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Effect of fiber orientation on interlaminar shear stresses and thermal property of sisal fiber reinforced epoxy composites

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ABSTRACT

Sisal fibre reinforced epoxy composites are the subject of this study, which intends to evaluate the influence of fibre orientation on the interlaminar shear strength and thermal parameters of these composites. When it comes to defining the mechanical and thermal performance of natural fibre reinforced polymer composites, the orientation of the fibres is a significant factor, as established by the examination of the current literature. There have been observations that the overall qualities of the composite can be improved by the hybridisation of sisal fibre with other reinforcements, such as glass or carbon fibres. Insights into the ideal fibre orientation that can maximise the interlaminar shear strength and thermal stability of the sisal fibre reinforced epoxy composites are anticipated to be provided by the result of the experimental investigation. Due to the influence of sisal fibre orientations such as 0/90°, 90°, and ± 45° orientation, an experimental investigation was carried out in order to assess the ILSS and thermal property of the material. According to the findings of this research, the orientation 90° demonstrates superior ILSS of 5.531MPa and thermal property 0.396 W/m*K of in comparison to the orientations 0/90° and ± 45° for the same purpose.

Keywords: Sisal fiber; Epoxy resin; Compression molding; Fiber orientation; ILSS.

1. INTRODUCTION

Due to the fact that natural fibres are beneficial to the environment, cost-effective, and possess good mechanical qualities, the utilisation of natural fibres as reinforcement in polymer composites has garnered a large amount of important interest [1]. In particular, sisal fibre is noteworthy for its high tensile strength, durability, and biodegradability. Sisal fibre is obtained from the leaves of the Agave sisalana plant. The orientation of the fibres affects the interlaminar shear strength (ILSS) and thermal characteristics of the composites in question. Natural fibres including sisal, jute, and hemp are increasingly being employed as reinforcements in polymer composites [2]. This trend is expected to continued. Considering that these fibres have a number of benefits, such as low density, high specific strength, and biodegradability, they are appropriate for a variety of applications in the automotive, construction, and packaging sectors [3]. A significant amount of research has been conducted on sisal fibre in particular because of its potential to serve as a replacement for synthetic fibres in composite materials such as glass and carbon. There are a number of elements that can have an effect on the mechanical characteristics of sisal fiber-reinforced composites [4]. These factors include fiber-matrix adhesion, fibre volume fraction, and fibre orientation. It has been demonstrated via research that the mechanical performance of these composites may be greatly improved by utilising a variety of treatments and hybridisations [5]. As an illustration, it has been discovered that subjecting sisal fibres to an alkali treatment can enhance their interfacial interaction with the matrix, which ultimately results in improved mechanical characteristics. Furthermore, both the mechanical and thermal characteristics of composites that combine sisal fibres with other natural or synthetic fibres have been shown to be enhanced [6]. When it comes to defining the mechanical characteristics of fiber-reinforced composites, the orientation of the fibres is an extremely important factor. It has been demonstrated via research that the orientation of the fibres has an effect on the load transfer efficiency between the matrix and the fibres, which in turn has an effect on the strength and stiffness of the reinforced composite. For instance, a study that was conducted on sisal fiber-reinforced epoxy composites discovered that

