

Study on Mechanical Behaviour of Epoxy Composites Reinforced With Sunn Hemp and Ramie Fiber

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Abstract:

Composite materials have found extensive applications in many fields such as the medical, aerospace, automotive, and sports industries due to their high strength-to-weight ratio and customizable properties. This project investigates the effect of natural fibers specifically Sunn hemp and Ramie on the mechanical properties of laminated composites. Laminates consisting of Sunn hemp and Ramie fibers embedded in an epoxy matrix (LY556) were fabricated using the hand layup techniques as per ASTM standards. The laminates were prepared with varying stacking sequences and fiber orientations to evaluate their influence on mechanical performance. Three different stacking sequences SRSR, RSRS, and SSRR were considered, with fiber orientations of $0/90^\circ$, $\pm 45^\circ$, and $\pm 60^\circ$. The main objective of the study was to determine how stacking sequence and fiber orientation affect tensile strength and Brinell hardness of the composites. Experimental results showed that the SRSR configuration exhibited the highest tensile strength of 52.8 MPa. In contrast, the SSRR sequence with $\pm 60^\circ$ fiber orientation demonstrated the highest Brinell hardness number of 18.08 MPa. These findings confirm that both fiber orientation and stacking sequence significantly influence the mechanical behavior of natural fiber-reinforced composites and are critical parameters for optimizing their performance in practical applications.

Keywords — Sunn Hemp Fiber, Ramie Fiber, Epoxy with Hardener, Tensile Strength, Brinell Hardness

INTRODUCTION

Composite materials are engineered materials made from two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct at the macroscopic or microscopic scale within the finished structure. Only condition is that one of the materials should retain its original physical identity after processing. In composites one of the materials, called the reinforcing phase, is in the form of fibers, sheets, or particles, and is embedded in the other materials called the matrix phase. The reinforcing material and the matrix

material can be metal, ceramic, or polymer. Historical or natural examples of composites are abundant: brick made of clay reinforced with straw, mud wall with bamboo shoots, concrete, concrete reinforced with steel rebar, granite consisting of quartz, mica and feldspar, wood (cellulose fibers in lignin matrix), etc.

I. LITERATURE SURVEY

A study examined how different stacking sequences and fiber orientations affect the strength and failure of Glass/Hemp/Jute/Epoxy laminates.

Using hand layup and tensile testing, results were analyzed with the Taguchi method.[1]

This study tested vetiver/banana fiber composites at 45° and 90° using compression moulding. Results showed that bonding between fiber and matrix affected performance. Longitudinal hybrids had better strength, while 90° vetiver mats had the highest impact resistance.[2]

Natural fibres like jute and ramie offer low cost and good strength but don't bond well with polymers. A 4-layer RJJR stack at 0° gave the best results, with 28.9 MPa tensile and 66.81 MPa flexural strength. A 5% alkali treatment boosted flexural strength by 34.5%, showing the benefits of fiber orientation and treatment.[3]

This study developed jute, glass, and hybrid composites using hand layup. Glass had the highest strength, jute the lowest, and hybrids fell in between. Hybrids also had moderate moisture absorption and thermal conductivity, making them suitable for furniture, interior, and automotive use. [4]

This study tested hybrid glass/carbon epoxy composites with different layer setups. The best strength came from laminates with three carbon and two glass layers, reaching 382.7 MPa. Tensile strength depended heavily on stacking sequence and layer count. [5]

This study explored how stacking sequence and ply orientation affect PALF/carbon hybrid composites. The [0°, 90°] setup with carbon inside had the best tensile strength, while carbon on the outside gave the highest flexural strength. Failures mainly began in the PALF layers, showing issues like fiber pull-out and cracking.[6]

This hand layup composite using ramie and hemp fibers showed strong antibacterial activity and good mechanical properties. Higher ramie content gave the best tensile strength (37.81 MPa), with decent flexural and impact strength. SEM confirmed solid fiber-matrix bonding and structural integrity.[7]

A. FIBERS

Fiber is a thin, thread-like material used to make textiles and fabrics. It is spun into yarn, which is then woven or knitted into cloth. Fibers come from natural sources like plants and animals or are made through chemical processes. Each type has special properties for different uses, such as in clothing, construction, medicine, and packaging.

