Experimental Study of Mechanical Properties of Natural Fiber Polymer Composite

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Abstract. Numerous studies and research projects have been conducted to develop natural fiber polymer composites. The researcher and engineers develop a composite by reinforcing natural fiber with a polymer that exhibits the desired mechanical properties. The experiment determines the composite’s mechanical properties, such as tensile, compression, flexural, and impact strength. This paper presents the experimental study of the natural fiber-reinforced composite, where hemp and jute fibers were reinforced with epoxy polymer as the test specimens for the experiment. The primary approach involved fabricating composite samples with fiber-weight fractions and matrix compositions. Then the appropriate sample is experimented with for its tensile strength, compression strength, and impact strength. Another property of the composite's the composite's water absorption was investigated through a water absorbability test. Key results show that composites containing a 30% weight fraction of natural hemp fiber demonstrated promising mechanical properties. This composite showed a tensile strength of 50 MPa, a compression strength of 55.6 N/m^2, an impact strength of 58.9 kJ/m^2, and a water absorbability of 7%. These results may offer valuable insight into the mechanical behavior of natural fiber composites, which can be used to optimize material design and engineering applications. Understanding the limitations and strengths of these composites allows for informed decision-making in selecting appropriate materials for specific engineering projects.

Keywords. Natural fiber, epoxy resin, mechanical property, composite

1. Introduction

Composite material is composed of two or more materials sharing each constituent property. The composite is composed of filler material embedded in the matrix. Normally, fiber is used as filler material, and the matrix could be thermosetting, thermoplastic, and/or elastomer type. The matrix is used to bind the fiber and ensure the orientation of the load[1]. Fibers used in composite preparation are broadly classified as synthetic (glass, carbon, basalt, etc.) or natural, each offering distinct advantages and challenges[2]. These composite offers material property such as strength, lightweight, stiffness, resistance to fatigue, corrosion, and impact strength, making them ideal for the diverse application. They have replaced many metallic components in the various manufacturing sectors. Due to their excellent mechanical properties, these materials have a wide range of applications in various industries such as aerospace and defense, energy, automotive, construction, sport, and many more[3]. However, the synthetic fiber’s composite is non-biodegradable and contributes to carbon footprint[4].

In engineering, material selection of a sustainable material plays huge role. One such sustainable solution could be a composite from Natural fiber. The competitive edge natural fiber provides over synthetic fiber as their abundance, availability, and low cost. But their moisture absorption property is key concern for their use in structural applications[5]. In addition to this, the mechanical properties of natural fiber composites are often inferior to those of synthetic fiber composites. Therefore, it is not possible to replace natural fiber with synthetic fiber in all application. However, natural fiber composites present a viable alternative in applications where exceptional strength is not required. Natural fiber composite is now used different application such as floor protection in passenger car, roofing, flooring and insulation, filters in cigarettes, membranes and barriers, biosensors and catalysts, thin sheets and films, packaging materials, etc[6]. Natural fibers obtained from the different sources like plant, animal, minerals, and geological processes can decompose[7]. Normally plant fibers are used for industrial applications.

Fibers such as flax, hemp, bamboo, and jute have been marketed as prospective substitutes for traditional composite reinforcement[8]. Roughly aligning these fibers possesses limitations such as poor matrix interfacial bonding, moisture absorption, and low damage tolerance. To address these issues, fiber is made in textile form (woven or knitted)[9]. The fiber in fabric is arranged in various orientation with respect to the axis of the composite and they are characterized by high in-plane strength and stiffness. The composite is prepared by assembling several fibrous layers and combining them with a matrix[10]. The most widely used matrices for natural fiber composites are thermosetting resins (such as epoxy resin) and thermoplastic resins (such as polypropylene (PP), polyethylene (PE), polyvinyl chloride (PVC), polylactic acid (PLA), etc. Thermosetting resins have higher thermal stability and mechanical strength than thermoplastic resins but are more brittle and difficult to recycle [11].

Several studies have been conducted to understand the mechanical properties of natural fiber composites. Darshil et al. experimented with flax/polyester for the small-scale wind turbine blade and suggested the composite is suitable for use in that case[12]. John et al. examined mechanical properties of bamboo epoxy laminate. The result showed the composite to have tensile strength of 175 MPa and modulus to be 20 GPa[13]. Palanikumar et al. performed mechanical testing for the sisal fiber and glass fiber composite[14]. Sahayaraj et al. investigated on different mechanical property for jute and hemp in proportion 50:50 reinforced with the matrix PLA, and the composite exhibits a tensile strength of 69 MPa, an impact strength of 6.37 J[15].

