

MECHANICAL TESTING AND CHARACTERIZATION OF HEMP FIBER REINFORCED POLYMER COMPOSITES WITH SiO₂ FILLER

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Abstract — The growing demand for sustainable, high-performance materials has sparked interest in natural fiber-reinforced polymer composites. This study focuses on developing hemp fiber reinforced polymer composites with silicon dioxide (SiO₂) filler and systematically evaluating their mechanical and wear properties. Hemp fibers were chosen because they are biodegradable, lightweight, and have good specific strength, making them a practical alternative to traditional synthetic reinforcements. The composite specimens were made using an appropriate polymer matrix mixed with different amounts of hemp fiber. Adding SiO₂ filler is expected to increase stiffness, hardness, and wear resistance by reinforcing the polymer matrix. A series of experiments were conducted to evaluate the performance of the developed composites. Flexural testing measured bending strength and stiffness, while impact testing assessed the material's capacity to absorb energy during sudden loads. Hardness testing was done to gauge surface resistance to deformation. Wear behaviour was examined using standard wear tests to analyze material loss from friction. Additionally, thermal conductivity tests evaluated the composites' heat transfer characteristics. The results show that adding SiO₂ filler significantly improves the mechanical properties of the hemp fiber composites. There was an increase in flexural strength and hardness due to better stress transfer between the matrix and the reinforcement. Impact strength showed moderate improvement based on filler content, and wear resistance increased significantly, indicating less material degradation under sliding conditions. In summary, the hemp fiber reinforced polymer composites with SiO₂ filler offer a good mix of mechanical strength, wear resistance, and thermal properties. These eco-friendly composites hold great promise for use in automotive, construction, and lightweight structural applications, supporting the development of sustainable materials.

Keywords: Hemp Fiber, Polymer Composites, SiO₂ Filler, Mechanical Properties, Wear Resistance, Thermal Conductivity.

I. INTRODUCTION

1.1 Overview of Polymer Composites

Polymer composites are sophisticated engineering materials made up of a combination of a polymer matrix and reinforcing materials such as fibers or particle fillers. The matrix is commonly made up of either a thermosetting or thermoplastic polymer, which holds the reinforcing materials together and distributes the load. The reinforcement is responsible for giving strength and rigidity to the composite material. Polymer composites find extensive applications in aerospace, automotive, maritime, and construction sectors owing to their lightweight nature, high strength.

1.2 Natural Fiber Reinforced Composites (NFRCs)

Natural fiber reinforced materials (NFRCs) are attracting more and more attention as being an eco-friendly replacement for synthetic fiber composites. NFRC materials minimize reliance on non-renewable materials and help lower the carbon footprint. Moreover, natural fibers are more economical than synthetic fibers and safer to handle.

1.3 Importance of Hemp Fiber in Composite Materials

Fibers derived from hemp are one of the best natural fibers that can be used in composite manufacturing owing to their mechanical performance, availability, and sustainability. They demonstrate high tensile strength, low density, and good moisture absorption properties. Moreover, hemp fibers have better sound and heat insulation properties. The addition of hemp fiber in polymers results in

improved stiffness and strength of the composites while decreasing their weight.

1.4 Role of Fillers in Polymer Composites

Fillers are added to composite polymers in order to change the property of the composite material. These can be either organic or inorganic substances in the form of particles that are used to modify the properties of stiffness, hardness, and wear resistance. In addition, the fillers also help in lowering the cost of production by substituting for some percentage of the polymer matrix itself.

1.5 Significance of SiO₂ (Silica) Filler

Silicon dioxide (SiO₂), also referred to as silica, is an inorganic material extensively employed as filler in composites owing to their superior physical and thermal properties. Incorporation of SiO₂ particles into composites increases their hardness, modulus, and resistance to abrasions. Moreover, SiO₂ filler also confers thermal stability to the composite material, and at the same time decreases the wear rate under friction conditions. In addition, incorporation of SiO₂ particles also increases adhesion at the interface between fibers and matrix.

