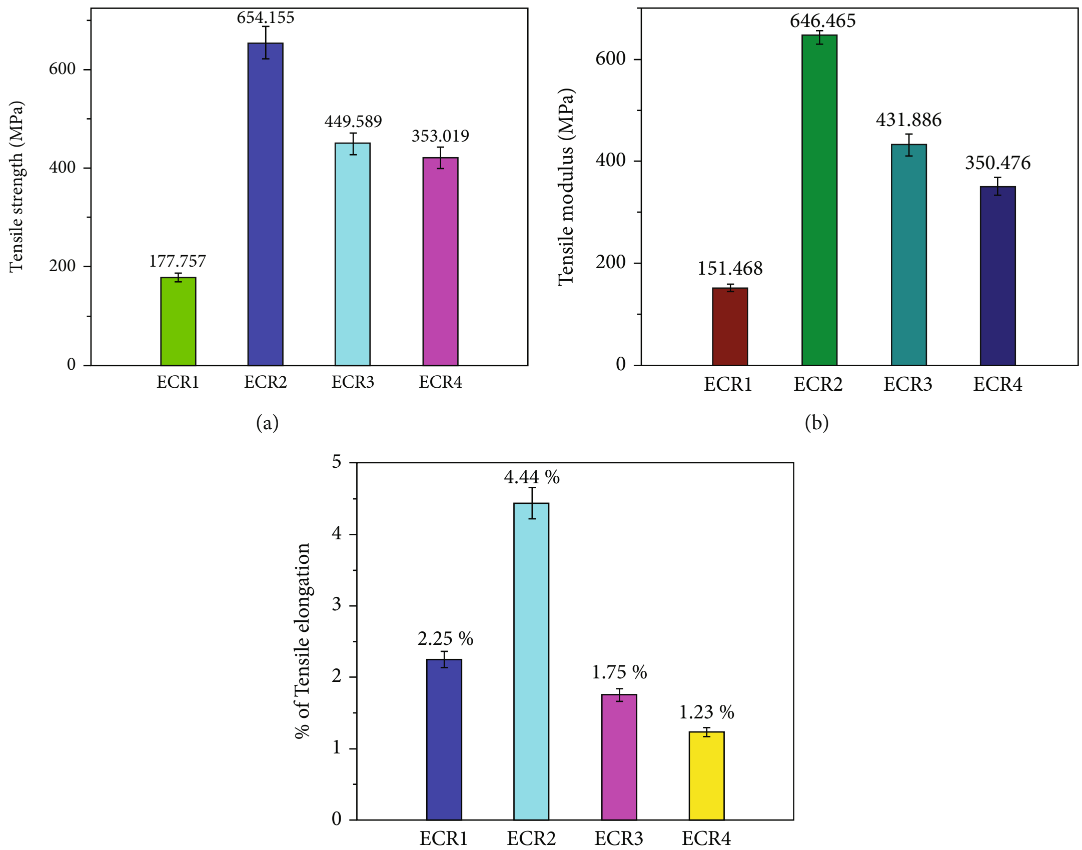
Sample	Epoxy resin (%)	Carbon fiber (%)	Natural rubber particle (%)
ECR1	75	20	5
ECR2	70	20	10
ECR3	65	20	15
ECR4	60	20	20

2. Materials

Epoxy resin of grade LY556 is used as a thermoset matrix, and a hardener of grade HY951 is used as a curative agent. Carbon woven mat fibers of 300×300 mm size, 40 grams/layer, and a density of 1.79 gm/cm^3 are used as reinforcements. Natural rubber granules of 10 μm are used as fillers to prepare ECR hybrid composites. Natural rubber has superior viscoelastic behavior and high energy absorption. The addition of natural rubber powder will add to increased tensile strength and resilience.

Table 2: Tensile test results of ECR hybrid composites.

Tensile properties	ECR1	ECR2	ECR3	ECR4	Standard deviation
Ultimate load (N)	9280.00	30360.00	30390.00	28950.00	8716.58
Tensile strength (MPa)	177.75	654.15	449.58	353.01	97.78
Tensile modulus (MPa)	151.46	646.46	431.88	350.47	113.97
Tensile elongation (%)	2.25	4.44	1.75	1.23	1.22



(c)

Figure 2: (a) Tensile strength of ECR hybrid composites. (b) Tensile modulus of ECR hybrid composites. (c) % tensile elongation of ECR hybrid composites.

