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Investigation of Mechanical Behaviour in Brake Shoe Liner by Using Composite and Nano Materials

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Abstract

The mechanical performance of the brake shoe liners dictates the safety and efficiency of the vehicles; thus, brakes are very vital in ensuring controlled deceleration and stopping. In the past few decades, composites have significantly impacted the automotive industry through lighter, stronger, and sturdier alternatives to traditional materials improving overall performance. Nano additives are of key importance in such composites, improving not only the mechanical properties but, more significantly, the tribological ones when used in wear strength-stress conditions. This research paper addresses the mechanical and tribological properties of natural fiber brake shoe liner material, such as banana and coir, used as a base material for the composite. Besides, nano additives like aluminum oxide (Al_2O_3) and silicon carbide (SiC) are added to 10% weight ratio in composite samples for further improvement in the properties of these natural fiber composites. The nanomaterials, added to the brake lining, will improve the hardness, wear resistance, and thermal stability of such materials. These are factors to be considered in determining its service life and ensuring that the automotive brake system is reliable. The experimental results give the comparative analysis of the mechanical properties that are tensile strength, hardness, and wear resistance between the base composite and the nano-reinforced composite. Sample 4 and Sample 5 performed better when compared to other specimens. The wear rate of these specimen increases slowly as the distance increases. The COF obtained was 0.4 which is equal to COF of semi-metallic brake liner. Both Sic and Al2O3 provide same range COF. But Al2O3 provides less wear rate in long run. The test results present that the addition of Al_2O_3 and SiC significantly enhance the brake liners' performance.

Keywords: Banana fibre, coir fibre, Al_2O_3, SiC, epoxy resin, tensile test, flexural test, wear test, water absorption test, compression test.

INTRODUCTION

The work is important for solving the main problems of the industry, especially brake shoe liners, with improved mechanical and tribological properties: better wear resistance, hardness, tensile strength, and thermal stability. The conventional materials degrade fast, hence putting the vehicle safety and the composites often have to be replaced frequently. Addition of nano additives like aluminum oxide and silicon carbide improve the performance and lifespan of the natural composites. The use of banana and coir comes up as a sustainable alternative to synthetic material with less environmental harm for emission and waste alongside reducing the bad and harmful emissions into the atmosphere. These nano-reinforced composites ascertain uniform coefficient of friction in addition to a minimized wear rate over a long period of time therefore leading to safe as well as durable brake systems. Moreover, the monetary

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saving with a longer service life, minimum maintenance requirements, and reduced material costs make material an attractive solution for vehicle manufacturers seeking better performance along with sustainability.

The mechanical characteristics of epoxy composites reinforced with different silicon carbide (SiC) nanoparticle weight percentages. The findings indicated a decline in tensile strength with increased SiC content, attributed to suboptimal interfacial bonding, while also revealing enhanced wear resistance due to the nanoparticles' rough surface facilitating load transfer and reducing plastic relaxation [1]. The mechanical properties of composites reinforced with banana fibers in an epoxy matrix, revealing that a 50% banana fiber and epoxy resin blend maximizes tensile and flexural strength. While composites with 60% glass fiber exhibit superior impact strength, 50% banana fiber and epoxy resin mixture also demonstrates substantial impact resistance, indicating its potential as an effective alternative to traditional fiber-reinforced polymers for applications such as braking systems [2]. An investigation utilizing MINITAB software revealed that the inclusion of Multi Walled Carbon Nanotubes (MWCNT) in E-glass/epoxy composites significantly enhances wear properties, with reinforcement percentage being the primary factor influencing wear rate and friction coefficient, while microscopic analysis indicated fiber debonding and pullout occurring at excessive stress levels. [3].

Creation of a lightweight aluminum 6061 nano hybrid composite cylinder liner, which outperforms traditional cast iron liners in diesel engines by improving thermal efficiency and reducing harmful emissions, while demonstrating durability and mechanical integrity over extended use [4]. The utilization of agricultural waste fibers, such as banana peels and palm kernel shells, as alternative fillers alongside various binders like phenolic and epoxy resin for composite development. The resultant composite, primarily composed of orange peel and other materials, demonstrated comparable performance to asbestos brake pads, offering enhanced environmental and health safety [5]. To enhance the characteristics of flax fibre-reinforced composites through the application of vacuum molding, thereby increasing their suitability for industrial use. The findings reveal that incorporating a single carbon ply significantly mitigates porosity and water absorption, while the stacking sequence notably influences mechanical characteristics, highlighting the trade-offs between performance and environmental sustainability [6].

The mechanical characteristics of SiC particles and sisal fibers composites within an epoxy matrix, fabricated via a hand layup technique and subsequently evaluated. Findings revealed that while the addition of SiC particles diminished ultimate tensile strength and elongation, a 5 wt.% increase in SiC particles enhanced flexural strength, with varying effects on impact strength observed up to 10 wt.% [7]. Findings revealed that the reinforced Epoxy Resin Composite with Coir Fibre Sheet, focusing on its mechanical properties and constituent components exhibits moderate stiffness, low density, and affordability, suggesting that enhancements could be achieved through fiber treatment and optimized manufacturing techniques [8]. The mechanical attributes of hybrid-epoxy composites enhanced with diverse stacking configurations of sisal and bagasse fibers were investigated. The composites were produced utilizing a manual layup method and assessed for their mechanical properties, encompassing tensile and flexural strength, alongside water absorption and biodegradation, following ASTM protocols. Notably, the incorporation of three layers of sisal fibers significantly improved tensile strength, impact resistance, and reduced water absorption, attributed to enhanced matrix-fiber adhesion and minimized voids [9].

Coconut fiber as an enhancement in the creation of composite brake pads for motorcycles, assessing their mechanical properties against conventional alternatives per ASTM and ISO standards. Although the composite brake pads demonstrated a hardness of 97.27 HD and a reduced specific wear rate compared to commercial options, they exhibited higher porosity; thus, while their mechanical properties are sufficient for alternative use, further optimization is required to align them more closely with the performance of asbestos or semi metallic brake pads, albeit still inferior to ceramic materials [10]. Graphene oxide coatings have recently gained of great importance especially in the engineering area because the process is cost-effective and rather simple in processing when applied to natural fiber composites used for multilayered ballistic armor. The results of FTIR show that such a coating alters the molecular architecture of curaua fibers, thereby improving thermal stability and interfacial shear strength. Such coatings have great potential for advanced protective applications in enhancing the mechanical properties of such composites [11]. The characteristics of Polytetrafluoroethylene (PTFE) composites enhanced with carbon materials and aramid fibers. The findings revealed that while the elastic modulus increased with 7µm CF, tensile strength and elongation at break significantly diminished, accompanied by substantial reductions in wear rates when modified with carbon fillers [12].