Similarly, various studies have been done on the different types of natural fibers and matrices. However, there are very few papers in natural fiber composite in the context of Nepal, and resin locally available in Nepal. In this paper, we focus on two types of natural fibers: hemp fiber and jute fiber. We use epoxy resin as the matrix material for all the composites. We fabricate the composites using the hand lay-up method with different fiber weight fractions ranging from 10% to 50%. We test the composites for water absorption taking reference of the ASTM D570 standard[16]; tensile strength with reference to ASTM D3039 standard[17]; compressive strength with reference to ASTM D695 standard[18]; and impact strength with reference to ASTM D256 standard [16]. The fabrication of the composite involved the wet hand layup method. We further analyze the result obtained various mechanical testing and discusses the failure mode as well.

2. Material and Method

The experimental study was conducted to determine the mechanical properties of natural fiber composites by fabricating the composites using the hand lay-up method for different matrix weight fractions ranging from 10% to 50%. The composites were then tested for water absorption, tensile strength, compressive strength, and impact strength. The effects of fiber type, fiber content and water absorption on the mechanical properties of the composites were analyzed. Possible failure mechanisms and factors influencing the mechanical behavior of the composites are suggested. The following sub-sections give further details about material selections and experimentation.

2.1. Material

2.1.1.Fiber

In this study, jute and hemp fibers were taken for experimentation purposes. Additionally, a flax and cotton fabric was used as a reference to compare the mechanical behavior of the jute and hemp composites. The fabric taken is a woven mat having a biaxial orientation. The fabric is cut into 10*10 cm to observe the following properties of the fabric.

Table 1: Properties of the fiber

Fibers	Weight (g)	Mesh size (mm)	No of fibers in warp direction	No of fiber in weft direction
Hemp	4.60	0.28	66	54
Jute	3.45	0.76	43	39

2.1.2.Matrix

A thermosetting epoxy resin (318A-7T) of the brand Sparko was used as a matrix material for the composite. The resin was mixed with hardener (318B-7T) in the ratio of 3:1 by volume and 100:33 by weight. They are bought from the authorized distributor of the Sparko adhesive Champak and Chirag International. The curing time of the epoxy resin was 24 hours at 25º C. The following are the properties of the resin by manufacturer:

Table 2: Properties of the resin before hardening

Part	318A-7T	318B-7T
Color	Transparent	Transparent
Specific gravity	1.15	0.97
Viscosity (25º C)	2000-4000CPS	50max CPS
Mixing ratio	A:B = 100:33 (weight ratio)	
Hardening condition	At 25º C 24-48 hours (100g)	
Usable time	120 min 25º C (100g)	

Table 3: Properties of resin after hardening

Hardness, shore D	<86
Flexural strength, Kg/mm^2	28

Thermal conductivity, W/M.K	1.36
Withstand high temperature, ºC	80
Moisture absorption	<0.15
Compressive strength, Kg/mm^2	8.4

2.2. *Experimentation*

Different details of the experimental setup are given in the sub-sections below:

2.2.1. Mold Preparation

Mold preparation involved the use of wood, foam, plastic paper, and candle wax, ensuring the uniformity of the composite specimens. Various tools, including weighing machines, scissors, brushes, and more, were employed during the fabrication process.

2.2.2. Specimen Composition and Dimension

Composite specimens were prepared with varying fiber-to-resin weight ratios (20/80, 30/70, 40/60, 50/50, 60/40) to determine the optimal proportion where the fiber and matrix properly bind. After the observation, the appropriate proportion is used for the preparation of specimens for different tests. The following table shows the labeling of specimens:

Table 4: Label of different composite specimen

Label of specimen	Fiber type	Proportion of matrix by weight	Proportion of fiber by weight
H73	Hemp	70%	30%
H82	Hemp	80%	20%
J73	Jute	70%	30%
J82	Jute	80%	20%

2.2.3. Composite fabrication

The composite specimens were fabricated using the hand layup technique. This method involves a systematic process of mold preparation, precise cutting and preparation of the fiber, accurate weighing of the fiber and resin, thorough mixing and application of the resin, molding of the composite, and finally, cutting the specimens to standardized dimensions.