1.6 Mechanical Properties of Fiber Reinforced

Composites The mechanical properties of the composites play an important role in determining their performance. The flexural strength determines how resistant the composite material is against deformation under the applied bending force, whereas the impact strength reflects the capacity of the material to withstand impacts by absorbing the energy produced during the process. This property is linked with surface resistance against scratching and penetration.

1.7 Thermal Properties of Composites

Thermal properties such as thermal conductivity and thermal stability are important for materials exposed to varying temperature conditions. Natural fiber composites generally have low thermal conductivity, making them suitable for insulation applications. The addition of inorganic fillers like SiO₂ can alter thermal behaviour by improving heat resistance and stability.

1.8 Need for Hybrid Composites (Fiber + Filler)

The use of hybrid composites involves the mixing of natural fibers with fillers to attain a synergy of the mechanical, thermal, and tribological properties of these materials. Though natural fibers offer strength and eco-friendliness, filler additives improve their hardness, durability, and thermal stability. Hybrid composites have gained more popularity in engineering fields owing to their numerous advantages over other forms.

1.9 Challenges in Natural Fiber Composites

Although natural fiber composites have certain benefits, they do have several problems as well, such as water absorbency, weak bonding, and inconsistencies in the physical characteristics of the fibers themselves. This can negatively impact the mechanical strength of the composite material and decrease its longevity. Surface modification and using fillers such as silicon dioxide could solve these issues.

1.10 Overview of the Proposed Work

In this experiment, specimens will be prepared by reinforcing composite materials with hemp fibers and adding silicon dioxide (SiO₂) particles as filler. All standard tests will be conducted for analyzing mechanical (flexural strength), impact resistance, hardness, wear resistance, and thermal conductivity of the composite material. The test results will be studied to determine the effect of silica filler on the composite material's performance.

II. LITERATURE REVIEW

2.1 Introduction to Literature Review

Literature review is an integral component of research, as it helps in comprehending the past work done in the area in question. It facilitates in determining the advancements that have been achieved in the area, and also, it assists in defining the limitations of research carried out previously and the scope of the current study. Numerous works have been accomplished concerning polymers reinforced with either synthetic or natural fibers within the area of composite materials. Recently, natural fiber composites have become popular among researchers because of environmental and

sustainability issues. Further, the efforts have also been made to enhance their performance through the use of various fillers, for instance, silicon dioxide (SiO₂).

Research Article 1

K. G. Prakash, Ranga Vittal H. K, A. Thimmana Gouda, “Characterization of Hemp/Glass Reinforced Epoxy Hybrid Composites with Filler Material for the Engineering Application,” International Journal of Recent Technology and Engineering (IJRTE) ISSN: 2277-3878, Volume-8 Issue-6, March 2020.

Contribution: The study makes a notable contribution to the field of composite materials by introducing cenosphere as a filler material in hybrid composites. Cenosphere is an industrial waste from thermal power plants. The research combines natural fiber (hemp) and synthetic fiber (glass) in an epoxy matrix to create a cost-effective, eco-friendly alternative to traditional materials. This work supports sustainable engineering by promoting the use of biodegradable fibers and industrial by-products while improving material performance, especially for applications like automobile components.

Experimental Roots: T

The experimental methodology involves the fabrication of hybrid composite specimens using the hand lay-up technique. The researchers incorporated different weight fractions of hemp fiber, glass fiber, and cenosphere filler into the epoxy matrix. They tested the prepared samples according to ASTM standards to assess mechanical properties such as tensile strength, impact strength, wear resistance, and vibration behaviour.

Outcome / Results:

The results show that adding cenosphere filler significantly improves some mechanical properties of the hybrid composite. The mix of hemp and glass fibers enhances strength while keeping the material lightweight. The study found better performance in areas like impact resistance and wear behaviour, making the composite fit for engineering applications.

Research Article 2

Kevin Conley et al., “Silica-Silicon Composites for Near- Infrared Reflection: A Comprehensive

Computational and Experimental Study,” Department of Applied Physics, Aalto University School of Science, Finland, 2020.

