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# Study of Compression, Hardness and Wear Resistance Properties of Cordia Dichotoma Fiber Reinforced Epoxy Composite

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## Abstract

The use of composite materials reinforced with natural fibers has gained popularity in recent years. These fibers are naturally occurring, inexpensive, less-harmful to human resources during processing, recyclable, and non-toxic to the environment as compared to manmade reinforcements like carbon and glass fiber. A study was conducted to explore the compression, hardness, and wear resistance properties of composites formed by reinforcing Cordia-Dichotoma natural fibers with epoxy resin. Water retting and hand methods were used to remove the natural fibers. In this work, Cordia-Dichotoma fibers were subjected to an alkaline (NaOH) solution to diminish their hydrophilicity and moisture absorption. After that, they were inserted into the epoxy resin as reinforcement, and the composite was fabricated by hand layup technique. The fabricated composite's compression, hardness, and wear resistance properties were assessed to make sure it was suitable for its intended use. Amongst the composites, wear resistance property was superior at 20wt. Percentage fiber content when compared to the other combinations of reinforcements. Compression and hardness properties are maximum at 20wt. Percentage fiber content. Images from a scanning electron microscope (SEM) were used to better understand the interfacial bonding between the resin and the fibers. Due to the above properties these composites are suitable for automobile, shoe making and structural applications. The investigation of the compression, hardness, wear, and morphology —all of which have not been previously covered in the literature— makes this study original.

**Keywords:** Compression, Cordia-dichotoma Fiber, Hardness, SEM, Wear Resistance.

## Introduction

Over decades, traditional materials such as metals, ceramics, and polymers have found widespread applications in various industries. These materials provide high strength and durability, and high temperature resistance (1). However, these have some disadvantages, such as weight, susceptibility to corrosion, partial design flexibility, and environmental impact when compared to composites. To overcome the above disadvantages, natural fibers are introduced and used as an alternative reinforcement for the present day industry and society. Natural fibers stand out because they are lightweight, biodegradable, less hazardous, affordable and widely available (2). These materials are useful to society and industry since they are biodegradable, in- expensive and possess high compressive strength, hardness and wear resistance properties. Since a single natural fiber may not be able to support an adequate load, these fibers are reinforced with thermosetting and thermoplastic polymers to increase their load carrying capacity. A composite material is a physical combination of two or more distinct materials that produces a component with better qualities than any one of the original materials alone (3). The components of a composite are the matrix and the reinforcement. The reinforcement, which acts as a stiffening element, consists of fibers, mats, or particles inserted into the matrix. A matrix is a material that binds reinforcements and transfers load between fibers (4). Because of their hydrophilic nature, natural fibers absorb a lot of moisture and connect poorly with the matrix. In order to resolve this, chemical and physical



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changes were made to the fibers that were inserted into a matrix (5).

Natural fiber reinforced polymer composites are gaining popularity due to their improved stiffness, lower weight, corrosion resistance, and strength. These characteristics might be useful in the automobile, door panels, structural, packing, and sporting industries. After researching the mechanical properties of composites reinforced with Date Palm Fiber fibers, Shariff *et al.,* (6) came to the conclusion that Date Palm Fiber fiber reinforcement enhances the impact, and flexural capabilities of the epoxy matrix material. Singh and Hirwani (7) looked into the mechanical properties of Saccharum Munja fiber reinforced with epoxy matrix. Proving that the composite with 20 wt. % of fiber shown enhanced mechanical properties in comparison to other composite combinations. Cordia dichotoma fiber embedded in an epoxy composite was examined for its mechanical properties by Reddy *et al.,* (8) indicating that these properties increase as fiber weight increases. Alagumalai *et al.,* (9) conducted a review of wear characteristics in natural fiber-based composites. The wear performance of the composite is determined by several aspects, including fiber bonding, fiber orientation, fiber content, and fiber length. Venkatesan *et al.,* (10) created a hybrid composite using abaca and sisal fibers in various orientations ($0^o$, $45^o$, $90^o$), analyzed its mechanical properties, and compared the results to simulation using ABAQUS. The compressive strength of the hybrid composite is lowest at $0^o$ orientation compared to other orientations. The $90^o$ orientation has the most hardness when compared to the other orientations ($0^o$ and $45^o$). In order to increase the applicability in other engineering domains, it is necessary to analyze properties other than mechanical ones, such as compression, hardness, and wear.