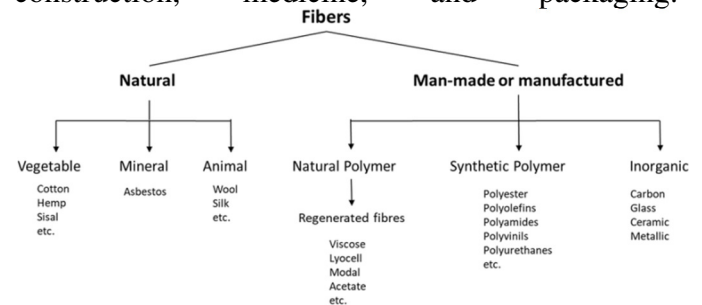


Fig No 1 Classification of Fiber

Natural Fibres

The fibers obtained naturally from both plants and animals are termed as the natural fibers. These fibers are hair-like raw material directly obtainable from different plants and animals.

The natural fibers are further classified into

- Plant fibers come from sources like cotton, jute, bamboo, coconut, flax, and wood.
- Animal fibers like wool and silk come from animals such as sheep, goats, camels, and silkworms.
- Mineral fibers, like asbestos, are made from inorganic materials and are used in industries because they resist fire and acid.

Man-made fibers

Man-made fibers are created using chemicals in industries. They are made from polymers, which are long chains of repeated units. Examples include rayon, nylon, polyester, acrylic, and acetate.

Types of Man-Made Fibers

- Regenerated fibers: Made from natural cellulose (e.g., viscose rayon, bamboo).

- Synthetic fibers: Made from chemicals through polymerization (e.g., polyester, nylon, acrylic).
- Inorganic fibers: Made from metals like copper, silver, and nickel.

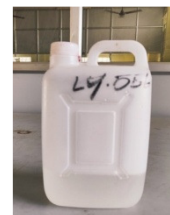


Fig.1 Epoxy (LY556)

Resins

Primary Function: “To transfer stress between reinforcing fibers and to protect them from mechanical and environmental damage”

Types

➤ **Thermoplastic**

Thermoplastics are polymers made by addition polymerization. They can be reshaped when heated due to weak secondary bonds between their molecular chains. Common processing methods include injection moulding, extrusion, and blow moulding. They have lower melting points, tensile strength, and molecular weight compared to thermosetting plastics.

➤ **Thermosetting Plastics**

Thermosetting plastics are made by condensation polymerization and processed using methods like compression and reaction injection moulding. They have strong cross-linked bonds, making them rigid, durable, and heat-resistant. Unlike thermoplastics, they have high melting points and superior tensile strength.

B. EXPERIMENTAL SETUP

Materials and Method

Table 1 Material Table

Si.No	Composite Material	Material Selection
1	Matrix Material	Epoxy(LY556) – Hardener(HY951)
2	Fiber Material	Sunn Hemp & Ramie

Epoxy (LY556)

Epoxy LY556 is a liquid resin based on Bisphenol-A, known for its strong adhesion and versatility. It is widely used in composites, adhesives, coatings, and encapsulation due to its compatibility with different hardeners and fillers.

Hardener (HY951)

Hardener is a low-viscosity, amine-based curing agent used with epoxy resins like LY556. It enables room temperature curing and provides good strength, chemical resistance, and stability in composites, adhesives, and coatings.



Fig.2 Hardener (HY951)

Sunn Hemp Fiber



Fig 3. Sunn Hemp

Sunn Hemp is an eco-friendly natural fiber from the stem of *Crotalaria juncea*, a fast-growing legume native to tropical Asia. Traditionally used in India, it is biodegradable, renewable, and requires minimal environmental impact. The fiber is extracted through retting and separation, then spun into yarn or products like ropes, sacks, nets, and biodegradable composites. It’s valued for its strength, versatility, and sustainability. Additionally, sunn hemp enriches soil, suppresses weeds, and fixes nitrogen, making it beneficial for both green industries and sustainable agriculture.