Contribution:

The study makes a valuable contribution to the field of near-infrared (NIR) reflective materials by integrating computational modeling with experimental validation. It demonstrates that incorporating a small fraction of semiconductor particles, particularly silicon, into a silica matrix can achieve high broadband NIR reflectance while minimizing energy losses. Furthermore, the work establishes a clear relationship between microstructural features and optical performance, highlighting a scalable and cost-effective pathway for thermal management applications.

Experimental Roots: The study employs pulsed electric current sintering (PECS) to fabricate silica-silicon composite compacts using both nano- and micro-sized silica powders. Comprehensive characterization techniques such as X-ray diffraction (XRD), scanning electron microscopy (SEM), and UV-Vis-NIR spectroscopy are used to evaluate structural and optical properties.

Outcome / Results:

The results reveal that the developed composites achieve NIR reflectance values of up to 72% for a 3 mm thick sample containing only 1% silicon. The research concludes that silica-silicon composites fabricated via PECS are highly effective for controlling radiative heat transfer and show strong potential for thermal insulation, energy systems, and high-temperature technologies.

Research Article 3

Kanyarat Boonsomwong et al., “Rejuvenating the structure and rheological properties of silica nanocomposites based on natural rubber,” Department of Chemistry, Mahidol University, Bangkok, Thailand, Elsevier, 2020.

Contribution: The study significantly enhances our understanding of the structural and rheological behavior of silica-filled natural rubber nanocomposites. It explores how mechanical processing through milling and thermal annealing affect these materials. The research introduces the idea of “rejuvenation,”

where thermal treatment repairs the silica network that breaks down during processing.

Experimental Roots: The study uses a latex compounding method to create silica-natural rubber nanocomposites with different filler contents, ranging from 10 to 50 phr. The research employs advanced techniques such as small-angle X-ray scattering (SAXS), differential scanning calorimetry (DSC), thermogravimetric analysis (TGA), and rheological measurements for structural and dynamic analysis.

Outcome / Results: The results indicate that milling gradually disrupts the silica filler network, leading to better dispersion but less mechanical reinforcement. In contrast, thermal annealing at high temperatures restores the silica network structure, reversing milling effects and increasing stiffness. Optimizing processing and thermal treatment can help tailor nanocomposite properties for industrial applications.

Research Article 4

Mohan Kumar Anand Raj et al., “Study on the mechanical Characteristics of a natural Fiber based hybrid polymer composite,” Nature Portfolio, 2025.

Contribution: The study plays an important role in advancing sustainable hybrid polymer composites by systematically analyzing the mechanical behavior of natural fiber-reinforced systems using sisal, flax, and ramie fibers. The findings clearly demonstrate how hybridization and fiber arrangement influence load-bearing capacity, interfacial bonding, and overall mechanical performance.

Experimental Roots: The composites were fabricated using a hand lay-up method followed by compression molding to ensure uniform thickness, with a fiber-to-epoxy ratio of 70:30. Mechanical characterization included tensile, flexural, impact, and hardness tests. Scanning electron microscopy (SEM) was used to analyze fracture surfaces and identify defects such as fiber pullout, voids, and matrix cracking.

Outcome / Results: The F/S/S/S/F configuration exhibited the highest tensile strength (36.28 MPa). Overall, hybrid composites consistently outperformed pure fiber systems. The research establishes that

optimizing stacking sequences can significantly enhance mechanical properties, making these composites suitable for lightweight structural and engineering applications.

Research Article 5

R. Jumaidin, S.M. Sapuan, and H. Ismail, “Biofiller- Reinforced Biodegradable Polymer Composites,” First edition published by CRC Press, Boca Raton, 2021.

Contribution: The reviewed work makes a significant contribution to the field of sustainable materials by presenting a comprehensive overview of biofiller-reinforced biodegradable polymer composites as environmentally friendly alternatives to conventional petroleum-based plastics. It highlights diverse applications across industries such as packaging, automotive, construction, and biomedical sectors.