According to the literature, mechanical, thermal, and morphological properties of cordia dichotoma fiber reinforced composites are studied (2). Cordia-dichotoma fibers are naturally available, biodegradable, lightweight, and less expensive than alternative reinforcements, making them suitable for use in composite materials. Other mechanical properties including compression, hardness, and wear characteristics were not examined. In this study, an epoxy matrix reinforced with cordia dichotoma fiber was employed to build a composite employing a hand layup method. Standard methodologies are used to determine compression, hardness, and wear characteristics of the prepared composite. Scanning electron microscopy examination was performed on the compression, hardness, and wear tested samples, and photographs are furnished in the results and discussion section. These properties broaden the range of possible applications, including structural, piston ring, cylinder surface, and automotive engineering.

# Methodology

This section outlines the materials and methodologies that are desirable for fabricating and assessing the properties of the composites.

## Materials

Dry cordia-dichotoma fibers (The sourced from Dorigallu village in the Sri Sathya Sai district of Andhra Pradesh) were extracted from the bark using water retting. The resulting fibers were then subjected to a 5% NaOH (The Madhu Scientific Labs in Kurnool district of Andhra Pradesh) solution before being used to make composite materials. Epoxy resin of the grade LY 556 and hardener of the grade HY 951 (Ram Composites, located in Vishakhapatnam, Andhra Pradesh, India) are used.

## Composite Fabrication

Cordia-dichotoma fiber and epoxy resin were used to make a composite using a hand layup method. The composite was made using a glass mould, releasing agent, overhead projector sheet, and flat glass mold. In the prior paper, a thorough explanation of the composite fabrication process was provided (8). Sample designations are reported in Table 1.

**Table 1:** Sample Designations of the Prepared Composite

| Designation of composite | Cordia-dichotoma Fiber content (Wt. %) | Epoxy (Wt. %) |
|---|---|---|
| C5 | 5 | 95 |
| C10 | 10 | 90 |

| | | |
|---|---|---|
| C15 | 15 | 85 |
| C20 | 20 | 80 |
| C25 | 25 | 75 |

### Compression test

This test evaluates the strength and behavior of materials under compressive loads (11, 12). For it, the ASTM D3410 standard was applied. The compression test specimen has the following dimensions: 15 cm (length), 1.5 cm (width), and 0.3 cm (thickness). A computerized INSTRON Model-3369 Universal Testing Machine is used to conduct this test.

### Hardness Test

A Rockwell hardness testing machine was used to determine the hardness of composites made of cordia-dichotoma fiber and epoxy resin. As per ASTM D785, samples of hardness were fabricated and tested. A steel ball dent that is put on the substrate of the composite specimen is subjected to a modest load (10 kgf) to set up a zero datum point for each trial. The minor load will be delivered after the main load (50kgf) has been exerted for a specific period. Rockwell hardness number is the distance between the zero datum and dent resulted from the primary load (13, 14).

### Wear Test

A wear test is used to evaluate the resistance of a material to wear and abrasion. In this test, the sample is put through a controlled rubbing and sliding motion on another surface. To conduct wear test, a pin-on-disc tribometer (Ducom Made) was employed. The composite samples of size 10 x 4 x 80 $mm^3$ were prepared as per ASTM G99 standards. The wear testing machine composed of a horizontal revolving disc with a speed varying from 100-1000 rpm. The pin kept consistently rubbing upon the disc under different loads, and the sliding distance remained the same at 3000 m, while the sliding speed was changed (15, 16).