Proposed alternatives are in the form of natural fibers, such as banana, coconut and rice husk instead of asbestos-based automotive brake pads. Some additives, graphite powder, and epoxy resin can be introduced in making these brake pads to achieve acceptable performance. In relation to this, bio-composites mean much superior mechanical properties; that is, hardness increases and wear against the benchmark brake pad formulation reduces as shown with the addition of rice husk powder [13]. The desirability function analysis presented that hybrid composites with banana-glass fibers and MWCNTs have improved composite wear characteristics, including the wear rate and coefficient of friction, up to 13.5% and 15.55%, respectively. Thus, one can conclude that resistance to wear and surface characteristics by adding MWCNTs in a polymer-based hybrid composite define possible applications for these materials within the durable industries [14]. Novel bio-mulberry-reinforced polyacrylonitrile fiber-based brake composites were fabricated and the test results showed that 3% composites of mulberry-PAN were giving high friction with low wear, while its 12% version was showing good recovery and thermal stability [15]

Alkaline treatment, in interaction with the application of graphene oxide coatings, provided GO presence in thin layers, displaying distinctive Raman bands. More importantly, this combined action has an influence on the augmentation of the thermal stability and crystallinity, showing remarkable improvements in thermal and chemical properties of the fibers and, therefore, possible applicability [16]. The incorporation of eco-friendly natural fibres into brake pads has emerged as a significant trend in recent decades, with the potential to supplant traditional materials in tribological contexts. The optimal natural fibre content can enhance tribological characteristics, such as the coefficient of friction and wear rate, while also impacting the composites' porosity and hardness, although mechanical properties are also subject to the influence of compression load during processing [17]. Natural fibres have been enhanced to mimic certain metallic properties, achieving partial replacement through various methods. Coating techniques, particularly dip-coating, are employed to mitigate the inherent hydrophilic nature of these fibres, leveraging their excellent liquid absorption capabilities. An overview of such coating methods and anticipates the advancements in the application of coatings to natural fibres [18].

The brake pad materials underscoring the importance of superior wear resistance, thermal management, and longevity, while exploring the beneficial role of nano-fillers in polymer composites that augment their mechanical and tribological characteristics for enhanced safety in automotive use, alongside the application of various analytical techniques such as SEM, TEM, AFM, and XRD to assess these properties, ultimately offering critical perspectives on the versatility of brake pad materials across automotive, railway, and aerospace domains [19]. Halloysite nano clay significantly enhances friction and wear characteristics of brake pad formulations. Addition of the same highly optimizes pad performance hence safety, efficiency in the automotive industry. Friction performance and environmental benefit of apricot kernel shell can be brought in focus with the help of this composite material. The mechanical properties of the material make it highly effective for use as a brake pad without losing structural integrity or supporting green automotive innovation [20-21]. The impact of ZrO_2 nano material coatings on the structural, thermal, and wear properties of automotive brake liners, highlighting the significance of thermo-elasticity in brake design and offering a robust analytical framework through modeling and simulation tools such as ANSYS and CATIA, with the objective of improving mechanical brake performance and durability to foster future brake technology advancements [22].

The tribological properties of a novel CoNiCrAlY matrix multi-nano particle coating on brake pads, demonstrating that the CoNiCrAlY + nano Al_2O_3 variant offers enhanced wear resistance and reduced pin temperature compared to coatings with ZrO_2 and AT40, indicating a potential improvement in the efficiency and durability of brake pads in four-wheel vehicles [23]. The criticality of material selection for automotive brake pads, advocating for carbon-based nanomaterials as superior options due to their enhanced tribological and braking performance, while also addressing the environmental and health concerns associated with their use, thereby necessitating further investigation and innovation within the automotive brake pad sector [24]. The synthesis and characterization of a carbon nanotube-reinforced polymer brake liner material, revealing that the incorporation of nanotubes markedly enhances the mechanical strength and durability, thereby positioning it as a viable option for automotive applications [25].

Varying grain sizes of borax powder influence the friction and wear characteristics of automotive brake linings, revealing that nano-sized borax improves friction stability and efficacy, whereas micro-sized borax reduces the friction coefficient due to elevated interface temperatures, thereby underscoring the significance of material dimensions and composition in enhancing brake lining performance [26]. The effects of nano-sized alumina (Al_2O_3) on the performance of automotive brake friction materials, producing four distinct brake linings with varied alumina particle sizes and quantities, with tribological properties assessed via a brake dynamometer, revealing that the integration of nano alumina markedly improves the performance metrics of the brake materials [27]. The efficacy of a novel kaolin/TiO_2 (KATI) nanocomposite as a functional additive in automotive brake pads, revealing that its integration enhances durability, diminishes wear rates, and preserves adequate friction performance, with microscopic assessments indicating a uniform distribution within the friction layer that may mitigate wear particulate emissions during use [28].

From the above findings the mechanical properties of brake shoe liners are crucial for the safety and operational efficiency of vehicles concerning braking systems, which are regarded as one of the most vital components for regulated deceleration and halting. Recently, composite materials have increasingly influenced the automotive sector by providing alternatives that are not only lighter and stronger but also exhibit superior durability compared to conventional materials, thus enhancing overall performance. The incorporation of nano additives has become progressively significant in augmenting the mechanical and tribological characteristics of these composites, aiming to achieve elevated wear resistance and strength for various applications.

Banana and coir like Natural fibers are utilized in the fabrication of composite materials. An examination of the mechanical and tribological attributes of brake shoe liners is conducted. The subsequent characteristics of these natural fiber composites are improved by integrating nano additives like Al_2O_3 and SiC at a weight ratio of 10% into the composite formulation. These nanomaterials are anticipated to contribute positively to the enhancement of hardness, wear resistance, and thermal stability of the brake lining, aspects that will ultimately aid in extending the longevity and dependability of automotive braking systems.

EXPERIMENTAL WORK

Materials and Properties

The materials that were chosen are Banana Fibre, Coir Fibre, Aluminum Oxide, Silicon Carbide and Epoxy resin. Banana Fibre is a bast Fibre that is harvested from the pseudo-stem of banana plant. Coir Fibre is a Fibre that is obtained from the outer layer of coconut shell. Aluminum Oxide and Silicon Carbide are hard and brittle ceramics. Epoxy resin is a thermosetting polymer in nature, giving strong bonds thereby increase in stiffness along with elasticity in the material. The properties listed in Table 1 and 2.