Ramie fiber



Fig 3. Ramie

Ramie fiber, known as one of the strongest natural textile fibers, is derived from the bark of *Boehmeria nivea* and is often called "China Grass" or "Grass Linen." Used since ancient times, including by Egyptian royals, ramie is valued for its strength, luster, and absorbency. It's mainly blended with cotton and silk for making clothes, curtains, towels, and industrial fabrics. The waste fiber is used in currency notes and cigarette papers, while the woody part is used for biodegradable products like plywood and fiberboard. Ramie is primarily grown in China, which accounts for over 96% of global production. In India, cultivation is limited to small areas in Assam and North Bengal but has potential in several northeastern states due to suitable climate conditions.

C. Collection Of Material

The fabrication process begins with gathering materials and tools. The main materials are natural bast fibers—Sunn hemp and Ramie—and a thermosetting epoxy resin (LY 556) with hardener (HY 951) in a 10:1 ratio. A flat plywood base with a glass or acrylic sheet is used to create a smooth, non-porous surface. Tools like rollers and brushes help apply resin evenly and remove air bubbles during lamination.

Fabrication Procedure

The fabrication process begins by hand lay-up techniques and selecting an open, clean, and dust-free workspace. The plywood board is positioned as the working surface, and the glass sheet is firmly fixed on top of it to serve as the mould base. Following this, natural fiber mats of Sunn hemp and Ramie are prepared by cutting them into square shapes of 30 cm × 30 cm using accurate measuring tools and a sharp cutter. The fibers are cut according to the required orientations: 0°/90° (bidirectional), ±45° (angled cross-ply), and ±60° (angled cross-ply).

Once cut, the fibre layers are arranged on the mould surface in specific stacking sequences based on the sample type: SRSR for 0°/90° orientation, RSRS for ±45° orientation, and

SSRR for ±60° orientation. After the fibers are properly positioned, epoxy resin and hardener are mixed thoroughly in the prescribed ratio of 10:1 (by volume). The mixed resin is then carefully poured over the fiber layers by hand lay-up method, ensuring complete saturation. A hand lay-up method used a roller is used to uniformly spread the resin and to compress the layers, effectively removing any air bubbles trapped within the laminate. This step is crucial to achieving optimal bonding between the fibers and the resin matrix, resulting in a structurally sound and defect-free composite laminate.

Once the composite layer is correctly aligned within the mould, a plywood sheet is placed on top to ensure uniform pressure distribution during the curing process. The assembly is then subjected to curing, either under ambient conditions for 24 to 48 hours or using an accelerated protocol at 60°C for 2 hours. During this period, a compressive load greater than 10 kg is applied to enhance interfacial bonding and reduce the formation of voids within the laminate. After curing, the composite was carefully demoulded, and any excess material was trimmed to achieve a consistent and precisely defined final geometry. Specimens for mechanical testing were then prepared accordingly. For the tensile test, samples were cut in accordance with ASTM D638 standards, with dimensions of 165 mm × 19 mm and a thickness of 3 mm. In addition, a separate specimen was prepared for Brinell hardness testing, following the ASTM E10 standard.



Fig.4 SRSR (0°/90°)



Fig.5 RSRS (±45°)



Fig.6 SSRR(±60°)

TABLE 2 TABLE OF EXPERIMENT

Sl.No	DIFFERENT STACKING SEQUENCE OF FIBER	ANGLE OF ORIENTATION	MATRIX MATERIAL (EPOXY LY556 & HARDENER HY951)
1	SRSR	0/90	ROM 10:1 75%

2	RSRS	$\pm 45^\circ$	ROM 10:1 75%
3	SSRR	$\pm 60^\circ$	ROM 10:1 75%

Universal Testing Machine



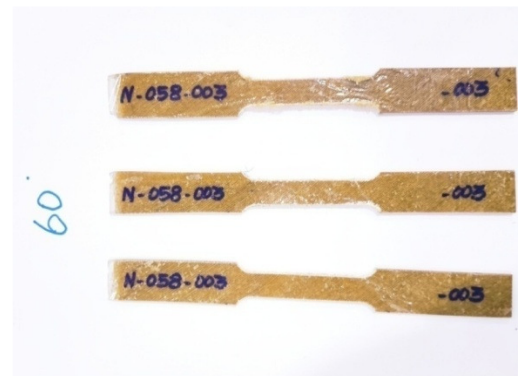
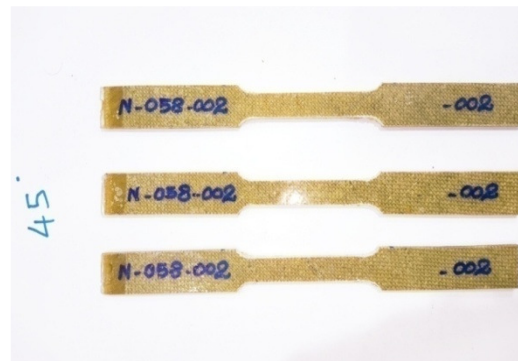
Fig 7. Universal Testing Machine (UTM)