### SEM Analysis

Scanning electron microscopy (Make: JEOL/EO; Model: JSM-6390) pictures have been used to study the effects of compression, hardness, and wear characterization on the microstructure of the composite specimen created utilizing a Cordia-dichotoma fiber. Gold-coated sample piece surfaces and cross sections were micro-graphed to better understand the internal structural changes.

## Results and Discussion

The above-mentioned test methods were used to test composite samples, and the results were recorded in tables and figures along with a discussion of the results.

### Compression Test

Five distinct composite samples with variable fiber contents (5, 10, 15, 20, and 25% by weight) had their compressive parameters, such as compressive load, stress, and modulus, determined and shown in Table 2. For easier comprehension, the same data were displayed in several bar charts, as seen in Figure 1-3. Figures 1-3 made it evident that adding the amount of fiber in composites enhanced their load, stress, and modulus; the values are highest at 20% fiber content (20C). The figures 1-3 illustrate that the 20C composite has higher compressive values in comparison to the other prepared composites (5C, 10C, 15C and 25C). The improvement in compressive properties of the composite is ascribed to the enabling of fibers as stress transmission elements in the epoxy at 20 weight percent (20wt. %). In composite, a glass mould can hold 20 weight percent (20 wt. %) of fiber, and an adequate amount of epoxy resin has been evenly dispersed between the fibers. Compressive properties growth is primarily influenced fiber stiffness and matrix-fiber bonding. Beyond 20 wt. % fiber (C25), compressive properties started to decline because not enough epoxy resin was being distributed thoroughly into the Cordia dichotoma fibers, which led to a decrease in compressive properties. The correlation between fiber content and compression properties is directly proportional up to 20 wt. % of the fiber. As fiber content increases, compression properties eventually decline. The mechanical qualities gradually decrease as the fiber content increases further. With the obtained compressive properties, this composite is used for infrastructure, and automotive applications.

**Table 2:** Compression Test Results for Prepared Composites

| Specimen label | Maximum Compressive Load (kN) | Compressive Stress (MPa) | Compressive Modulus (MPa) |
|---|---|---|---|
| C5 | 3.36 | 26.59 | 2414.39718 |
| C10 | 4.69 | 37.09 | 2679.27621 |
| C15 | 5.53 | 43.77 | 2856.73127 |
| C20 | 6.87 | 54.37 | 4391.57587 |
| C25 | 5.96 | 47.20 | 3559.41726 |