Experimental Roots: The literature compiles a wide range of fabrication and characterization methods used in the development of bio-composites. Various biofillers including coconut shell, eggshell, banana fiber, microalgal biomass, and cellulose nanofibers are incorporated into polymer matrices such as polyester, epoxy, PLA, PHB, and PBS under controlled processing conditions.

Outcome / Results: The incorporation of biofillers improves the mechanical and thermal properties of biodegradable polymers. Tensile strength, Young’s modulus, and flexural behavior show clear enhancement. Interfacial adhesion also improves with optimal filler content. However, moisture sensitivity remains a key limitation. Overall, these composites show strong industrial potential with further optimization.

2.2 Research Gap

Despite significant advancements in composite materials, several research gaps remain to be addressed. Most existing studies focus separately on natural fiber composites or synthetic fiber composites, with limited attention given to optimized hybrid systems that incorporate fillers for balanced performance.

The combined effect of stacking sequence and filler interaction is not extensively explored, particularly in natural fiber-based hybrid

composites. While many studies report improvements in mechanical properties, less emphasis is placed on long-term durability, moisture resistance, and environmental stability. In addition, there is a lack of standardized processing techniques to ensure uniform filler dispersion and consistent composite quality.

Furthermore, optimization of key parameters such as fiber content, filler ratio, and composite thickness remains incomplete in many studies. There is also a need to develop cost-effective composites that can simultaneously achieve high mechanical strength, lightweight properties, and environmental sustainability. Addressing these gaps is essential for advancing the practical application of composite materials in engineering fields.

III. MATERIALS AND METHODOLOGY

The current chapter describes in detail the materials used, fabrication, specimen preparation, and methods employed in this research work. The main purpose of the present study is to prepare the composites using hemp fiber as reinforcement material and SiO₂ as a filler material and characterize its mechanical, wear, and thermal properties.

3.1 Problem Identification

In recent times, sustainable and environmentally friendly materials have become an essential requirement in engineering applications. Traditional materials like metals and fiber composite materials such as glass fiber and carbon fiber provide higher strength and durability but pose certain disadvantages such as high costs, inability to degrade, and environmental pollution during manufacturing and disposal processes.

Natural fiber-reinforced polymer composites have provided a possible solution due to their environmentally friendly characteristics, low weight, and economical nature. Despite different types of natural fibers being used in composite materials, the most preferred one is the hemp fiber because of its favourable mechanical properties and accessibility. Nevertheless, natural fiber composites have certain disadvantages such as lower strength levels

when compared to synthetic fiber composites, poor wear properties, and inconsistent property values due to moisture absorption and weak fiber-matrix interactions.

The addition of inorganic fillers like silicon dioxide (SiO₂) in polymer based composites has been found to improve various characteristics including mechanical strength, wear resistance, and thermal stability. However, the magnitude of improvement greatly relies on other factors like the type of filler used, its amount and interaction with fiber/matrix.

3.2 Problem Statement

Composite materials based on natural fibers have gained significance, especially those which are reinforced with fibers like hemp. Such materials face limitations of low strength, wear resistance, and poor thermal conductivity compared with synthetic composite materials.

The incorporation of fillers, such as silicon dioxide (SiO₂), could prove beneficial in enhancing the performance of the composites. Nevertheless, the effect of the SiO₂ filler on the performance of the mechanical property of the flexural strength, impact strength, hardness, wear and thermal conductivities of the hemp fiber reinforced polymer composites has yet to be fully determined.

3.3 Materials Used

1. Hemp Fiber

Hemp fibers are one of the best natural fibers for composite manufacturing owing to their mechanical performance, availability, and sustainability. They demonstrate high tensile strength, low density, and good moisture absorption properties. Hemp fibers have better sound and heat insulation properties. The addition of hemp fiber in polymers results in improved stiffness and strength while decreasing weight.