Banana fibre

Mainly, this is very well-known as a substitute for conventional abrasives owing to its high tensile strength, toughness, and high resistance against wear and abrasion (Table 1). Other reasons for this being a good eco-friendly substitute for conventional abrasives are its low production cost and the fact that it is abundantly available in most tropical regions.

Coir fibre

Coir fiber is the hardest among natural fibers of vegetable origin, obtained from the outer skin of a coconut. It finds wide application as an abrasive because of its toughness and resistance to water (Table 1). This material is renewable, biodegradable, and cheap in the tropics, and thus an eco-friendly alternative to synthetic abrasives.

Aluminium oxide

Al2O3, as a strengthening material to natural fibers in the process of abrasive machining, tenses the strength and resistance of wear of the fibers, particularly for banana and coconut coir, by as much as 70 microns (Table 2). Such a crystalline substance will add on tensile strength to the natural fiber and go on to prove its sustainability and cost-effectiveness in polishing, sanding, and grinding.

Silicon carbide

Natural fibers will be considerably well reinforced by silicon carbide, considering its high strength, thermal stability, and other properties that would carry advanced composite applications (Table 2). Silica is a multifunctional chemical compound made of silicon and oxygen and thus widely used in the manufacture of glass, rubber, and plastic, and also in abrasives.

Epoxy resin

Natural fibers here included coconut, banana, acting as the reinforcement for the very rigid matrix of an epoxy resin (Table 3). The resulting composite has excellent strength-to-weight performance. This 'green' combination is very effective and economical substitution for a variety of uses against conventional synthetic materials.

Table 1. Properties of selected fibre.

S N.	Fibre name	Density(g/cc)	Tensile strength (MPa)	Young’s modulus (GPa)	Elongation (%)
1	Banana Fibre	1.3	540	5 - 16	4.2
2	Coir Fibre	1.15 - 1.2	140 - 593	4 - 6	30.4

Table 2. Properties of reinforcement material.

S N.	Properties	Aluminium oxide	Silicon carbide
Mechanical Properties			
1	Compression Strength	1920 MPa to 2750 MPa	2780 MPa to 3900 MPa
2	Young's Modulus	220 GPa to 370 GPa	370 GPa to 490 GPa
3	Poisson's Ratio	0.22 to 0.24	0.14 to 0.21
4	Ultimate Tensile Strength	210 GPa to 290 GPa	210 GPa to 370 GPa
Thermal Properties			
1	Maximum Temperature	650°C to 1730°C	500°C to 1590°C
2	Specific Heat Capacity	870 J/(kg.K) to 940 J/(kg.K)	670 J/(kg.K) to 1180 J/(kg.K)
3	Thermal Conductivity	14 W/(m.K) to 30 W/(m.K)	120 W/(m.K) to 170 W/(m.K)
4	Thermal Expansion	6.7 K^{-1} to 8.2 K^{-1}	4.0 K^{-1} to 4.5 K^{-1}

Table 3. Material composition.

S N.	Sample	Sample 1(wt.%)	Sample 2(wt.%)	Sample 3(wt.%)	Sample 4(wt.%)	Sample 5(wt.%)
1	Epoxy Resin	90	80	75	80	75
2	Banana Fibre (Main Fibre)	6	6	9	6	9
3	Coir Fibre (Reinforcing Fibre)	4	4	6	4	6
4	Micro material reinforcement	-	10(SiC)	10(SiC)	10(Al_2O_3)	10(Al_2O_3)
5	Total	100	100	100	100	100

CALCULATION OF MATERIAL COMPOSITION FOR SAMPLE PLATE

For sample plate preparation calculations performed to find the weight-

<table>
<tr><td colspan="2">Sample 1
Coir Fibre Volume = (Total volume × wt.%)/100 = (270 × 4)/100 = 10.8cm^3
Density = 1.5g/cm^3
Mass = Density × Volume = 1.5 × 10.8= 16g
Banana Fibre Volume = 270 × 6/100 =16.2cm^3
Density = 1.33g/cm^3
Mass = Density × Volume = 1.33 × 16.2 = 21.5g
Resin Volume = 270 × 90/100 = 243cm^3
Density = 1.4g/cm^3
Mass = Density × Volume = 1.4 × 243 = 340.2g</td></tr>
<tr><td>Sample 2
Coir Fibre Volume = (total volume × wt.%)/100
= 270 × 4/100 = 10.8cm^3
Density = 1.5g/cm^3
Mass = Density × Volume = 1.5 × 10.5 = 16g

Banana Fibre Volume = 270 × 6/100 = 16.2cm^3
Density = 1.33g/cm^3
Mass = Density × Volume = 1.33 × 16.2 = 21.5g
Resin Volume = 270 × 80/100 = 216cm^3
Density = 1.4g/cm^3
Mass = Density × Volume = 1.4 × 216 = 302.4g

SiC Volume = 270 × 10/100 = 27cm^3
Density = 3.21g/cm^3
Mass = Density × Volume = 3.21 × 27 = 86.67g</td><td>Sample 3
Coir Fibre Volume = (total volume × wt.%)/100
= 270 × 5/100 = 13.5cm^3
Density = 1.5g/cm^3
Mass = Density × Volume = 1.5 × 13.5 = 20g

Banana Fibre Volume = 270 × 7/100 =18.9cm^3
Density = 1.33g/cm^3
Mass = Density × Volume = 1.33 × 18.9 = 24.57g

Resin Volume = 270 × 75/100 = 210.6cm^3
Density = 1.4g/cm^3
Mass = Density × Volume = 1.4 × 210.6 = 283.5g

SiC Volume = 270 × 10/100 = 27cm^3
Density = 3.21g/cm^3
Mass = Density × Volume = 3.21 × 27 = 86.67g</td></tr>
<tr><td>Sample 4
Coir Fibre Volume = (total volume × wt.%)/100
= 270 × 4/100 = 10.8cm^3
Density = 1.5g/cm^3
Mass = Density × Volume = 1.5 × 10.5 = 16g

Banana Fibre Volume = 270 × 6/100 = 16.2cm^3
Density = 1.33g/cm^3
Mass = Density × Volume = 1.33 × 16.2 = 21.5g