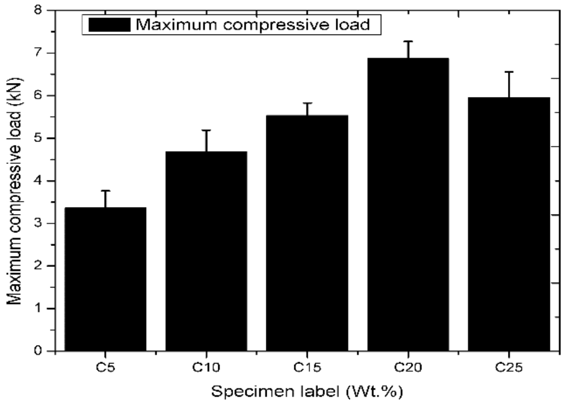


**Figure 1:** Compressive Load vs Specimen Label for Prepared Composite

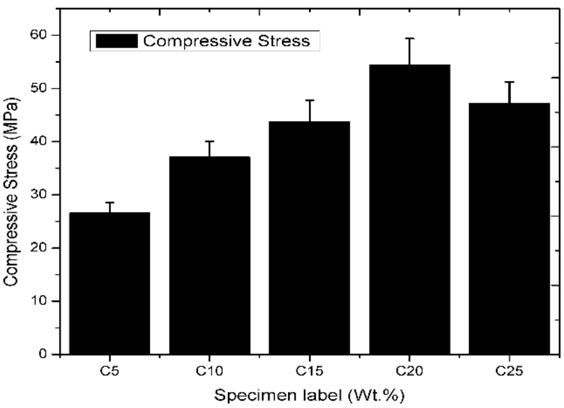


**Figure 2:** Compressive Stress vs Specimen Label for Prepared Composite

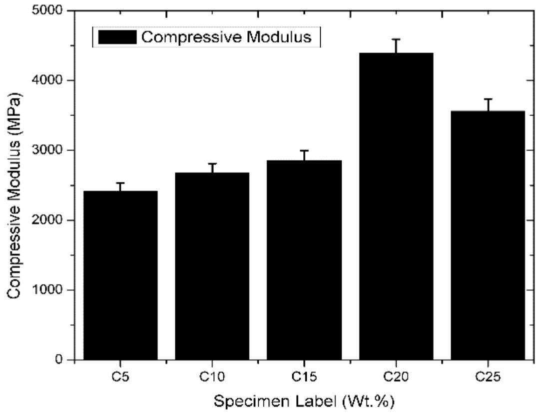


**Figure 3:** Compressive Modulus vs Specimen Label for Prepared Composite

## Hardness Test

Figure 4 and Table 3 depicts the hardness numbers for the manufactured composites. Figure 4 illustrates that the 20C composite has higher hardness value in comparison to the other generated composites (5C, 10C, 15C, and 25C). Additionally, it should be mentioned that the manufactured composites' hardness value rises as the weight percentage (wt. %) of fiber increases up to 20wt%. In composite, a glass mould can hold 20 weight percent (20 wt. %) of fiber, and an adequate amount of epoxy resin has been evenly dispersed between the fibers. Beyond 20 wt. % fiber (C25), hardness values are started to decline because not enough epoxy resin was being distributed thoroughly into the Cordia dichotoma fibers, which led to a decrease in hardness properties. With the obtained hardness numbers, this composite is used for infrastructure, and automotives and piston applications (16, 17). The correlation between fiber content and hardness property is directly proportional up to 20 wt. % of the fiber. As fiber content increases, hardness property gradually decreases.

**Table 3:** Hardness Test Results for Prepared Composites

| Specimen Label | Rockwell Hardness Number (HRB) |
|---|---|
| C5 | 18 |
| C10 | 20 |
| C15 | 24 |
| C20 | 28 |
| C25 | 19 |

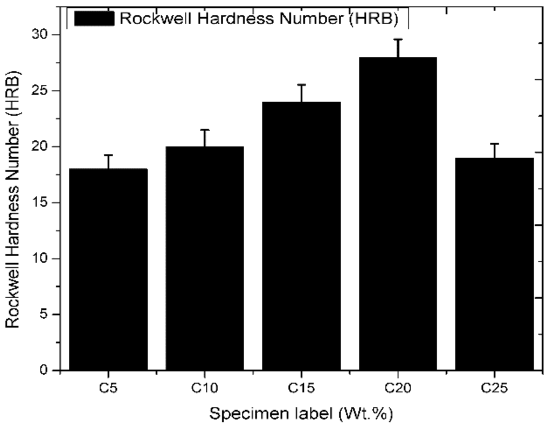


**Figure 4:** Hardness Values vs Specimen Label for Prepared Composites

## Wear Test

Depending up on weight loss information obtained from different loads and sliding speeds, the specific wear rate of the produced composites (C5, C10, C15, C20, and C25) was estimated. Equation [1] was used to determine the prepared composites' wear rate, and Table 4 displays the estimated wear rate values. For different sliding speeds (1-3 m/s), it was shown that the wear rate of the samples decreased as the applied load increased as shown in Figure 5.