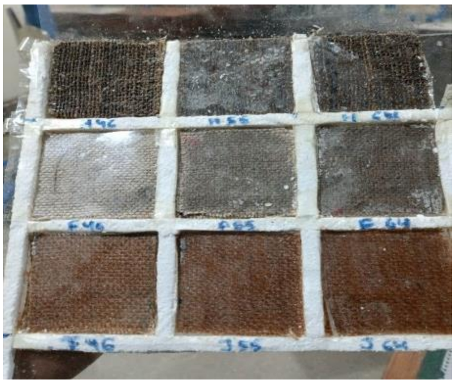


Figure 1: Sample Fabrication

2.2.4.Experimental Setup

1. Microscopic Setup: A Radical stereo zoom microscope was used to facilitate a high-resolution examination of composite specimen. External camera is used to capture the microscopic view. The microscopic view of composite is used to analyze the void formed in composite and failure mode after experimentation.
2. Tensile Test: Tensile tests were conducted on AIM UTM machine. The specimen is prepared with reference to the ASTM D3039, where the size is about 250*25*3.2 ± 2.5 mm. For gripping sand paper was wrapped at the top of specimen where it is clamped.
3. Charpy Impact Test
   The standard size of the sample for the Charpy impact test is 55x10x10 mm and has V-shaped notch. The specimens were prepared according to standard; however, maintaining a consistent thickness was challenging. Therefore, specific impact energy was calculated to provide an accurate representation of the material properties.
4. Compressive Strength Test
   The compressive strength test was prepared according to the ASTM D 695 having dimension 25.4*12.7*12.7 mm. The test was done in a compressive strength testing machine named ENKAY DIGIMAX- 109.
5. Water Absorbability Test
   The water absorbability tests involved submerging specimens in water-filled containers for 36 hours with meticulous observation and quantification of water absorption. The size of test specimen was 20*15*4 mm.

3. Result and Discussion

3.1. Initial Observation of the composite

The composite of the hemp and jute was prepared first with the following resin-to-fiber weight ratios 40/60, 50/50, 60/40, 70/30, and 80/20. Preliminary observation showed that 40/60 and 50/50 ratios did not achieve desired adhesion. Consequently, the composites with weight proportions of 70/30 and 80/20 were selected for the mechanical testing. The figure below depicts the specimen having improper adhesion:

Figure 2: Composite specimen with improper adhesion

3.2. Tensile Test

The result of the tensile test experiment of different specimen is illustrated in figure below:

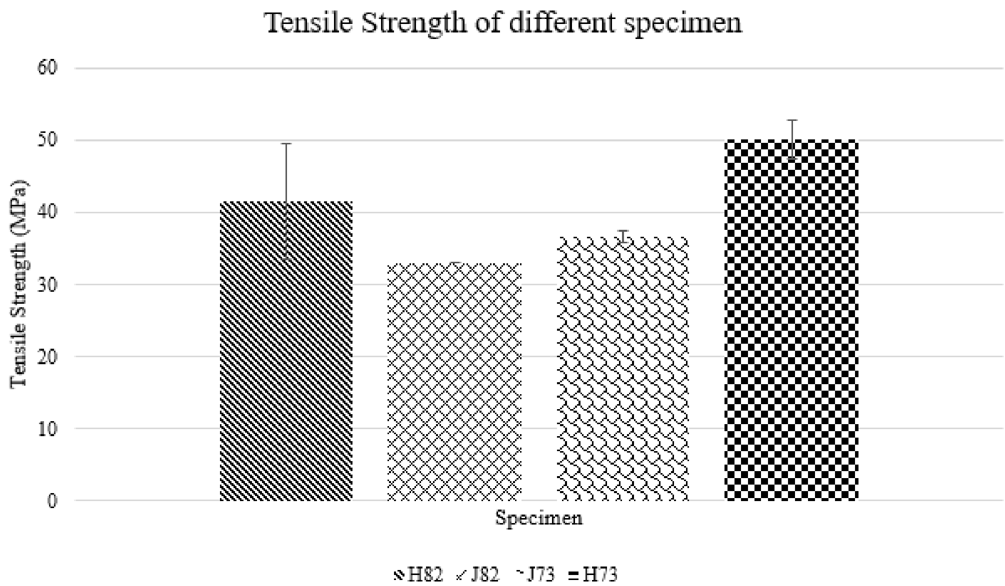


Figure 3: Tensile strength of different specimen

Table 5: Average tensile strength and standard deviation of the observed data

Specimen	Average Tensile strength (MPa)	Standard deviation
H82	41.50	8.04
J82	32.96	0.03
J73	36.63	0.8
H73	50	2.64