Fig. 3.1 – Hemp Fiber

2. Polymer Matrix (Resin)

Epoxy or polyester resins were selected for the polymer matrix because of their excellent mechanical and adhesive properties, as well as ease of processing. Resin contributes to the

rigidity, shape, and environmental resistance of the composite. The addition of an appropriate hardener initiates the curing process. The proportions between the resin and hardener were kept according to manufacturer recommendations to ensure complete curing and optimal performance.

3. SiO₂ (Silica)

Filler Silica, or silicon dioxide (SiO₂), was used in this study as a filler material. Silicon dioxide is an inorganic substance which has the characteristic features of high hardness, heat resistance, and wear resistance. With the addition of SiO₂ filler, mechanical properties of the composite such as hardness and rigidity increase. Moreover, the wear resistance property increases due to decreased material loss during friction. The silica particles also facilitate better fiber-matrix bond formation. Fig. 3.2 – Filler

IV. 3.4 FABRICATION OF COMPOSITE (HAND LAYUP METHOD)

3.4.1 Introduction to Fabrication Method

The process of hand lay-up technique was used to fabricate composite samples. Hand lay-up is among the easiest and most economical techniques that can be used in manufacturing fiber-reinforced composites. The technique does not use any special equipment.

3.4.2 Mould Preparation

The mould was chosen with a flat surface. The mould was cleaned properly to get rid of any dirt, grease, and dust particles from its surface. Any suitable releasing agent such as wax or PVA (polyvinyl alcohol) was sprayed over the mould surface.

3.4.3 Preparation of Resin Mixture

The mixing of resin with hardener was done according to the required ratio, as per the instructions from the manufacturer. The process of mixing was ensured so that the hardener gets evenly distributed in the resin. Subsequently, SiO₂ filler was added to the resin with continuous stirring so that there is no agglomeration.



Fig. 3.3 – Resin Mixture

3.4.4 Layup Process

A thin layer of resin was initially laid on the mould. A layer of hemp fibers was then added to the resin. A second layer of resin was added over the fiber. This was then followed by further layering of resin until the desired thickness was achieved. Bubbles of air were squeezed out using rollers or brushes to ensure that all the layers were properly adhered to one another. Care was exercised to ensure that uniformity was maintained.



Fig. 3.4 – Layup Process

3.4.5 Curing Process

Once the lay-up procedure was completed, the composite material was allowed to cure at room temperature for a time period ranging from 24 to 48 hours without any disturbance. Curing is a very important stage which helps the resin to form a good bond with the reinforcement.

3.5 Specimen Preparation

Post curing, the composite laminate was subsequently removed from the mould. The specimens were thereafter sectioned into standard sizes as required for testing purposes. The specimens were finished at their edges so that stress concentrations could be avoided when testing was conducted. Dimensions were

precisely maintained to get accurate and reproducible data from the tests.

3.6 Experimental Testing Methods

3.6.1 Flexural Test

Flexural testing was carried out to assess the flexural strength and modulus of the composite material. It was done in the Universal Testing Machine (UTM) in three-point bending. The material was loaded incrementally until failure took place. The flexural strength is an indication of the material's resistance to bending.

3.6.2 Impact Test The energy absorption test was conducted to determine the energy that the composite absorbs under sudden loading. This test gives an insight into the toughness and ability of the material to resist breakage. This test is especially significant for materials that will experience dynamic loads.

3.6.3 Hardness Test The test was done to check the resistance of the surface to indentations. This test shows the resistance of the composite material to any form of wearing and distortion on the surface.

3.6.4 Tensile Test The purpose of performing the tensile test on the composite material consisting of hemp fibers and reinforced by SiO₂ was to ascertain the strength and deformation characteristics of the sample in response to tensile loads. The load applied and the resulting deformation was recorded. From this data, tensile strength and strain were determined.

3.6.5 Thermal Conductivity Test The thermal conductivity test is performed on a composite sample to evaluate its heat transfer characteristics. This is accomplished by applying controlled heat flux using standard apparatus and measuring the temperature gradient across the sample.