Resin Volume = 270 × 80/100 = 216cm^3
Density = 1.4g/cm^3
Mass = Density × Volume = 1.4 × 216 = 302.4g

Al_2O_3 Volume = 270 × 10/100 = 27cm^3
Density = 3.95g/cm^3
Mass = Density × Volume = 3.95 × 27 = 106.65g</td><td>Sample 5
Coir Fibre Volume = (total volume × wt.%)/100
= 270 × 6/100 = 16.2cm^3
Density = 1.5g/cm^3
Mass = Density × Volume = 1.5 × 16.2 = 24.3g

Banana Fibre Volume = 270 × 9/100 = 24.3cm^3
Density = 1.33g/cm^3
Mass = Density × Volume = 1.33 × 24.3 = 32g

Resin Volume = 270 × 75/100 = 202.5cm^3
Density = 1.4g/cm^3
Mass = Density × Volume = 1.4 × 202.5 = 283.5g

Al_2O_3 Volume = 270 × 10/100 = 27cm^3
Density = 3.95g/cm^3
Mass = Density × Volume = 3.95 × 27 = 106.65g</td></tr>
</table>

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FABRICATION OF SPECIMEN

The process of manufacturing a composite starts with the fragmentation of Fibre into small pieces and processing it in a mixer grinder. The exact quantification of Fibre, Al_2O_3 and SiC is done, segregated further, and additions of resin and micro material are added to it. The mixture so obtained is moulded and compressed and exposed under sunlight with the purpose of solidification, followed by post-processing to finalize the composite product (Figure 1).

MECHANICAL PROPERTY TEST

The prepared specimen is subjected to the following major mechanical properties: compressive strength, ultimate tensile strength, wear rate, coefficient of friction, flexural strength, and water absorption capacity. This review is made within the context of a body of relevant scholarly articles and research papers.

Tensile Test

Tensile testing is a mechanical test conducted to find the tensile strength and yield properties of materials under pulling forces (Figure 2). Axial loading is applied in increasing magnitude to a specimen of testing material until failure, either by fracturing or excessive deformation, occurs. It also gives much information concerning tensile strength, modulus of elasticity, ductility, and several other mechanical properties of the material essential in the design and fabrication of components and structures that have to be strong and lasting. The above test was conducted as per ASTM D638-03 was provided by Associated Scientific Engineering Works, New Delhi (Figure 3).

Flexural Test

A flexure test, more commonly known as a bending test, is one of the specific mechanical tests aimed at strength and rigidity measurements of materials under the action of bending forces. It measures the ultimate stress of a material that it can resist prior to its failure under a scheme of three- or four-point loading. Now, under the three-point bending test, there are two points of support and one point where the force is applied. As for the four-point bending test, once again there are two points of support, but there are two load-carrying points on the specimen (Fig. 4). The above-described methodology of testing will help to explore the structural behavior of the discussed materials. The test was conducted following the ASTM D790 standard unit fabricated by Associated Scientific Engineering Works, New Delhi (Figure 5).

Figure 1. Photographic view of sample plates.

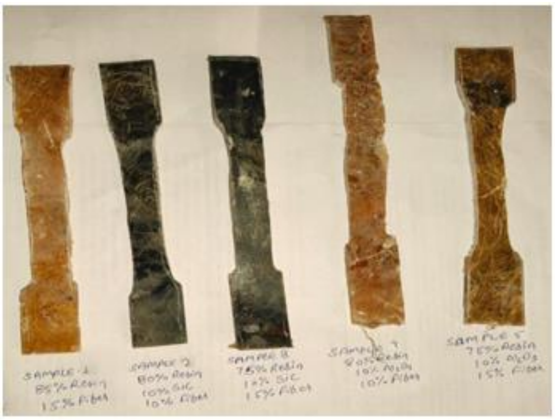

Figure 2. Photographic view of tensile test specimen

Figure 3. Photographic view of tensile test performed on specimen

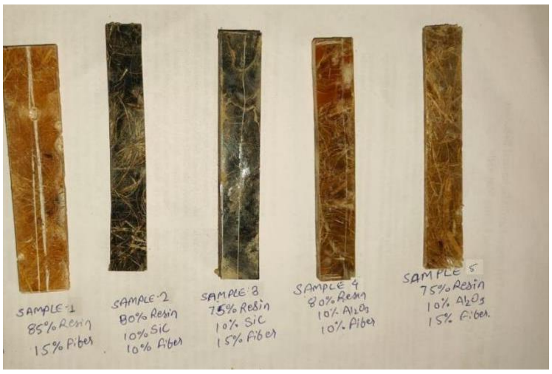

Figure 4. Photographic view of flexural test specimen.

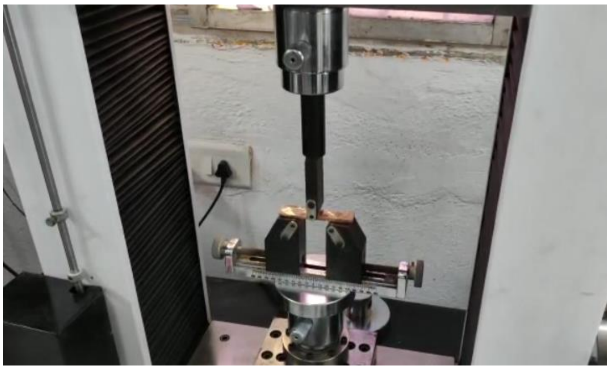

Figure 5. Photographic view of flexural test performed on specimen.

Compression Test

Mechanical testing to determine the compressive strength and deformation characteristics of a material. It quantifies the forces applied to a specimen in terms of compressive forces to failure or gross deformation (Figure 6). The test result gives the deduction of compressive strength of the material and elastic modulus. The test was conducted according to standard ASTM D6641 using an associated machine bought from Associated Scientific Engineering Works, New Delhi, India (Figure 7).

Wear Test

In material studies, the Pin on Disc wear test is one of the classical methods of assessing wear and friction properties. It shows a small cylindrical pin taken under load, rubbing against the turning disc. The sliding motion is controlled within the definite parameters. Wear in the pin and disc provides important information on the resistance of a material against wear and determines the friction behavior. Wear test was done by Ducom Pin/Ball on Disk Tribometer as per ASTM G99 (Figure 8). A specimen of size 30mm × 8mm × 4mm was kept on the tribometer at a load of 10N and with the speed of 478 rpm for 7 minutes. Sliding distance was 400m (Figure 9).