The Insight 100 SL is a manual universal testing machine (UTM) used to measure how materials respond to different forces like tension, compression, bending, and shear. It has a 100 kN capacity and runs on a standard 230V power supply. The machine includes precise servo controls, accurate load cells (meeting ASTM and ISO standards), and Test Works software for automated testing and data analysis. It supports various testing standards for metals, plastics, and rubber, making it ideal for industries like aerospace, automotive, construction, and R&D.

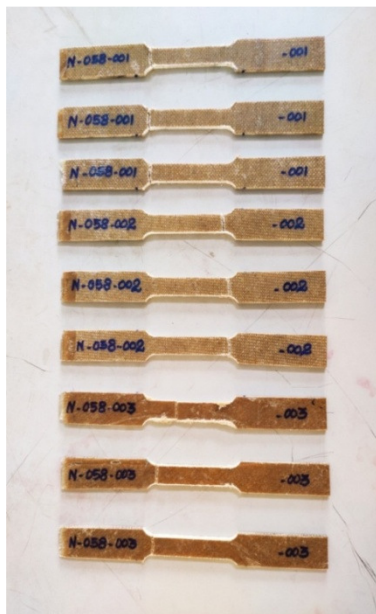
Brinell Hardness Machine

The Brinell Hardness Testing Machine measures the hardness of metals, especially those with coarse or uneven grain like castings and forgings. It uses a 10 mm steel or carbide ball pressed into the material under a load of 500–3000 kgf (commonly 3000 kgf for steel) for 10–15 seconds. After the load is removed, the indentation diameter is measured with a microscope, and the Brinell Hardness Number (BHN) is calculated. This method follows ASTM E10 and ISO 6506 standards.

TENSILE STRENGTH BEFORE TESTING OF SAMPLES



AFTER TESTING OF SAMPLES



Maximum Tensile Strength of Samples

Table 5 Comparison of Maximum Tensile Strength

Different stacking sequence	Maximum Tensile Strength of different Samples			Maximum Tensile Strength (E) Avg in MPa
	Sample 1	Sample 2	Sample 3	
SRSR	52.23667	49.78363	46.48101	49.50044
RSRS	31.77974	30.441	31.389	31.20325
SSRR	32.28553	33.02381	31.3066	32.20531

D. Result and Discussion

TABLE 3 Experimental Results of Tensile Strength in MPa

Si . No	Different Stacking Sequence Of Fiber	Angle Of Orientation	Maxi. Load in kN	Maxi. Tensile Strength in MPa	Young's Modulus (E) in MPa	Brinell Hardness Number in MPa
1	SRSR	0/90°	2.340	52.8	52.23667	10.2
2	SRSR	0/90°	2.221	50.2	49.78363	
3	SRSR	0/90°	2.094	46.9	46.48101	
4	RSRS	±45°	1.574	32.0	31.77974	17.5
5	RSRS	±45°	1.538	30.7	30.441	
6	RSRS	±45°	1.572	31.6	31.389	
7	SSRR	±60°	1.528	33.5	32.28553	18.08
8	SSRR	±60°	1.468	33.3	33.02381	
9	SSRR	±60°	1.447	31.5	31.3066	