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the 90° fibre orientation demonstrated superior mechanical capabilities in comparison to other orientations [7]. This demonstrates how important it is to optimise the orientation of the fibres in order to get the required type of mechanical performance. The shear shear strength (ILSS) of fiber-reinforced composites is a crucial characteristic that defines the resistance of these composites to delamination when there is shear loading. The ILSS of natural fibre composites has been the subject of investigation in a number of research, with a particular focus on the role that fiber-matrix adhesion and fibre orientation contribute. One example is the research that was conducted on hybrid epoxy composites that were reinforced with sisal and groundnut shell particles. The findings showed that optimising the orientation of the fibres might greatly improve ILSS as well as other mechanical characteristics. In addition, the utilisation of chemical treatments such as alkalisation can significantly increase the ILSS by increasing the contact between the fibres and the matrix. It is essential for the application of fiber-reinforced composites in situations with changing temperatures that these composites possess sufficient thermal characteristics [8]. Composites made of natural fibres often have a lesser thermal stability when compared to composites made of synthetic fibres. Treatments and hybridisations, on the other hand, have the potential to increase their thermal characteristics. For instance, it has been demonstrated that the addition of nano-fillers made from fly ash into bio-epoxy composites that are reinforced with sisal fibres may improve both the thermal stability and the mechanical performance of the composites [9]. In addition, the orientation of the fibres in sisal fibre composites can have an effect on the thermal conductivity of the composites, with some orientations resulting in superior thermal performance. There have been a number of different chemical treatments that have been utilised in order to change the surface of sisal fibres in order to improve their compatibility with polymer matrices [10]. Alkalisation, acetylation, and the use of silane coupling agents are some of the usual treatments that are utilised in order to enhance the adhesion between the fibres and the matrix [11]. By enhancing the interfacial bonding and permitting improved stress transmission between the fibres and the matrix, these treatments have the potential to dramatically improve the mechanical characteristics of composites made from sisal fibres [12]. In terms of mechanical and thermal qualities, hybrid composites, which are composites made by combining sisal fibres with other natural or synthetic fibres, have demonstrated encouraging results [13]. An example of this would be a study that was conducted on sisal-jute-glass fibre reinforced polyester composites. The researchers discovered that the hybridisation of fibres led to superior mechanical characteristics when compared to single fibre composites [14]. To a similar extent, the utilisation of hybrid composites has the potential to improve the thermal stability of sisal fibre composites, hence rendering them appropriate for a wider variety of applications [15]. The development of sisal fibre composites that are both environmentally benign and high-performing has been the focus of recent study [16]. For instance, investigation has been conducted into the utilisation of polylactic acid (PLA) as a matrix material for sisal fibre composites, which has led to the development of biocomposites that exhibit enhanced mechanical performance [17]. There have also been developments in processing techniques, such as extrusion-rolling melt mixing, which have made it possible to manufacture continuous long fibre composites that have improved fibre orientation and mechanical characteristics [18,19]. The optimal configurations for improving thermal stability, strength, and durability, thereby enhancing the material's suitability for diverse engineering applications [20, 21]. The influence of glass fiber orientation on the mechanical performance of epoxy-based composites, including tensile strength, flexural strength, and impact resistance. The study aims to determine the optimal fiber alignment to enhance the overall durability and efficiency of these composites in various applications [22]. To investigate how varying the fiber orientation in betel nut (areca palm) stem fiber-reinforced polyester composites affects their mechanical properties, such as tensile strength, flexural strength, and impact resistance. This study aims to optimize fiber alignment for improved composite performance in engineering applications [23]. This above literature review comes to know the increasing use of natural fibers, particularly sisal, in polymer composites due to their environmental benefits, cost-effectiveness, and mechanical properties. It discusses the impact of fiber orientation, treatments, and hybridizations on the mechanical and thermal properties of sisal fiber composites, emphasizing their potential. To overcome this by enhancing the properties by changing the orientation of fibers and reinforced with epoxy to improve their above properties. The different fiber orientations in sisal fiber reinforced epoxy composites influence interlaminar shear stresses and thermal properties. It provides new insights into optimizing fiber alignment for enhanced performance and thermal management in eco-friendly composite materials, expanding their practical applications.

2. MATERIALS AND EXPERIMENTAL METHODS

2.1. Sisal fiber

In recent years, the field of composite materials has shown a large amount of interest in sisal fibre, which is obtained by extracting it from the leaves of the Agave sisalana plant. Its strong tensile strength, low density, and excellent thermal and acoustic insulation make it an ideal candidate for use as a reinforcing ingredient in polymeric matrices. Its distinctive physical attributes include these characteristics. A composite material that has improved mechanical, thermal, and acoustic characteristics may be produced by incorporating sisal fibre into a polymer matrix. This can be accomplished by including sisal fibre. A significant factor in determining the overall performance of the composite is the selection of the matrix material, which can be either thermoplastic or thermoset. Additionally, the compatibility between the fibre and the matrix is also an important consideration. Hardeners such as epoxy resins, polyester resins, and vinyl ester resins are frequently utilised for the production of composites that are reinforced with sisal fibre. These hardeners have the ability to crosslink with the polymer matrix in an efficient manner, which results in an improvement in the composite's mechanical and thermal characteristics. The physical properties of the sisal fiber is given in the Table 1.

2.2. Physical property sisal fiber

Table 1: Physical properties of the sisal fiber and its values.