3. Material Preparation

Specimens were prepared using the vacuum bag moulding process. The first step in the preparation of specimens of dimension $300 \times 300 \times 3$ mm is the mixing of epoxy resin with a hardener of grade HY951 in the ratio of 10 : 1 with varying proportions of natural rubber particles as filler material. The natural rubber granules, hardener, and epoxy resin were mechanically stirred in a bowl. The paste of resin, hardener, and rubber particulates was applied in the mould using a brush, and the woven carbon mat fibers were placed over the paste in the ratio of 4 : 1. This procedure was continued until six such layers of paste and carbon fibers were obtained to fabricate rectangular specimens of $300 \times 300 \times 3$ mm for varying weight proportions of natural rubber powder. The prepared specimens were then moved to the vacuum bag process. Air was sucked continuously with the help of a vacuum pump operating at the vacuum pressure of 650 mm of Hg. The specimens are kept in the vacuum bag process for 3 hours, and the specimens were then heated in the furnace which is at a constant temperature of 150°C for one hour. Specimens were then exposed to ambient air for 5 to 6 hours and are shown in Figures 1(a)–1(d), respectively. The designation and composition of ECR hybrid composites are given in Table 1.

4. Experimental Methods

The mechanical properties like ultimate tensile strength; tensile modulus; % tensile elongation; flexural strength; flexural modulus; reactivity towards water, acid, and base; and dynamic mechanical analysis were evaluated for the hybrid composites with different weight proportions of rubber

Table 3: Flexural strength of ECR hybrid composites.

Flexural properties	ECR1	ECR2	ECR3	ECR4	Standard deviation
Ultimate load (N)	150.00	420.00	420.00	450.00	96.04
Flexural strength (MPa)	6.08	11.77	10.28	10.21	1.51
Flexural modulus (MPa)	2.27	5.35	4.58	4.18	0.61

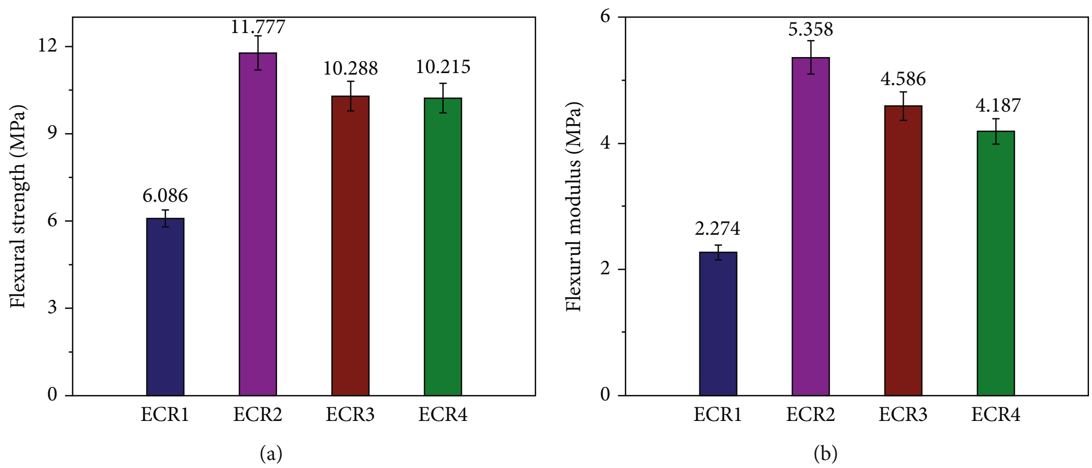


Figure 3: (a) Flexural strength of hybrid composites. (b) Flexural modulus of ECR polymer composites.

particles, and also, corrosion reactivity towards water, acid (HCL), and base (NAOH) was studied.

4.1. Tensile Test. The tensile test was conducted in a computerized universal testing machine (UTM), and the specimens for the tensile test were according to ASTM D3039 standards. The specimen for ASTM D3039 is a rectangular specimen size $250 \times 25 \times 3$ mm [18]. For each test, three samples were used. In UTM, specimens are fixed between two movable grips and a load was applied to it until it fractured. In ASTM D3039 tensile testing, the maximum load and elongation were recorded. The parameters tensile strength, tensile modulus, and % of tensile elongation ECR hybrid composites were calculated.