The average tensile strength of the specimens is different for different compositions of matrix and fiber. H73 exhibits the highest tensile strength at 50.00 MPa, and J82 showed the lowest at 32.96 MPa. The specimens H82 and J73 had tensile strengths of 41.50 MPa and 36.63 MPa, respectively. The results give an insight that increasing the proportion of epoxy resin lower the tensile strength. The standard deviation values provide insight into the consistency and reliability of the tensile strength measurements. The greater variation in H82 implies that there must have been some error while preparing the composite specimen.

3.3. Compression test

The test results, which include the compressive strength and standard deviation for each specimen, are summarized in the table and chart below:

Table 6: Average Compressive strength and standard deviation of the observed data:

Specimen	Compressive strength (N/mm^2)	Standard Deviation
H82	56.14810961	11.19558735
H73	55.64949705	5.361594506
J82	48.56052723	1.353841048
J73	35.11966701	10.64692088

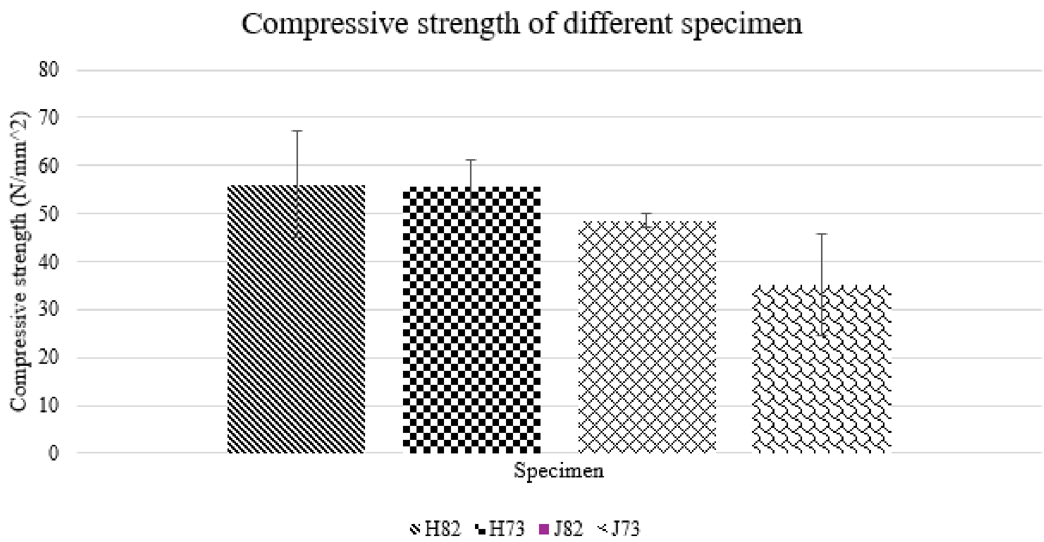


Figure 4: Compressive strength of different specimens

It is observed that compressive strength for H82 and H73 composite specimens have the highest compressive strengths, with values of 56.15 N/mm² and 55.65 N/mm², respectively. The J82 specimen follows with a compressive strength of 48.56 N/mm², while the J73 specimen has the lowest value at 35.12 N/mm². We can observe that increasing the proportion of resin in composite also increases the compressive strength of composite. The case was opposite in tensile test. There is greater variation in the result of hemp fiber composite. The variation can be reduced if the composite is prepared with consistent dimension, and conducting careful experimentation. In terms of compressive strength, hemp fiber composite possesses better strength than jute fiber.