Specific wear rate = g/ρLF = weight loss/(density x load x sliding distance) ………..[1]

In the equation (a), g denotes weight loss, ρ denotes density of specimen (g/cm$^3$), F denotes load (N) and L denotes sliding distance (m). According to the literature, a density value of the specimen was taken (18-19). According to the findings, it is obvious that adding fibers to the matrix greatly improved wear performance. The increase in temperature that occurs as the specimens begin to slide across the disc is what causes the epoxy to wear out quickly since the specimen begins to losing weight in the mode of fine tiny particles. However, the addition of fibers to the sample causes a delay in the removal of the material, which improves wear performance and acts as a barrier to the removal of the material. Similar findings for composite consisting of polyester resin and betel-nut fiber reinforcement with increased load have been reported in the literature (20). According to their study's findings, wear decreased as load increased; this pattern is also seen in the current investigation. The fact that the weight loss is slower despite an increase in applied stress testifies to the effectiveness of the matrix-fiber interface.

All composites (C5, C10, C15, C20, and C25) experience an increase in sliding speed, a rise in wear rate of up to 2 m/s, and a subsequent decline in wear rate of 3 m/s. Owing to friction in between the testing sample and disc caused the boundary temperature to raise as the load increased. The composite sample becomes soft due to friction at the contact and begins to lose composite particles across the fibers. The behavior of the reinforcing content in the composite sample is what causes the variation in wear rates for the same process restrictions. This demonstrates unequivocally that the wear characteristics are decided by both ingredients, such as fiber and matrix. Wear properties of composites are reduced by improper bonding. Up to 20 weight percent of the fiber, there is a direct proportionality between the fiber content and wear characteristics. Wear characteristics gradually decrease with an increase in fiber concentration.

**Table 4:** Wear Test Results for Prepared Composites

| Specimen Label | Load (N) | Specific Wear rate (mm$^3$/Nmm)x10$^{-8}$ | | |
|---|---|---|---|---|
| | | Sliding Speed | | |
| | | 1 m/s | 2 m/s | 3 m/s |
| C5 | 10 | 4.5786 | 3.5476 | 2.5624 |
| | 20 | 6.5453 | 7.7144 | 2.8692 |
| | 30 | 4.7634 | 4.3428 | 5.7644 |
| C10 | 10 | 3.6896 | 2.6582 | 1.6744 |
| | 20 | 5.8082 | 6.8704 | 1.6744 |
| | 30 | 3.8438 | 3.3128 | 3.1408 |
| C15 | 10 | 3.3774 | 2.3454 | 1.3598 |

| | | | | |
|---|---|---|---|---|
| | 20 | 5.3296 | 6.7494 | 1.2624 |
| | 30 | 3.6326 | 3.1145 | 3.6848 |
| C20 | 10 | 2.5884 | 1.5564 | 1.2368 |
| | 20 | 4.5406 | 5.9648 | 1.1154 |
| | 30 | 3.3748 | 2.8564 | 3.4265 |
| C25 | 10 | 2.4778 | 1.4453 | 1.1156 |
| | 20 | 4.2192 | 5.6432 | 0.8842 |
| | 30 | 3.0058 | 2.4876 | 3.0548 |

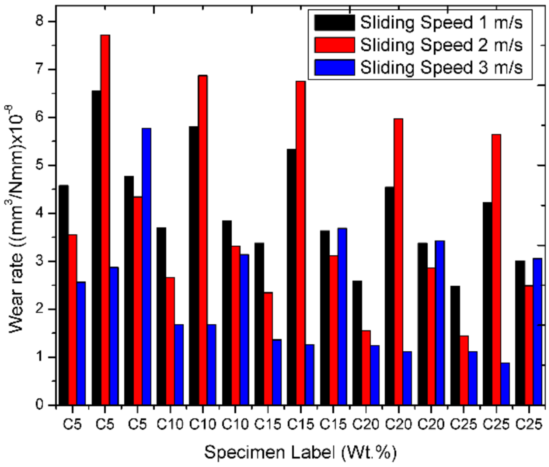


**Figure 5:** Wear Rate vs Specimen Label for the Prepared Composites

## Comparison of Mechanical Properties of Cordia-Dichotoma Fibers to Other Natural Fiber-Reinforced Composites

Table 5 compares the mechanical properties of Cordia-Dichotoma fibers to other natural fiber-reinforced composites. Table 5 shows that Cordia-Dichotoma fiber reinforced epoxy composites have greater compressive stress than date palm and sheep wool fiber reinforced epoxy composites. Cordia-Dichotoma fiber reinforced epoxy composites have higher hardness than bagasse and coir fiber reinforced epoxy composites. However, jute fiber reinforced composites have a lower hardness value. Cordia-Dichotoma fiber reinforced epoxy composites have higher Specific wear rate value than tapsi fiber reinforced epoxy composites. However, prosopis juliflora and abuliton indicum fiber reinforced composites have lower Specific wear rate value.