3.7 Testing Standards

All experiments were carried out following the standard methodology prescribed in standards such as ASTM and ISO. These standards ensure consistency, accuracy, and reliability of the experimental results. Using the standard methodology will help in comparing the findings with existing studies.

3.8 Plan of Experiment

In this experiment, an organized approach was adopted. Composites were made using certain proportions of hemp fibers and SiO₂ filler. All five tests were conducted on each specimen, and the results were noted. Analysis of the experimental data collected from various tests was done. The influence of the SiO₂ filler on the composite's behavior was determined by comparing these results.

3.9 Summary of Methodology

The methods used for this research include material selection, fabrication of the composite through the hand lay-up technique, preparation of specimens, and testing to determine their properties. Such an approach helps to analyze the mechanical, wear, and thermal performance of polymer-based composites made from hemp fibers and silicon dioxide fillers.

IV. RESULTS AND DISCUSSION

4.1 Introduction

The results of the experiments carried out using tests of different kinds performed on polymer matrix composite with reinforcement made of hemp fiber and containing SiO₂ filler will be provided in this chapter. The tests included flexural test, tensile test, impact test, hardness test, wear test, and thermal conductivity test. The results will help estimate the effect of SiO₂ filler on the composite.

4.2 Flexural Test Results and Discussion

This flexural test was done to measure the bending strength of the composite material.

TEST STANDARD: ASTM D 790

S.NO	SAMPLE ID	IMPACT ENERGY (J)
1	1	2.9
2	2	3.2

Discussion: The experimental results indicate a noticeable improvement in the impact strength of the composite material, with values increasing from 2.9 J to 3.2 J, representing a gain of 0.3 J. This improvement suggests that the composite has become more resilient and less prone to catastrophic failure when subjected to dynamic stresses. The enhancement in toughness can be attributed to the incorporation of SiO₂ filler within the composite matrix. Specifically, SiO₂

particles act as barriers to crack propagation, effectively arresting or deflecting cracks as they form and attempt to grow under stress.

4.2 Hardness Test

Results and Discussion The hardness test measures the material's resistance to indentation.

TEST STANDARD: ASTM D 2240

S.NO	SAMPLE ID	MEAN (Shore D)
1	1	75.6

Discussion: The recorded hardness value of 75.6 indicates that the composite material has a strong resistance to deformation and surface wear. This means it is less likely to undergo indentation, scratching, or abrasion when exposed to external forces. The increase in hardness can be attributed to the addition of SiO₂ filler, which is naturally rigid and hard. These particles reinforce the composite by restricting internal movement and enhancing load distribution, thereby improving its overall resistance to wear and extending its service life in demanding applications.

4.3 Thermal Conductivity

Results and Discussion Thermal Conductivity test helps to evaluate the heat conductivity of the composite.

TEST STANDARD: ASTM C 177

S.NO	SAMPLE ID	THERMAL CONDUCTIVITY (W/m·K)
1	1	0.42

Discussion: A thermal conductivity value of 0.42 W/m·K indicates that the composite material exhibits moderate heat transfer capability. This means it can conduct heat more effectively than purely insulating materials while still providing some resistance to rapid temperature changes. The improvement in thermal conductivity is mainly due to the inclusion of SiO₂ as a filler. SiO₂ enhances the formation of conductive pathways within the composite, allowing heat to flow more efficiently through the material.

4.4 Tensile Test

Results and Analysis Tensile testing measures the material's strength under axial loading.

TESTING STANDARD: ASTM D 3039

S.NO	SAMPLE ID	LOAD (N)	STRAIN	TENSILE STRENGTH (MPa)
1	1	700	0.01	16.85
2	2	300	0.01	30.62

Discussion: The tensile strength of Sample F1A (16.85 MPa) is much lesser than that of Sample F1B (30.62 MPa). The discrepancy could be attributed to variations in fiber distribution, filler amount, or adhesion. The tensile strength of Sample F1B is considerably higher, suggesting superior load-carrying ability and stronger bond formation. It is clear from the findings that the correct distribution of SiO₂ filler improves tensile strength.