S.NO.	PROPERTIES	RANGE	UNITS
1	Density	upto1.5	g/cm^3
2	Specific modulus	6–15	Gpa
3	Cellulose content	67–78	%
4	Young's modulus	9–22	GPa
5	Diameter of ultimates	18.3–23.7	μm

2.3. Matrix and hardener

When combined with a hardener, epoxy, which is a thermosetting polymer resin, undergoes the curing process. For the purpose of this investigation, epoxy resin of grade LY556 was utilised for its high stiffness, and the hardener of grade HY-951 was adopted for its application. As part of the preparation process for the reinforced matrix material, a combination of epoxy resin and hardener was used in a proportion of 10:1. When it comes to defining the overall performance of the composite material, the mechanical properties of the acacia and raffia fibres are quite significant. The matrix (epoxy resin) offers high strength, rigidity, and excellent chemical resistance. Common hardeners, like amines, enhance curing speed and improve toughness and thermal stability. The combination of matrix and hardener provides a composite with superior mechanical properties, durability, and resistance to environmental factors.

2.4. Chemical treatment

An alkali treatment that makes use of sodium hydroxide (NaOH) is a process that is widely used and proven to be successful in bleaching and cleaning the surface of natural fibres in order to generate fibres of superior quality. For the purpose of this procedure, a solution of sodium hydroxide pellets dissolved in distilled water was painstakingly made to have a concentration of 5% NaOH. In order to strike a compromise between the effectiveness of cleaning and the maintenance of fibre integrity, this particular concentration of NaOH was selected. When it comes to the creation of composites, it is essential to keep in mind that raising the amount of sodium hydroxide (NaOH) might have a negative impact on the characteristics of the fibres by lowering the bonding capability involved. There is a possibility of severe delignification and fibre degradation, both of which undermine the structural integrity of the fibres and the interfacial connection that exists between the fibres and the matrix. This is the reason for this. For the course of this treatment, sisal fibres were submerged in a solution of 5% sodium hydroxide for a period of two hours. It is essential to have this immersion period because it enables the sodium hydroxide to permeate the fibre structure. This helps the NaOH to remove contaminants, hemicellulose, and lignin, which ultimately results in an improvement in the surface roughness and adhesion qualities of the fibres. Following the immersion procedure, the fibres were rinsed meticulously with running water in order to eliminate any traces of NaOH and dissolved contaminants that may have been present. For the purpose of neutralising the fibres and preventing any additional chemical reaction that may potentially weaken them, this washing step is very necessary. Immediately after the washing process, the fibres were put through a drying process in an oven that utilised hot air. They remained in the oven for three hours at a temperature of 80 degrees Celsius for the entire time. During the manufacturing of composites, it is vital to go through this drying process in order to eliminate any moisture content that may be present in the fibres. This is necessary in order to guarantee that the fibres will adhere well to the epoxy matrix. The regulated drying conditions contribute to the preservation of the fibres' physical qualities, so preventing any thermal deterioration or loss of mechanical strength that may occur. Through the careful use of this alkali treatment method, the sisal fibres that have been treated are able to attain better surface properties. These features are necessary for the production of fiber-reinforced epoxy composites that are of high quality, robust, and of long-lasting durability.

2.5. Composite preparation

Within the process of preparing the specimen, a mould that is made of EN90 steel is utilised. In order to guarantee uniformity and consistency in the specimens that are produced, the mould has precise dimensions of 250 millimetres by 250 millimetres by 5 millimetres (250*250*5 mm). After being derived from a mould plate, this mould undergoes painstaking refinement in order to meet the necessary parameters. The procedure of preparation involves a certain weight ratio for the composite materials. The epoxy resin, hardener, and fibre are mixed together in a ratio of 10:1 for the resin and hardener, and 250 grammes for the fibres. This weight ratio is used to prepare the composite materials. For the purpose of producing the appropriate mechanical qualities and preserving the integrity of the finished composite material, this ratio, which has been properly measured, is completely essential. Sisal fibres are manually laid over the mould in the desired orientation in order to get the desired result.

Figure 1: Experimental setup of compression molding with specimen.

Within the context of optimising the mechanical characteristics of the composite, this manual arrangement enables exact control over the fibre alignment, which is necessary for achieving the desired results. Immediately after the fibres have been positioned appropriately, the necessary quantity of epoxy resin is carefully poured over the fibres. This ensures that the fibres are well impregnated and that the resin has thoroughly wetted them. When rolling over the fiber-resin combination, a roller is utilised in order to eliminate any air bubbles and guarantee that the resin is distributed evenly throughout the mixture. It is possible to achieve a homogenous composite layer through the use of this rolling procedure, which also serves to strengthen the bonding between the fibres and the resin. The assembly is then put through a hydraulic press after this step has been completed. For thirty minutes, the pressing process is carried out at a temperature of 120 degrees Celsius, with a pressure of thirty-five kilogrammes per square centimetre. The initial curing of the resin, guaranteeing good adhesion, and minimising voids within the composite structure are all dependent on this stage, which is thus extremely important. When the specimen is ready to be withdrawn from the mould, a curing period of forty-five minutes is applied after the first pressing has been completed. During this period of curing, the resin is given the opportunity to properly set and solidify, which ultimately results in the composite acquiring the requisite mechanical strength. The specimen goes through a post-curing phase after it has been taken from the mould during the process. The specimen must be allowed to cure for a further three hours at room temperature in order to satisfy this requirement. It is essential to accomplish this post-curing phase in order to finish the polymerisation of the resin. This step guarantees that the composite will attain its maximum potential in terms of both mechanical and thermal qualities. Figure 1 shows the compression modeling with specimen which was used for carryout this research.