4.2. Flexural Strength. ASTM D-7264 standard for flexural testing of FRP composites was applied. The flexural test was conducted in UTM using a three-point bending fixture. The specimen for ASTM D-7264 flexural testing is a rectangular specimen size $250 \times 72 \times 3$ mm [19]. When the load was applied, the specimen was bent until it breaks. The material's maximum internal stress at the time of rupture is flexural strength. The deflection and load at the time of breaking of specimen were recorded. The parameters flexural modulus and flexural strength of ECR hybrid composites were calculated.

4.3. Water Absorption/Acid Corrosion/Base Corrosion Test. The water absorption test determines the % of water absorbed by ECR hybrid composites. The samples were dried up using an oven for the water absorption test. The dry (initial) weight of each sample is weighed and is submerged in distilled water for 12 hours. Samples are collected, wiped-off the surface water, and weighed. The % of water absorption is calculated using

$$\text{\%of water absorption} = \frac{\textbf{Wet weight} - \textbf{dry weight}}{\textbf{Dry weight}} \times \mathbf{100}. \quad (1)$$

The % of corrosion of an ECR hybrid composite is determined by exposing the composite to acid. The samples were dried up using an oven, and the initial (dry) weight was measured. The samples were soaked in hydrochloric acid for 12 hours. Specimens were cleaned with a lint-free cloth. Corrosion-related weight loss was calculated using

$$\text{\%of corrosion by acid} = \frac{\textbf{Dry weight} - \textbf{weight after corrosion}}{\textbf{Dry weight}} \times \mathbf{100}. \quad (2)$$

A similar procedure is followed to determine the % change in weight when it is exposed to NaOH (alkaline base) solution. Corrosion-related weight loss when it was exposed to base was calculated using

$$\text{\%of corrosion by base} = \frac{\textbf{Dry weight} - \textbf{weight after dip in base}}{\textbf{Dry weight}} \times \mathbf{100}. \quad (3)$$

4.4. Dynamic Mechanical Analysis (DMA). DMA test was conducted on the DMS 61000 Model of SII Nano Technology, Japan, and it determines the mechanical properties of composites as a function of time, frequency, and temperature. It determines the viscoelastic behavior such as loss and storage

Table 4: Water/acid/base absorption test results.

Sample	H_2O (gm)	HCl (gm)	NaOH (gm)
ECR1	4	4	4
ECR2	4	4	4
ECR3	4	4	4
ECR4	4	4	4

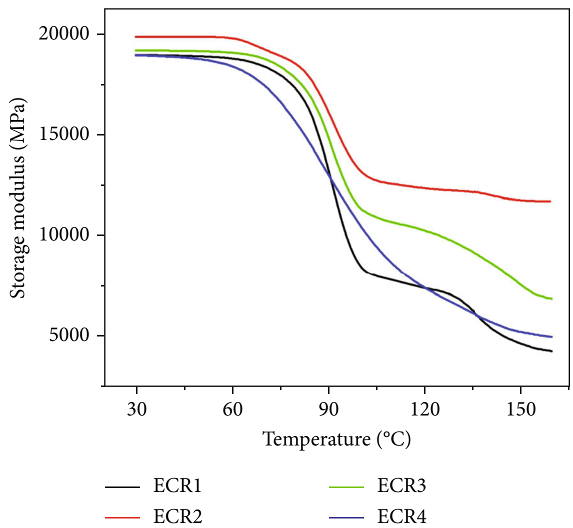


Figure 4: Variation of storage modulus with temperature of ECR composites.

modulus and damping factor of ECR hybrid composites. The specimen dimensions according to ASTM D4065 standard testing for DMA analysis are $55 \times 13.5 \times 3$ mm [20]. Experiments were conducted in a three-point bend loading system with a frequency of 1 Hz in an N_2 environment in the temperature range of 25°C to 150°C.

4.5. SEM Analysis. FEI Quanta 200 Scanning Electron Microscope (SEM) is used to investigate the microstructure of the surfaces of fractures for ECR hybrid composites. The microparticle dispersion, presence of voids and cracks, and adhesion bonding between rubber and epoxy resin can be determined by SEM images.

5. Results and Discussion

The results of tension testing, flexural testing, water absorption/acid corrosion/base corrosion tests, DMA test, and SEM analysis were presented.

5.1. Tensile Test Results. The ultimate tensile load, tensile strength, tensile modulus, and % of tensile elongation are given in Table 2. The tensile strength, tensile modulus, and % of tensile elongation of ECR hybrid composites are compared and are shown in Figures 2(a)–2(c), respectively.