3.4. Charpy Impact Test

The result of the specific impact energy obtained from the Charpy impact test is figure and table below:

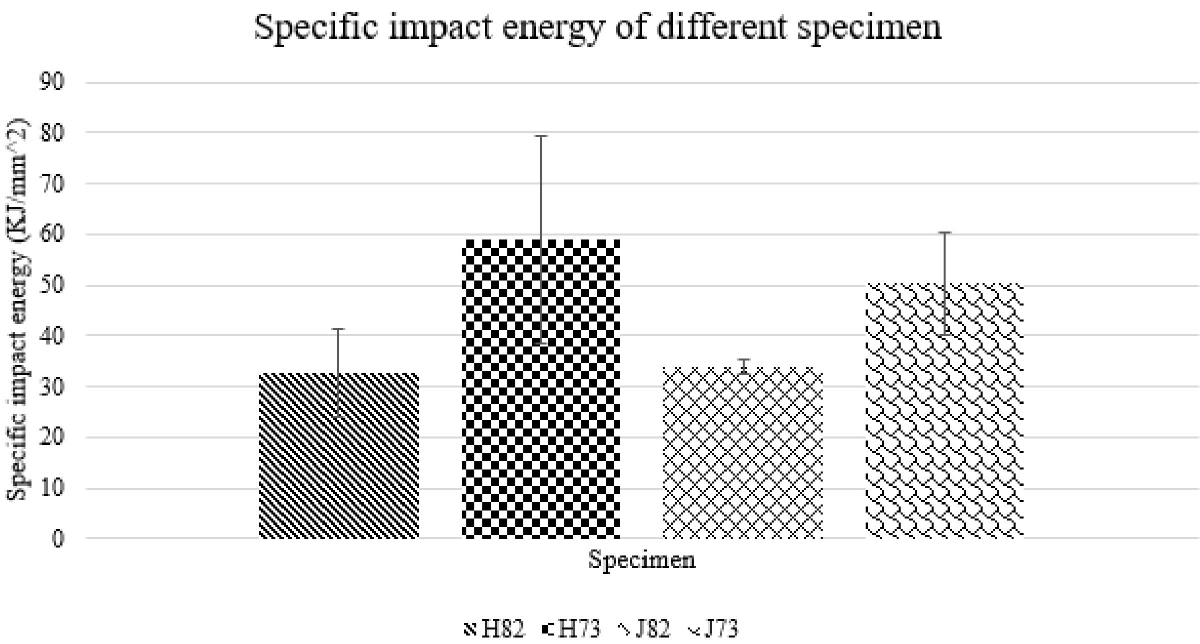


Figure 5: Specific impact energy of different specimen

Table 7: Average Toughness and standard deviation of the observed data:

Specimen	Specific impact energy (kJ/mm^2)	Standard Deviation
H82	32.7405008	8.618413206
H73	58.86588619	20.46321916
J82	34.05311195	1.429452221
J73	50.28401943	10.00813053

The Charpy impact test also reveals that hemp has better impact resistance property than jute fiber. From the result, H73 has great specific impact energy than all other specimen. Though, there is greater variation in data. The thickness for different specimen was very difficult to maintain which result in variation in data. Though the data can be taken as reference for further experimentation of same composite in another research.

3.5. *Water absorption test of the composite*

The water absorption test was conducted to evaluate the composite material's resistance to moisture penetration and retention. Specimens were submerged in water at room temperature (24ºC) for 36 hours. The water absorption test revealed varying degrees of moisture absorption among different composites, as depicted in the bar diagram.