## SEM Analysis

The morphological characteristics of the composite were investigated using SEM analysis. This analysis was done on samples that failed the compression, hardness, and wear tests. The SEM picture of the failed compression test sample is depicted in Figure 6. After imaging, the fiber and epoxy resin were clearly visible. After the compression test, de-bonding was happened because the composite could not withstand the more than this compressive stress due to the feeble connection between the fiber and epoxy. The SEM picture of the failed hardness test sample is depicted in Figure 7. After imaging, fiber, epoxy resin, and fiber pullout were clearly visible. The de-bonding was seen after the hardness test. The SEM picture of the wear test sample is shown in Figure 8. After imaging, it was possible to see fiber pullout, thin particle separation, and surface wear from wear testing.

**Table 5:** Compares the Mechanical Properties of Cordia-Dichotoma Fibers to Other Natural Fiber-Reinforced Composites

| Fibers | Resin | Compressive stress (MPa) | Hardness (HRB) | Specific Wear rate mm$^3$/N mm) x 10$^{-8}$ | Reference |
|---|---|---|---|---|---|
| Date palm fiber | Epoxy | 41.834 | -- | -- | (12) |
| Sheep wool | Epoxy | 43.516 | -- | -- | (12) |
| Bagasse | Epoxy | -- | 14.24 | -- | (13) |
| Coir | Epoxy | -- | 14.82 | -- | (13) |
| Jute | Epoxy | -- | 41 | -- | (14) |
| prosopis juliflora | Epoxy | -- | -- | 5.667696 | (15) |
| abuliton indicum | Epoxy | -- | -- | 5.254882 | (15) |

| | | | | | |
|---|---|---|---|---|---|
| tapsi | Epoxy | | | 2.364825 | (15) |
| Cordia-Dichotoma | Epoxy | 54.37 | 28 | 3.4265 | Present Paper |