From the results, the ECR2 specimen with 10% natural rubber particle addition performs better in tensile testing than other samples. The tensile test parameters of the

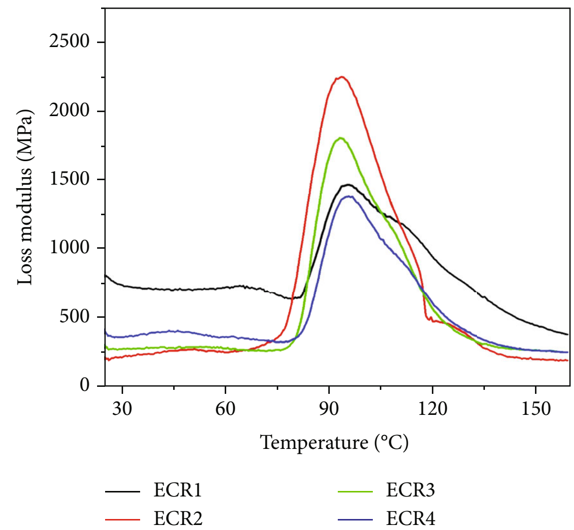


Figure 5: Variation of loss modulus with temperature of ECR composites.

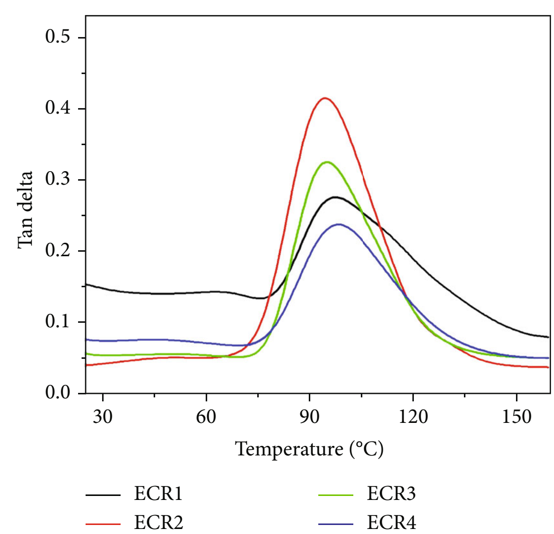


Figure 6: Variation of damping factor with temperature of ECR composites.

ECR1 specimen are less due to the less amount (5%) of natural rubber concentration. When the natural rubber concentration is 15% or 20%, rubber agglomeration and phase transposal cause the tensile strength to decline.

For the ECR2 specimen with 10% natural rubber powder addition, the amount of rubber particles causes the brittle epoxy matrices to yield under extended shear. The material fails by shear-yielding mechanisms. Also, hydrostatic tension in the rubber particles transforms the composite to a uniaxial tensile stress, and hence, increased tensile strength is obtained.

5.2. Flexural Test Results. The ultimate load, flexural strength, and flexural modulus of ECR polymer composites are presented in Table 3.