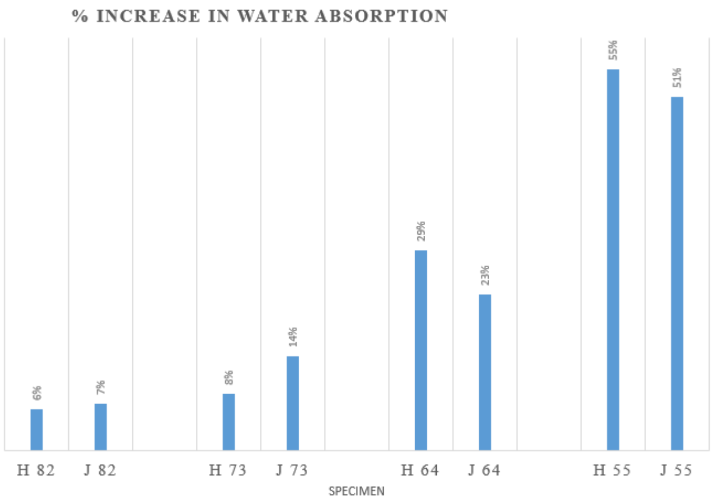
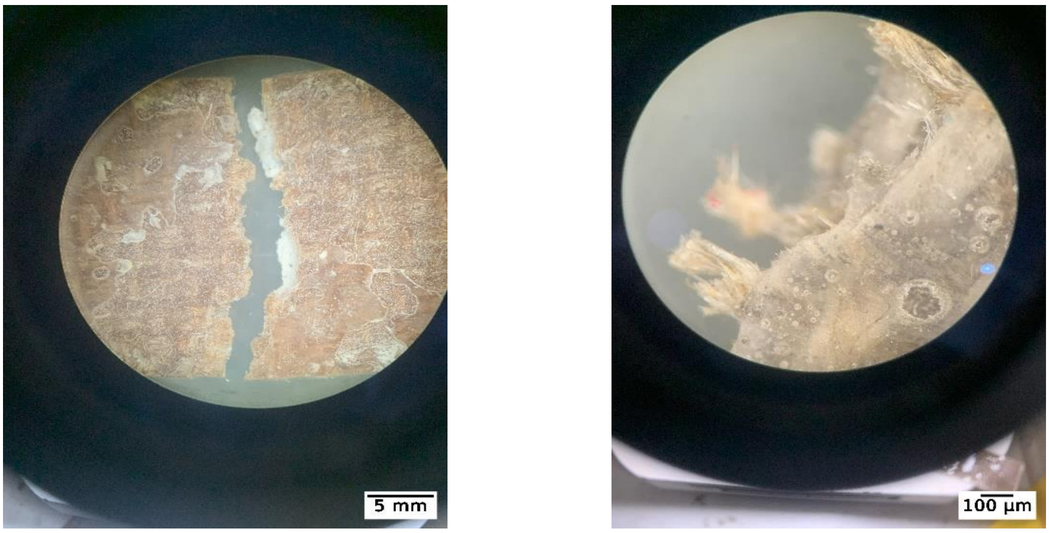


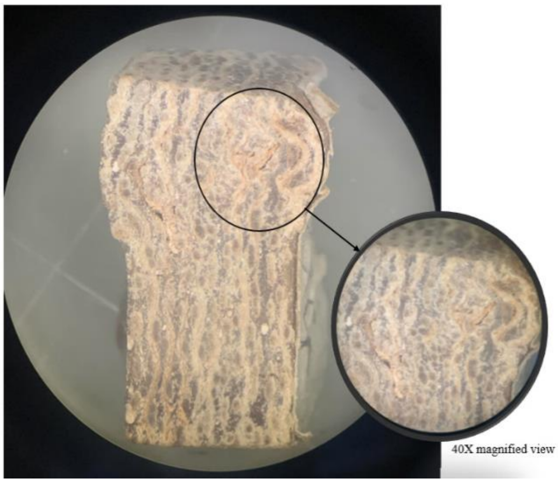
Figure 6: Water absorption % of different specimens

Notably, the 80/20 hemp fiber composite (H82) exhibited the least water absorption, indicating good resistance to moisture. On the other hand, the 55% fiber composition (H55) showed the highest water absorption, suggesting that a higher proportion of fibers in the composite matrix leads to increased water absorption.

3.6. *Post Test-Microscopic Analysis of Experimental Specimens*



(a) (b)



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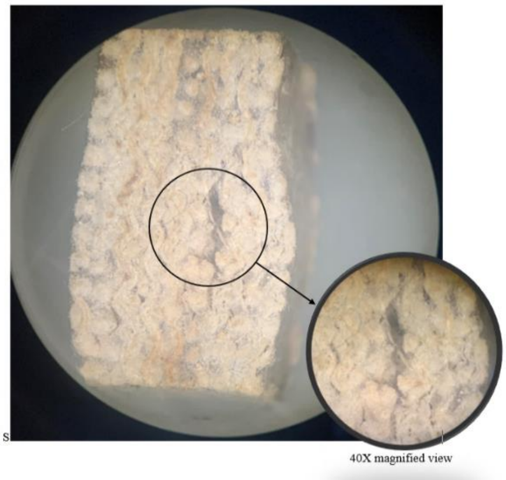