4.5 Comparative Analysis of Results

Overall discussion from the experimental study indicates that the incorporation of SiO₂ filler significantly enhances the performance of the composite material. A notable improvement is observed in flexural strength, indicating better resistance to bending stresses.

The impact strength shows a moderate increase, suggesting improved ability to absorb sudden loads. The hardness of the composite is relatively high, which reflects greater resistance to surface deformation and wear. However, the tensile strength varies depending on the composition, highlighting the importance of optimizing the filler content for best results. Thermal conductivity is found to be moderate, making the material suitable for applications requiring controlled heat transfer. Overall, the inclusion of SiO₂ filler positively influences most of the mechanical and physical properties of the composite.

4.6 Effect of SiO₂ Filler on Composite Performance

The incorporation of SiO₂ filler plays a crucial role in improving the composite properties: it increases hardness and stiffness, enhances wear resistance, improves load transfer between fiber and matrix, slightly increases thermal

conductivity, and reduces crack propagation. Thus, SiO₂ filler significantly improves the overall performance of hemp fiber composites.

4.7 Graphical Representation of Results



Fig. 4.1 – Flexural Strength Comparison Graph

4.8 Graphical Representation of Results

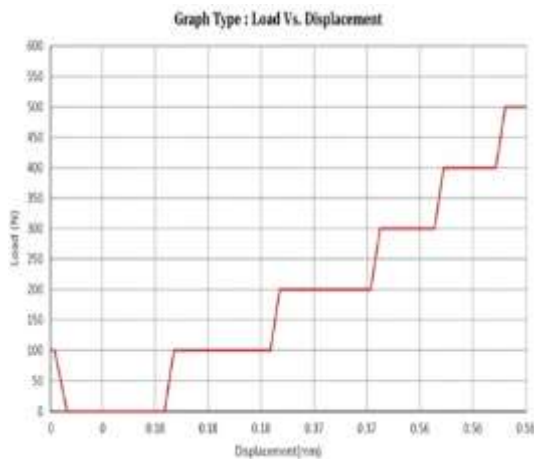


Fig. 4.1 – Flexural Strength Comparison Graph

4.9 Overall Discussion on Performance

The experimental findings clearly demonstrate that the polymer composite reinforced with hemp fibers and SiO₂ filler exhibits enhanced overall performance in terms of mechanical, tribological, and thermal properties. Notable improvements are observed in flexural strength, hardness, and resistance to wear, which indicate the effective role of silica particles in strengthening the composite structure.

CONCLUSION

Conclusion

In this research, composite samples with reinforcing hemp fibers containing filler SiO₂ were made via hand lay-up. These samples were then investigated in terms of their mechanical, wear, and thermal properties such as flexural strength, tensile strength, impact strength, hardness, wear, and thermal conductivity.

As can be seen from the results obtained from the experiments, the use of silica filler in the composition positively affects the characteristics of the material. Flexural strength has significantly been increased, as well as impact strength, which denotes improved toughness. Moreover, the hardness of the material is quite high, meaning that it is resistant to deformation and wear. The addition of hard silica reduces wear because the silica particles decrease the amount of material abrasion by rubbing against each other.

Variation was noted in tensile properties in different sample materials due to differences in fiber distribution and bonding process. The values of thermal conductivity denote that this material is moderately conductive to heat. Thus, the obtained results show that these polymer composites can serve as eco-friendly engineering materials with good wear and mechanical properties.

5.1 Key Findings

The flexural strength was greatly enhanced (up to 67.42 MPa), suggesting better bending strength. The impact strength is enhanced as well as toughness. High hardness value (75.6) suggests good resistance to indentation and wear. The tensile strength differs among samples, with maximum strength reaching 30.62 MPa. Better wear resistance is achieved by using the SiO₂ filler. The thermal conductivity (0.42 W/m·K) is moderate, suggesting good heat transfer.

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