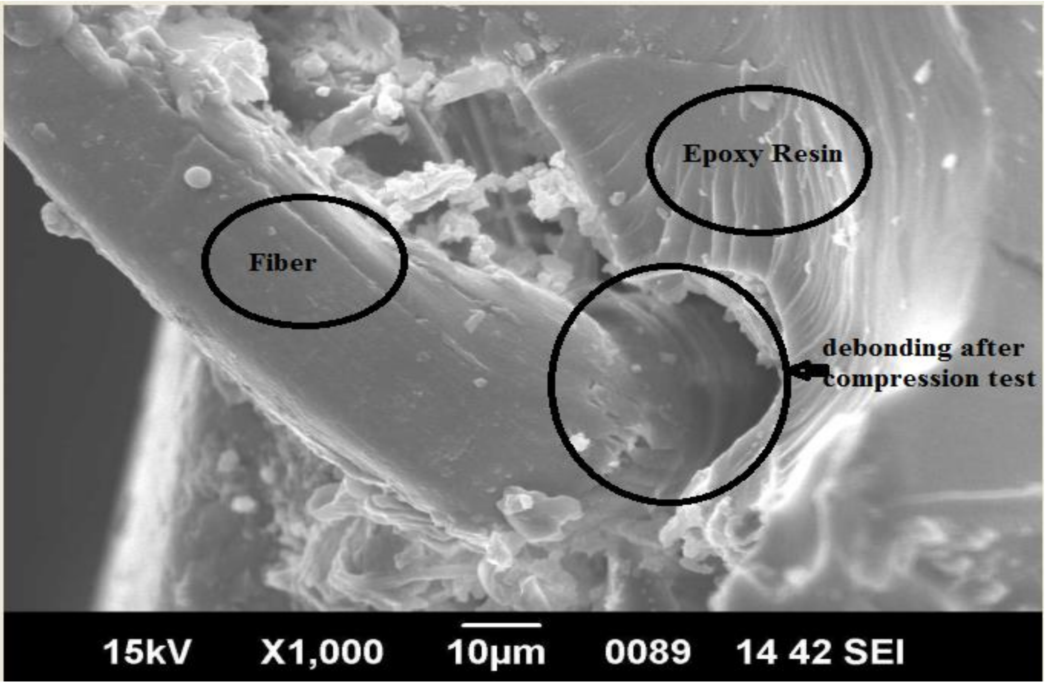


**Figure 6:** SEM Image of Failed Compression Test Sample

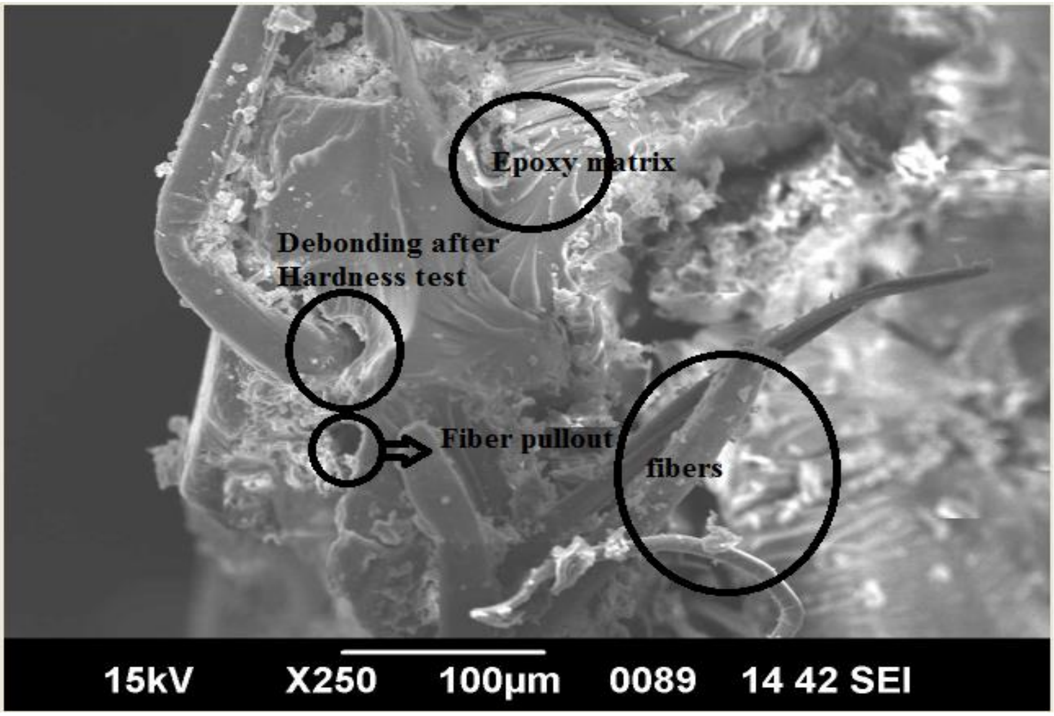


**Figure 7:** SEM Image of Failed Hardness Test Sample

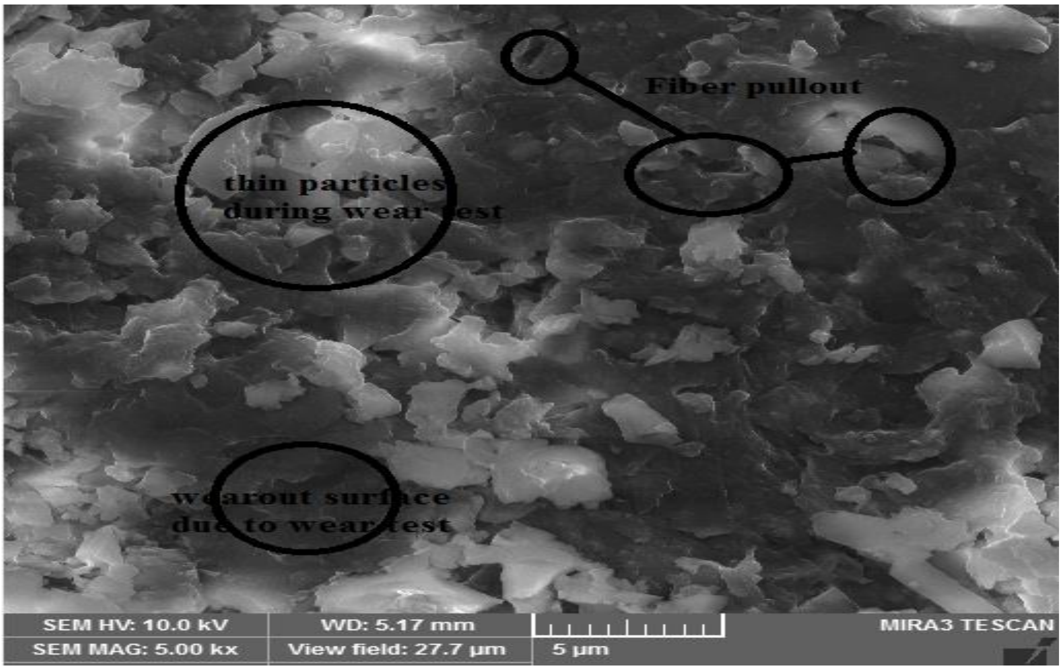


**Figure 7:** SEM Image of Wear Test Sample

## Conclusion

The composites are efficiently fabricated by introducing Cordia-Dichotoma fiber and epoxy using the hand lay-up method. The composites are successfully fabricated by inserting Cordia-Dichotoma fiber and epoxy by employing the hand lay-up method. Five distinct composite specimens—C5, C10, C15, C20, and C25—were created. Every number in the codes indicates the weight proportion of the natural fiber. Using appropriate instruments, several composite characteristics like compression, hardness, and wear properties have been assessed. By incorporating fibers into epoxy, compressive properties like load, stress, and modulus of epoxy matrix were greatly improved. The hardness numbers of the resulting composites are significantly raised by adding fibers to epoxy resin. The addition of fibers to epoxy considerably enhanced the wear characteristics of the composites. The composite material fabricated in this work is suitable for the following applications based on its compression, hardness, and wear properties. Beams and columns must endure compressive forces, which the current composite material does. Because, these materials offer lightweight alternatives to typical building materials such as, steel or concrete. This property may also be valuable in other industries such as automotive, aerospace, sports equipment,

furniture, and interior design. Bearings, tooling fixtures, brake pads, clutch plates, prosthetics, and grinding wheels are a couple of potential applications based on hardness values. Gaskets and seals that resist friction and stop leaks must be made of wear-resistant materials. Using the above prepared composites Shock absorbers, cylinder heads, and engine blocks in the automobile industry; roof supports and pillars in the construction sector; Landing gear, fuselage panels, and airframes in the aerospace sector.

## Abbreviations

SEM: Scanning Electron Microscope


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## Author Contributions

B. Madhusudhan Reddy: Gap identification, Methodology, drafting original manuscript. R. Meenakshi Reddy: examined the findings and participated in the discussion of the findings; Y.V. Mohana Reddy: corrected the original manuscript and made helpful recommendations; K. Madhava Reddy: proofreading, editing, and visualization; P.

Harisankar: assisted in conducting experiments and validating the findings; G. Sankaraiah: contributed with the imaging and characterization.

## Conflict of Interest

No Conflict of Interest.

## Ethics Approval

Not applicable.

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