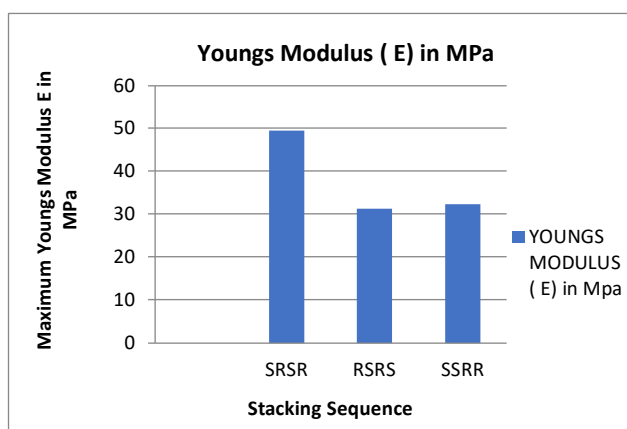


FIG 9. Comparison of young's modulus for different stacking sequence

Based on the results of the tensile test, the stacking sequence SRSR demonstrates the highest tensile strength among the tested configurations, as indicated by its superior Young's Modulus. The average Young's Modulus for SRSR is 49.50 MPa, which is significantly higher than that of SSRR (32.21 MPa) and RSRS (31.20 MPa). A higher Young's Modulus signifies greater stiffness and resistance to deformation under tensile loading, indicating that the SRSR stacking sequence offers the most effective mechanical performance in terms of tensile strength. The mechanical properties of natural fiber composites are significantly influenced by the fiber orientation and stacking sequence. These composites demonstrate high potential for applications in medical, aerospace, automotive, and sports industries due to their customizable mechanical characteristics.

BRINELL HARDNESS TESTS

Si.No	Different Stacking Sequence of Fiber	Angle of Orientation	Brinell Hardness Number in MPa
1	SRSR	0/90°	10.2
2	RSRS	±45°	17.5
3	SSRR	±60°	18.08

TABLE 6. Experimental Results of Brinell Hardness Number

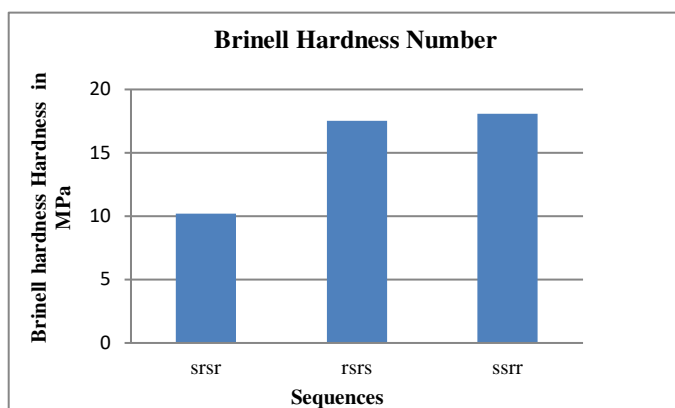


Fig10.Experimental Results of Brinell Hardness Number

A brinell hardness test was conducted on composite specimens with different stacking sequences and fiber orientation angles to evaluate their mechanical properties. The stacking sequences examined were SRSR, RSRS, and SSRR, with fiber orientations of 0/90°, ±45°, and ±60°, respectively. The results revealed that the SSRR stacking sequence with a ±60° orientation exhibited the highest Brinell hardness number (18.08 MPa), followed by RSRS with a ±45° orientation (17.5 MPa). The lowest hardness value was observed in the SRSR configuration with a 0°/90° orientation, recording a Brinell hardness number of (10.2 MPa).

II. CONCLUSIONS

The fabrication of new epoxy-based composites using different stacking sequences and fiber orientations reinforced with sunn hemp and ramie fibers has been successfully done through experimental methods.

- As per experiment results shows that variant (SRSR) maximum tensile strength of 52.8 MPa, maximum Young's Modulus of 49.50 MPa compare to other sequences of composite.
- The other sequence results shows tensile strength SSRR (32.21 MPa) and RSRS (31.20 MPa).
- The Brinell hardness strength results revealed a different trend. The SSRR stacking sequence with a ±60° fiber orientation achieved the highest surface hardness at 18.08 MPa, followed by the RSRS configuration with a ±45° orientation at 17.5 MPa. Notably, the SRSR sequence, despite its high tensile strength, recorded the lowest hardness value of 10.2 MPa, associated with a 0°/90° orientation.

The mechanical properties of natural fiber composites are significantly influenced by the fiber orientation and stacking sequence. These composites demonstrate high potential for applications in **medical, aerospace, automotive, and sports industries** due to their customizable mechanical characteristics.

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