Water Absorption Test

The water penetration test is one of the methods for measuring the water uptake property of natural fibers. In this test, a prepared sample of fiber is immersed in water for a prescribed period of time (Figure. 10). The changes of weight and dimension of the samples have been recorded. This gives an idea of absorption and desorption of moisture within the fiber, which can be a base for mechanical properties and durability. The specimens were allowed to remain in water for 24 hours (Figure 11).

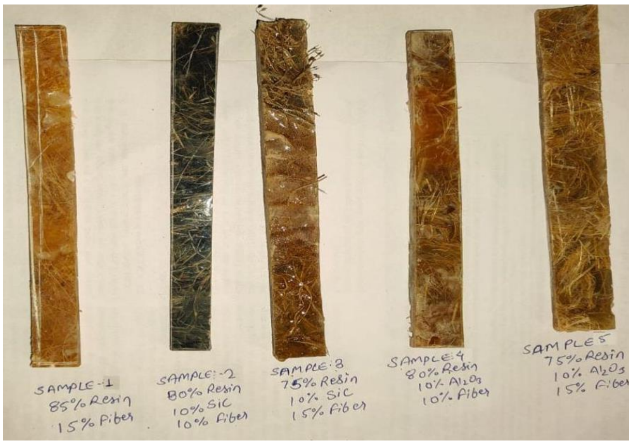

Figure 6. Photographic View of Compression Test Specimen

Figure 7. Photographic view of compression test performed on specimen

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Figure 8. Photographic view of wear test specimen

Figure 9. Photographic view of wear test performed on specimen.

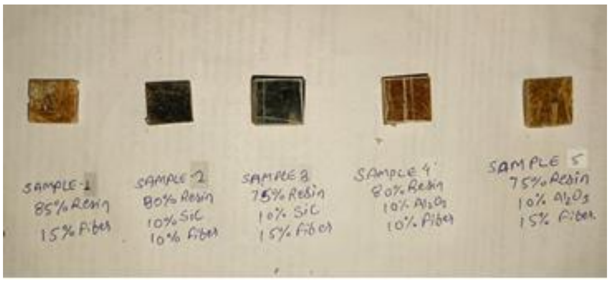

Figure 10. Photographic view of water absorption test specimen

Figure 11. Photographic view of water absorption test

RESULTS AND DISCUSSIONS

Tensile Test Results

The empirical data acquired from the tensile testing procedures clearly illustrate that the utilization of silicon carbide (SiC) and aluminum oxide (Al_2O_3) as reinforcing agents in the composite materials has contributed to a meaningful enhancement in the tensile strength of the resultant composite samples (Figure 12).

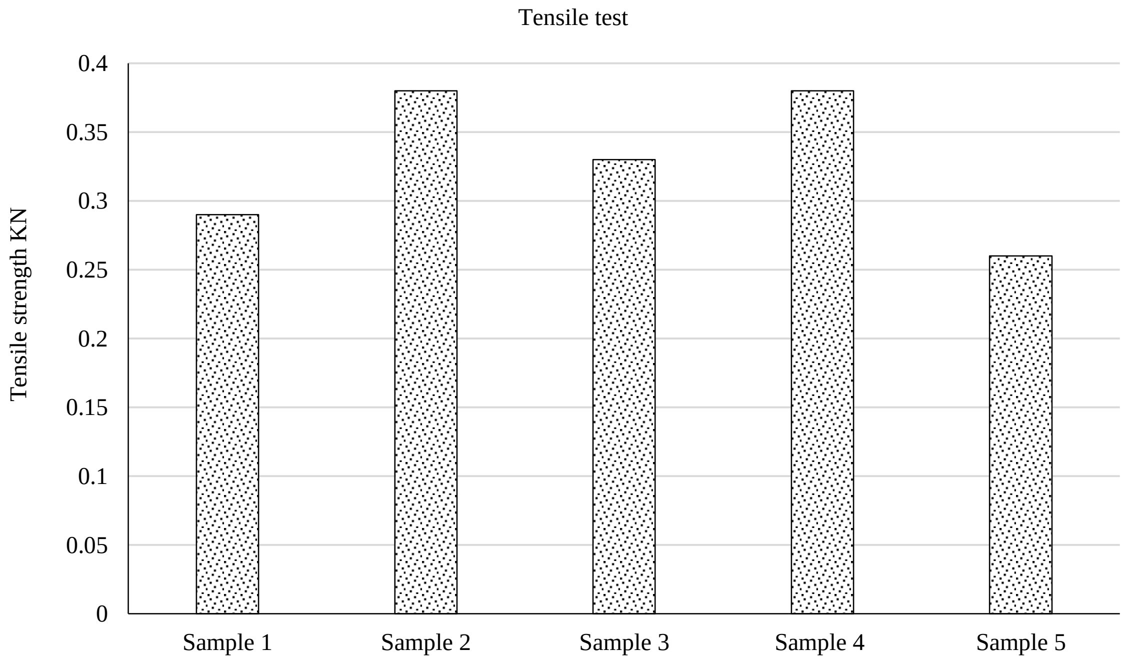

Figure 12. Comparison of tensile test on samples.

Moreover, it has been noted that weaving in natural fibers, such as banana and coir, significantly enhances the resilience of the composite structures; yet, it is vital to recognize that an overabundance of these fibrous elements can detrimentally influence the tensile strength of the composites, potentially jeopardizing their mechanical integrity. In particular, sample 2 and sample 4, which are characterized by their inclusion of SiC and Al_2O_3 reinforcement materials respectively, emerge as particularly suitable candidates for applications such as brake liners, where the tensile strength is of paramount importance due to the mechanical demands placed upon these components during operation, thereby enabling them to surpass the performance metrics of the other tested samples under conditions of tensile loading.

Flexural Test Results

The outcomes of the flexural examinations are illustrated graphically, elucidating the bending stress characteristics for all five composite specimens. This specific data regarding the ultimate flexural strength prior to failure that each specimen is capable of enduring is crucial when evaluating the material's capacity to withstand bending forces, particularly in the context of brake liners.