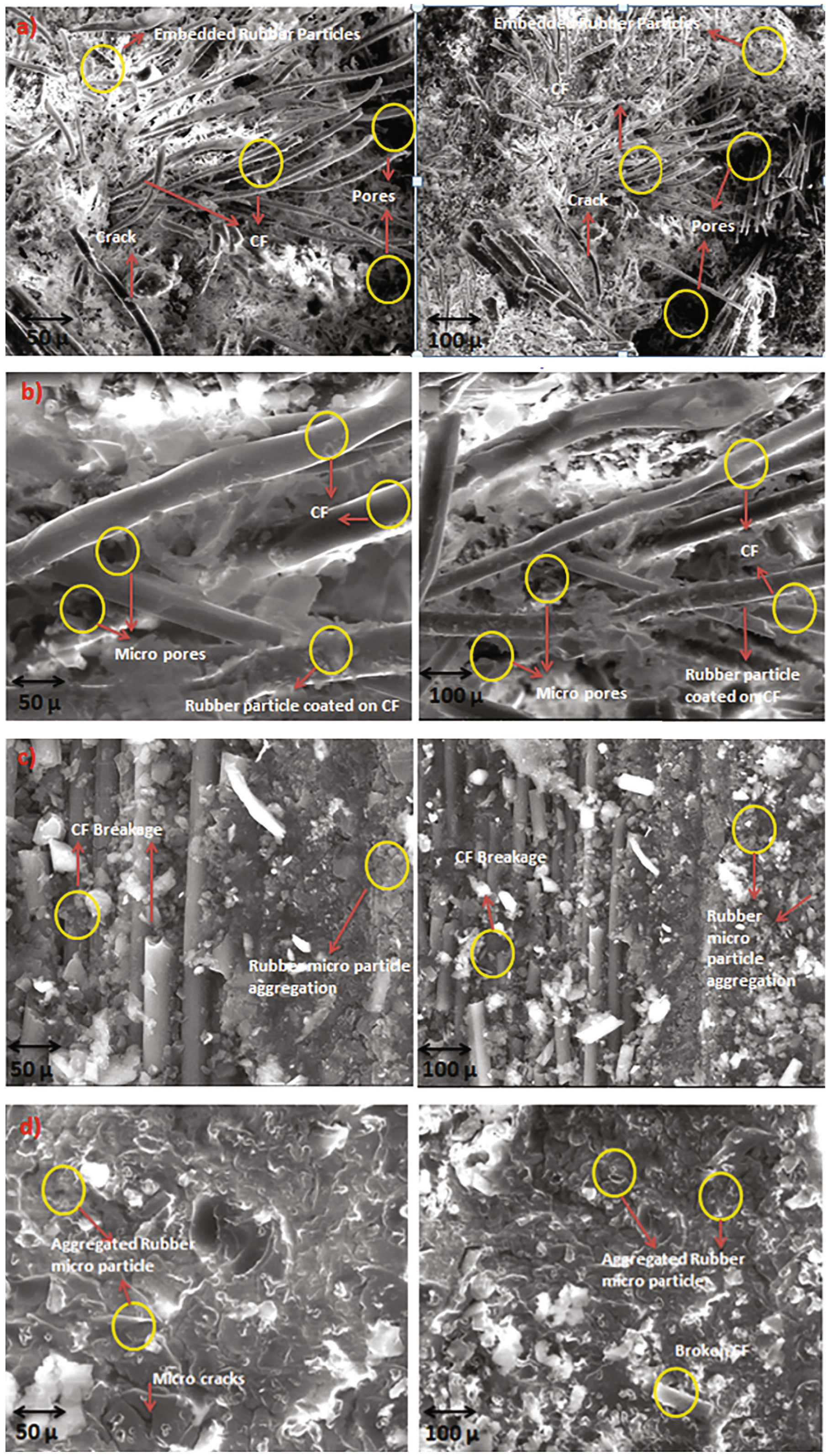


FIGURE 7: SEM images of the epoxy-based ECR composites with different percentages of natural rubber addition: (a) 5%, (b) 10%, (c) 15%, and (d) 20%.

The flexural strength and flexural modulus of ECR polymer composites are compared and are given in Figures 3(a) and 3(b), respectively.

From the results, the flexural strength of the ECR2 polymer composite with 10% natural rubber particle addition is greater than that of other samples. This higher value reveals that the ECR2 specimen can sustain maximum bending stress applied on it by gradually applying the load.

The flexural modulus of the ECR2 specimen is higher than that of other samples showing that the ECR2 specimen is stiffer than other specimens.

5.3. Water Absorption/Acid Corrosion/Base Corrosion Test Results. The amount of H_2O, HCL, and NaOH absorbed by ECR polymer composites is shown in Table 4. It is observed that all the four samples are not affected by water, acid, or base. This resistivity towards water, acid, and base is very significant in making aerospace components.

5.4. Dynamic Mechanical Analysis Results

5.4.1. Storage Modulus. Storage modulus is the energy-storing element's response to stress, and it is the ability to store energy and recover it during deformation; the storage modulus of ECR hybrid composites is shown in Figure 4. A change in storage modulus with temperature change was observed, and it has a tendency to drop off with increasing temperature. The ECR2 polymer composite with 10% natural rubber particle addition shows the highest storage modulus values, and it could be the cause of the increased interfacial adhesion between the matrix and the fibers. Additionally, a significant decrease in storage modulus was seen for the temperature range of 80 to 100°C which may indicate a change in the state of the rubber. As the temperature increases, the free electrons inside the EAC composite samples vibrate. As the lattice vibration increases, their molecular packing arrangement tends to change, and there is a decrease in material density. The storage modulus of rubbery regions gradually decreases as a result of this impact.