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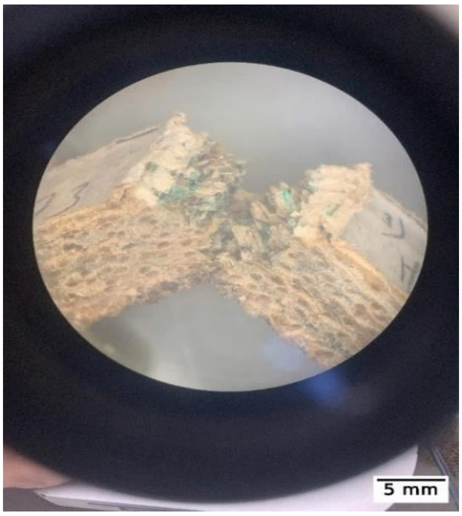
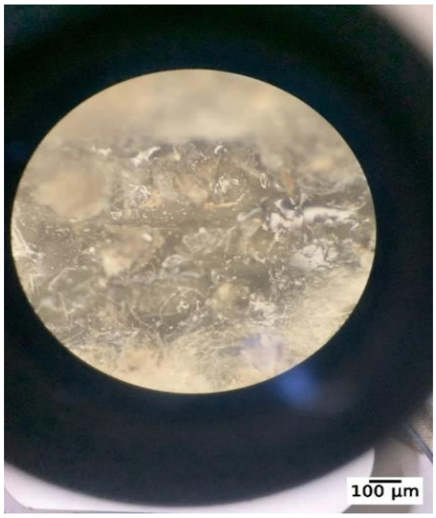


(e)



(f)

Figure 7: Microscopic views after failures

The post-analysis was conducted using a Radical stereo zoom microscope at different magnifications to thoroughly study the test specimens after their failure under various loads. The mode of failure of specimens under tensile loading, compression loading, and impact testing is studied by observing their images. As presented in Figure 7 (a) and (b), the composite specimen under tensile load demonstrated the failure mode like pulling out of the fiber and delamination showing the improper adhesion between matrix and fiber. This failure mode affects the tensile property of the composite. This problem can be solved by using filler material which increases the adhesion between the matrix and fiber. Similarly, the microscopic images of figure 7 (c) and (d) show the same failure methods under compression load i.e. buckling. Buckling occurred due to the weak interfacial bonding between the fiber and matrix or due to the geometric imperfections in the specimen, such as waviness or curvature. Figure 8 (c) shows the buckling at the top of the sample due to the bending of the fibers. These fibers were subjected to compressive stress causing them to bend and eventually buckle. Figure 7 (d) showed a distinct buckling pattern in the center of the specimen where the deformation was concentrated. The interface was weakened due to improper bonding or weak adhesive, which caused layers to separate when the specimen was subjected to compressive load. The failure modes that occurred in Figure 7 (e) and (f) were generally due to fiber fractures, matrix cracking, and fiber pullout. The fracture of the specimen occurred at the surface of the specimen where distinctive V-shaped notch was created before the test.

4. Conclusion

The study presents a comprehensive analysis of the mechanical properties of natural fiber polymer composites, with a focus on hemp and jute fibers reinforced with epoxy resin. The composites were fabricated using the hand lay-up method with varying fiber weight fractions (10% to 50%) and experimented for water absorption, tensile strength, compressive strength and Impact strength. The results observed indicates that the hemp fiber composites exhibit superior in mechanical properties to that of jute fiber composites. The hemp fiber composite with a 30% fiber weight fraction (H73) demonstrated the highest tensile strength (50 MPa), compressive strength (55.65 N/mm^2), and impact strength (58.87 kJ/m^2), while also exhibiting lower water absorption (7%) compared to the jute fiber composite (J73). This suggests that hemp fibers provide better tensile, compressive, and impact resistance and are less prone to moisture penetration. In addition, the microscopic post-analysis of test specimens after failure demonstrated similar modes of failure- delamination, fiber pull out, and buckling, indicating less interfacial bonding between fibers and the matrix. Therefore, future research should focus on enhancing the bonding between the matrix and the fiber, ensuring dimensional control during specimen preparation. Also, it’s important to conduct additional tests such as fatigue and thermal analysis, and explore alternative fabrication methods like vacuum-assisted resin transfer molding (VARTM) or compression molding under pressure to avoid forming voids and bubble form in composites, and achieve more consistent and precise results for natural fiber composites' mechanical properties.

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