From the graphical representation (Figure 13), Sample 2 (0.38 kN) and Sample 4 (0.38 kN) demonstrated the highest flexural strength, with the tensile stress being effectively resisted by these two specimens. These samples, comprised of 10% SiC in Sample 2 and 10% Al_2O_3 in Sample 4, exhibit remarkable reinforcement attributes that may enhance structural integrity under flexural loads. Sample 3 (0.33 kN) was the next closest, performing satisfactorily yet not as efficiently as Samples 2 and 4. The lowest flexural strength was recorded for Sample 1 at 0.29 kN and Sample 5 at 0.26 kN, with Sample 5 identified as the weakest. The diminished flexural strength in these samples may be attributed to the increased fiber content coupled with reduced reinforcement efficacy, indicating a suboptimal suitability for high-stress scenarios such as brake liners. In summary, Samples 2 and 4 have been selected for additional evaluations in brake liner applications due to their promising flexural performance, while Sample 5 is deemed an unsuitable candidate due to its comparatively low tensile and flexural test strength.

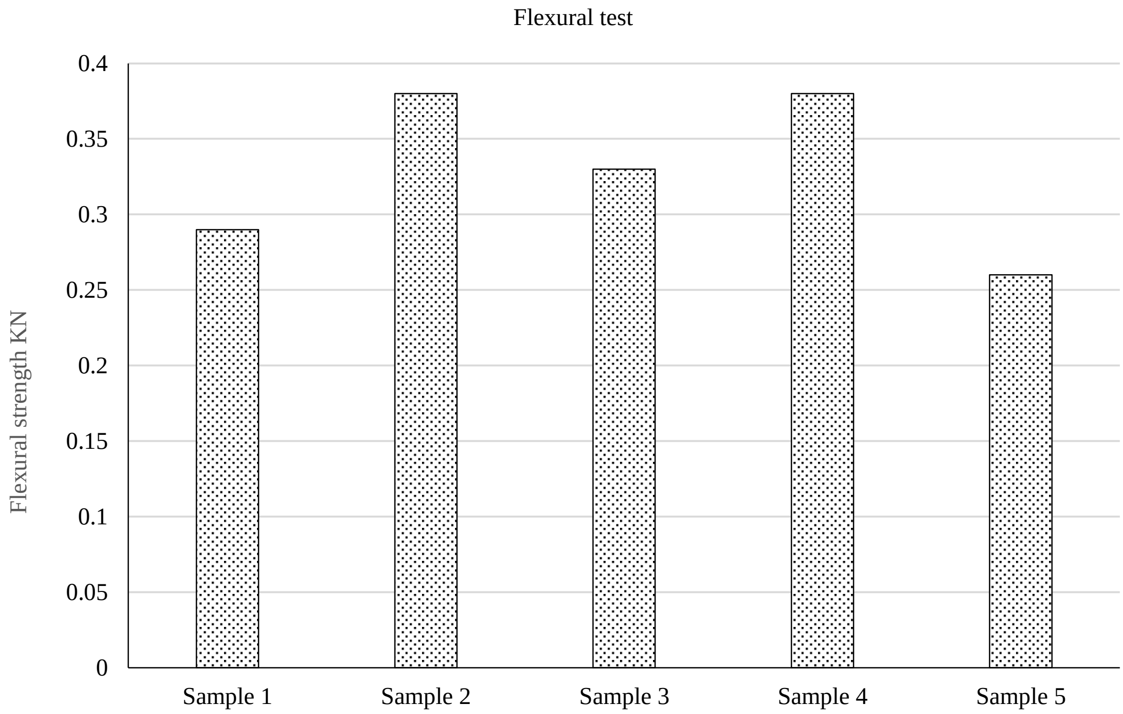

Figure 13. Comparison of flexural test on samples.

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Compression Test Results

The compression tests results indicate that all the five composite samples would have compressive capabilities-an important feature for brake liners, in which one has immense compression in braking. From Figure 14, Sample 3 (1.5 kN) shows up to be the strongest in terms of compressive strength, so it would possibly be extremely resistant to compressive forces. This discovery is significant for brake liners as these are permanently subjected to clamping pressures. Sample 3 does contain a significant percentage of 9% Banana Fiber and 6% Coir Fiber along with an enhancement of 10% SiC, by which its performance is most likely improved. Sample 5 (1.04 kN) demonstrates good performance but not as strong as Sample 3.

It means that the addition of 9% Banana Fiber and 6% Coir Fiber with 10% Al_2O_3 reinforcement is enough for compressive strength. Sample 4 with a compressive strength of 0.82 kN and Sample 2 with a compressive strength of 0.4 kN are of fair strength, but Sample 4 is better due to the high Al_2O_3 reinforcement, whereas the SiC in Sample 2 are less efficient on compressive strength. Sample 1 has 0.26 kN with least performance in compression and hence would not be good for brake liners that require high compressive strength not to deform when subjected to braking load. Summary In summary, Sample 3, with the best compression performance out, closely follows Sample 5. Both these samples may be better suited to brake liner application since they are much more able to withstand compressive forces.

Wear Test Results

Wear tests conducted on composite brake liners based on banana and coir fiber indicate the significant effects of nano-additives, namely silicon carbide (SiC) and aluminum oxide (Al_2O_3), on material wear resistance. Five samples were assessed (Figure 15), and Sample 1 was taken as reference without adding nano-additives, whereas Samples 2 and 3 used SiC and Samples 4 and 5 utilized Al_2O_3.

Without nano reinforcement

Wear test results for Sample 1 without nano-reinforcement display high wear, around 50 mm^3, thereby implying that only with the natural fibers, there is inadequate resistance. This baseline highlights how much the composite needs nano-additive reinforcement to make it tough.