5.4.2. Loss Modulus. Loss modulus is the energy-dissipating element's response to stress. The variation in the loss modulus of ECR composites is seen in Figure 5. The ECR2 polymer composite with 10% natural rubber particle addition shows the highest loss modulus values, and the ECR4 polymer composite with 20% natural rubber particle addition has the least loss modulus. As frictional thermal energy dissipation takes place in composites due to abruption of motion of polymer chain by huge surface area of rubber particles, it improves the interaction between the filler and matrix and increases loss modulus. Loss moduli of all ECR samples rose gradually until they reached their peaks before abruptly falling due to the inclusion of rubber particles. Additionally, it has been noted that the loss modulus values dropped by rising temperature as a result of free movement of the polymer chains.

5.4.3. Damping Factor (Tan δ). The damping factor determines the damping characteristics of polymer composites. The ECR2 polymer composite with 10% natural rubber powder shows the highest loss modulus values, and the ECR4 polymer composite with 20% natural rubber has the least loss modulus. The effect of rubber particles on the damping factor of carbon fiber/epoxy composites is depicted in Figure 6. As it is evident from the figure, if the damping factor increases, the temperature increases and influences a maximum value in the critical region. With the added temperature increase, the damping factor of the ECR4 specimen decreases. It reaches the rubber region. The tan δ plots prove that the fabricated samples exhibited a decreasing trend in the damping factor below the glass transition temperature. This is because of the frozen chain segments. That can lead to greater molecular mobility and lower damping factor. Interestingly, incorporating rubber particles into carbon fiber/epoxy composites improved the damping factor.

A composite ECR2 showed the highest damping values. It is evident from Figure 6 that the carbon/epoxy composite with additional rubber particles has a broader tan delta peak. A wider peak suggests that there has been more time for molecular relaxation, which may result in the polymer chains being less mobile, which improves the interface and increases the amount of cross-linking that forms.

5.5. SEM Analysis of Carbon Fiber-Reinforced Polymers (CFRP). Figure 7 displays the SEM images of the fractured surfaces of the epoxy-based ECR composites that comprised 5% to 20% rubber adhering to the tensile test. SEM pictures of ECR1 (Figure 7(a) showed that the epoxy matrix, carbon fiber, and embedded rubber particles are related to the surface. The carbon fiber is discernible in the form of a cluster. The SEM images of the ECR2 specimen (Figure 7(b)) show the presence of carbon fiber with rubber embedded in it, and there are also a few visible micropores. It showed that there is a good contact between the carbon fibers and the matrix material and that the inserted fiber and rubber particles are dispersed equally.

When natural rubber content is increased from 10% to 15% and 20%, Figures 7(c) and 7(d) are found to exhibit delamination, fiber-matrix deboning, and fiber breakage. Figure 7(d) clearly displays the broken fiber in 100 micron images. In particular, there is apparent broken fiber on one side and rubber particle aggregation on the other. This can be linked to the tensile strength data since, after raising the rubber content to 10%, the tensile strength increased along with a sign of fiber deformation and strength. Specifically, the fiber-breaking observation indicated that the external tensile load was effectively transferred to the carbon fiber reinforcements.

6. Conclusions

The present research work examined hybrid composites with the addition of 20% carbon fibers and 5%, 10%, 15%, and 20% rubber granules with epoxy resin by vacuum bag moulding process. The following conclusions are made.

(i) The tensile strength, tensile modulus, and % of tensile elongation of ECR2 specimen with 20% carbon fiber and 10% rubber granules exhibit better results

(ii) The flexural strength and flexural modulus for the ECR2 specimen with 10% rubber granules are higher than specimens with 5%, 15%, and 20% rubber granule addition

(iii) All the ECR composite specimens are not affected by water, acid, or base

(iv) Viscoelastic behavior of the ECR2 specimen with 10% rubber particle addition is better than that of other specimens

(v) For the ECR2 specimen with 10% rubber particle addition, SEM analysis reveals that there is a good contact between carbon fibers and matrix, and the inserted fiber and rubber particles are dispersed equally. When the rubber content is increased beyond 10%, there were delamination, fiber-matrix debonding, and fiber breakage

(vi) Vacuum bag moulding process has also reduced the voids or cracks present in ECR composites, making it suitable for aerospace interior application

Data Availability

The data collected, calculated values, and experimental analysis have been generated on our own and/or not copied from others' works. If required, all the backup documents will be shared based on request.

Conflicts of Interest

There is no conflict with the authors in submitting and publishing this paper.

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