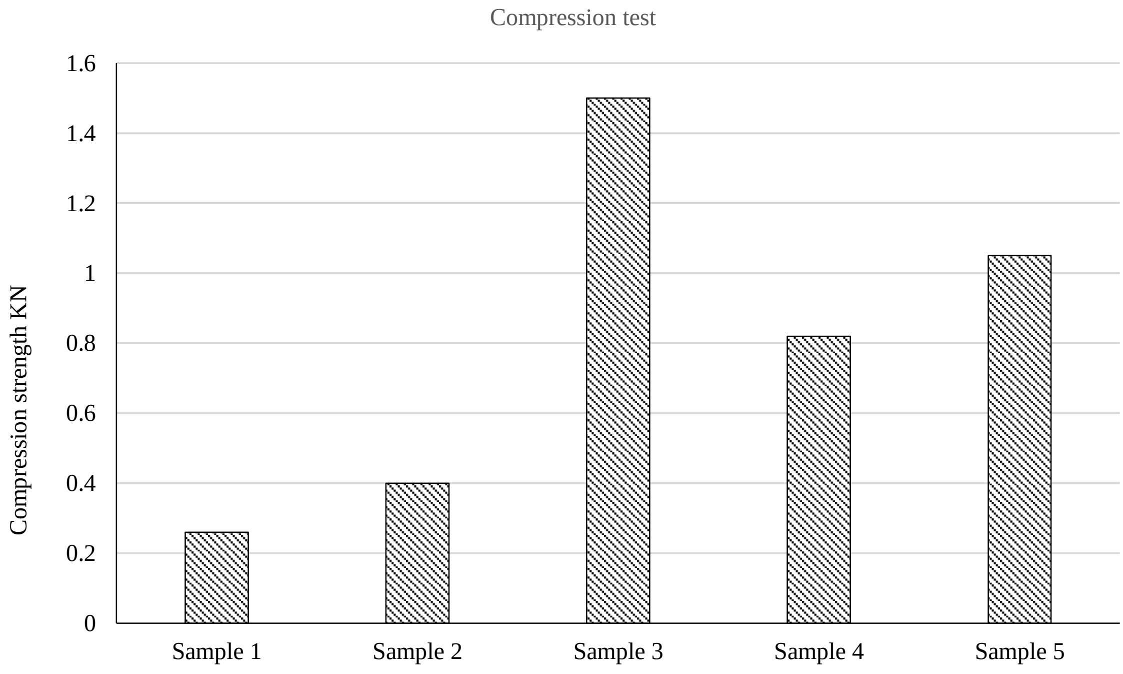

Figure 14. Comparison of compression test on samples.

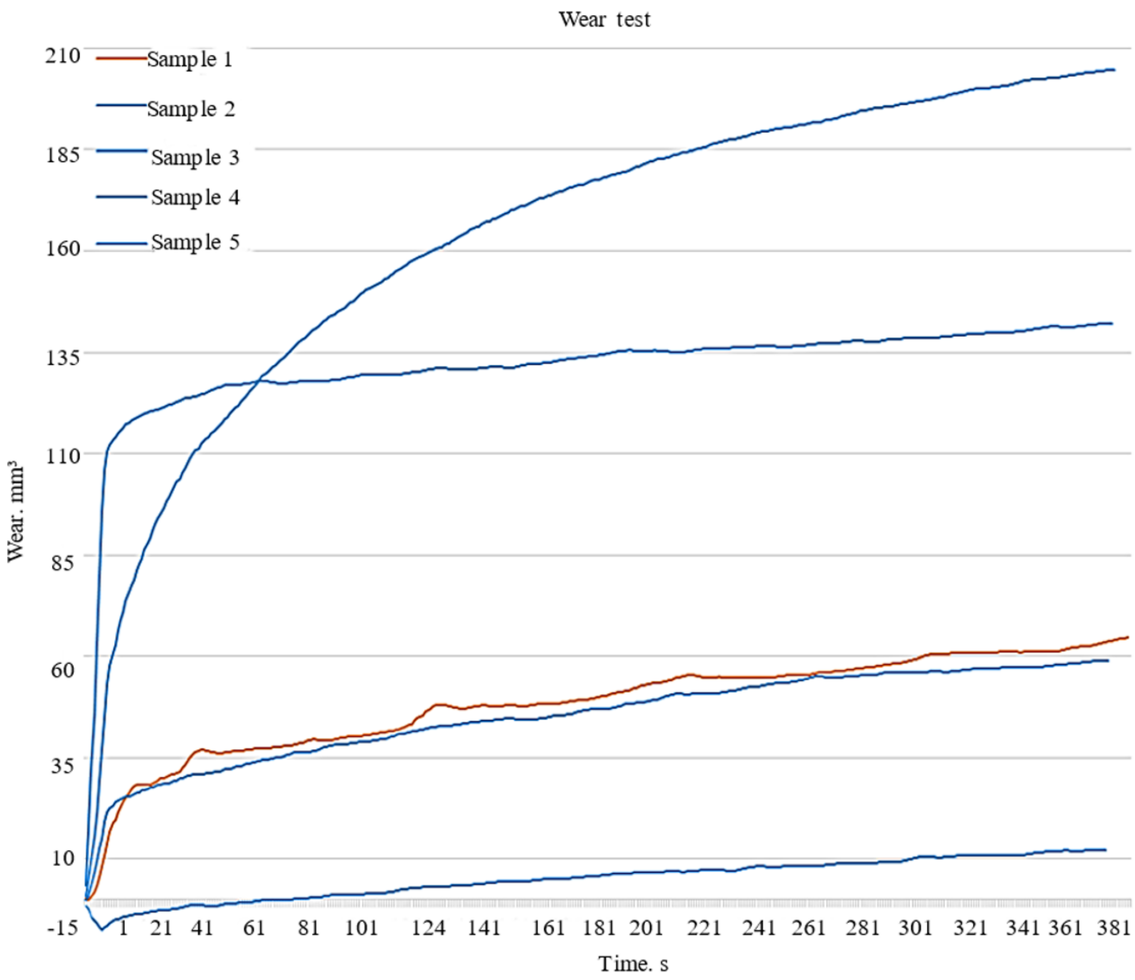

Figure 15. Comparison of Wear test on samples.

Reinforced with SiC

Sample 2 and Sample 3, SiC Nanoparticles wear resistance was greatly improved compared to the baseline; Sample 2 was around 200 mm³ in wear, and Sample 3, at approximately 150 mm³. These extraordinary results for Sample 3 reinforce the implications of SiC dispersion on wear behaviour and, more importantly, underline optimal configurations that improve resistance.

Reinforced with Al_2O_3

Samples 4 and 5, show better wear resistance than SiC-reinforced counterparts. Sample 4 shows a cumulative wear volume less than 50 mm³. Sample 5, although showing a slightly higher wear volume, is still more resistant in comparison to the wear volume shown by the SiC reinforced samples. Therefore, the high hardness and thermally stable nature of Al_2O_3 gives high protection against wear.

Finally, with SiC and Al_2O_3 nanoparticles added to banana and coir fiber-based composite brake liners, wear resistance is significantly increased. Although SiC still manages to show wear-enhanced properties, Al_2O_3 has even stronger efficiency and this efficiency stands out particularly in Samples 4 and 5, which relates to its importance in optimizing composite performance for critical brake applications.

Water Absorption Test Results

The findings of this water absorption test are essential in determining the extent to which composite materials are capable of resisting the intrusion of moisture, which may have significant implications for

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the shelf life as well as effectiveness of brake liners under diverse environmental conditions. Water absorption resistance is a very crucial issue of interest about brake liners. Moisture may cause precipitation that will deteriorate the material, lower frictional properties, and alter mechanical properties.

The samples above indicated that Sample 3 absorbed the highest amount of water at 10.626%, which also demonstrated intensive moisture absorption. The amount that it absorbed might be because of a higher content of fibers, in this case, 9% Banana Fiber and 6% Coir Fiber, which were already known to absorb high amounts of water. This tremendous ability to absorb makes Sample 3 less practical to use as brake liners because the material can eventually be soggy and moist (Figure. 16).

Sample 1 is the highest in absorption at 4.585%. Commonly speaking, it is moderate yet far more than the other examples. In this regard, it reveals a characteristic similar to Sample 3 in that its outcome might be explained by increased fiber levels, making it less fit for conditions where moisture is expected to be present. Low water absorption values are evidenced in samples 5 and 2 at 2.943% and 2.705%, respectively. This is more acceptable, and therefore, it indicates that these samples show improved moisture resistance, perhaps due to a lower fiber content, or possibly due to the reinforcing properties of the nano-materials used, namely Al_2O_3 and SiC.

The sample that showed the most effective resistance to water absorption was sample 4, recorded only at 1.202% uptake. This result indicates that sample 4 is the most water-resistant composite, thus uniquely suitable for applications that would have some exposure to moisture. The 10% Al_2O_3 reinforcement seems to significantly improve its resistance to water.

Thus, based on the absorption of water, Sample 4 is the best of them all. Samples 2 and 5 fall into the middle range and indicate average resistance. Sample 3, whose absorption rate is the highest, will probably degrade and fails wetting condition and will degrade much faster than the rest and thereby will not be the best choice to be used as a material for brake liners where there may be exposure to water.

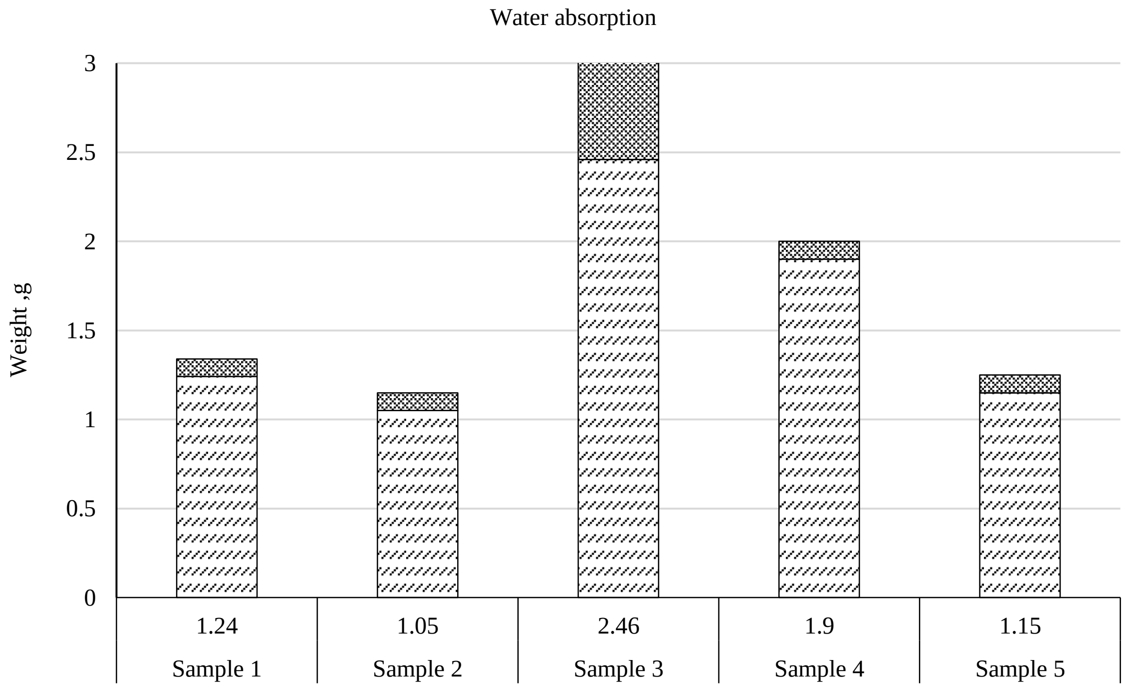

Figure 16. Comparison of water absorption test on samples.

CONCLUSION

The composite of Polyester resin, Banana Fibre, Coir Fibre, SiC and Al_2O_3 was fabricate with different composition. Several tests were carried out to determine the mechanical properties of the fabricated composite material. Based on the fabrication process and test results conclusion were drawn and are listed below:

The natural Fibre composite irrespective of Fibres needs to be processed and cut in adequate pieces for fabrication. While mixing the materials using mechanical stirrer can make the work easy and mixture uniform.

Hand lay method was used for fabrication of plates, but it would be strongly recommended to use Compression molding process. Because increasing the Fibre composition makes it hard to fabricate the plate manually and results in wastage of resources.

The tensile strength was highest for Sample 2 with 6.66 N/mm^2 as it has good bond between all the materials also the plate had even distribution of the Fibre. Lowest tensile strength was obtained for Sample 5 with 1.36 N/mm^2 this can be due to the fact there were few spaces in the specimen.

Result of flexural strength was highest for the Sample 4 which was 2.491 N/mm^2. This plate had decent bonding between the materials but the thickness of the plate was high when compared to other plates. Flexural strength obtained for Sample 3 which was 0.667 N/mm^2. In spite of being the thickest plate due to lack of proper adhesion the flexural strength was lowest.

Sample 5 showed highest Compression strength of 11.611 N/mm^2, which can be due to the uniform density of Fibre and the resin in the specimen. And Sample 1 had the lowest Compression strength of 4.294 N/mm^2. These result shows the reinforcements like SiC and Al_2O_3 improves the Compression strength by 2X.

The wear weight of all specimens was close. Sample 4 performed better when compared to other specimens. The wear rate of these specimen increases slowly as the distance increases. The COF obtained was 0.4 which is equal to COF of semi-metallic brake liner. Both Sic and Al_2O_3 gives same range COF. But Al_2O_3 gives less wear rate in long run.

The water absorption test is subjective to the fabrication of the plates. As suspected Sample 3 performed bad in test but when other specimens are compared adding reinforcements halves the absorption of water. It can be concluded as the reinforcement additives improve the property of the Fibre composite. As per the results obtained from test Al_2O_3 drastically improves the wear rate of the natural Fibre composite and SiC improves the strength of the composite.

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