3. EXPERIMENTAL TESTS

3.1. Interlaminar shear stresses

Interlaminar shear stresses, also known as ILSS, are the stresses that act on the interface between two adjacent laminae in a layered composite material. The interlaminar shear strength is the interfacial shear stress or shear strength of the matrix materials and is measured with the three-point bend test (ASTM D 2344) with (24*8* 5mm) dimensions. These stresses are referred to as interlaminar shear stresses. These stresses are caused by the varied reactions of each lamina to the loads that are applied, which results in relative deformation between the layers that are subsequent to one another. In the event that the interlaminar shear stresses are sufficiently severe, they have the potential to cause failure in the mid-plane between the two adjacent laminae, which ultimately results in delamination. Therefore, it is of the utmost importance to analyse ILSS by means of testing procedures that might trigger laminate failure in a shear (delaminating) mode. This will provide a knowledge of the composite's durability and structural integrity when subjected to shear stresses. Within the context of this particular instance, the ILSS of the laminates for various stacking sequences has demonstrated a similar tendency that is correlated with the flexural strength of the composite. Including Scanning Electron Microscopy (SEM) in ILSS studies can provide valuable insights. SEM images help visualize the failure modes and interfacial bonding between fibers and matrix. Analyzing these images can reveal: Failure Mechanisms: Identifying delamination, fiber pull-out, or matrix cracking. Bond Quality: Assessing the effectiveness of fiber-matrix adhesion. Microstructural Insights: Understanding how fiber orientation and matrix properties affect shear strength. The fact that this is the case shows that the same parameters, such as the quality of the fiber-matrix interface and the alignment of the fibres inside the matrix, are responsible for determining both flexural strength and ILSS tensile strength. These mechanical qualities are mostly determined by the stacking sequence, which defines the arrangement and orientation of the individual laminae that are included inside the composite. This sequence plays a key influence in the determination of these properties. In most cases, the evaluation of ILSS is carried out by means of standardised testing procedures, such as the three-point bend test which was shown in Figure 2. This test involves applying a bending stress to a composite specimen until it breaks. The test is repeated until the failure occurs. Calculating the interlaminar shear strength may be accomplished with the use of the data that was acquired during this test. This data includes the measurements of the load and displacement. For the computation, a certain equation is utilised, which establishes a connection between the load that is supplied and the shear stresses that are experienced by the composite. The three-point bend test is very helpful for analysing ILSS because it provides a well defined shear stress distribution throughout the material. This makes the test extremely effective. Because of this, it is possible to accurately measure and compare the ILSS across a variety of composite materials and stacking sequences. Researchers are able to acquire insights into the shear performance of the composite by analysing the results of the 3-point bend test. Additionally, they are able to discover possible areas for improvement in the process of material design and manufacturing. In order to determine the interlaminar shear strength (ILSS), the data that was gathered during the three-point bend test may be utilised by employing the equation known as

$$\mathrm{ILSS} = 3F/4bt$$

Where F is the breaking load (N), *b* and *t* are the width and thickness of the specimen (mm).

3.2. Thermal conductivity

In order to ascertain the thermal conductivity of polymer composite materials, a heat flow meter is a specialised equipment that provides this information. It is possible for the thermal conductivity of a material, which is a measurement of the material's capacity to transfer heat, to alter dramatically depending on the temperature that is being applied. In situations when thermal management is of the utmost importance, doing precise measurements of this attribute is absolutely necessary. It is the Heat Flow Meter, more precisely the HFM 436 Lambda, that is utilised in this particular scenario. In order to conduct tests on samples that have dimensions of 30.5 centimetres by 30.5 centimetres and varying thicknesses ranging from 5 millimetres to 10 centimetres, this apparatus was especially built. As part of the testing procedure, the sample is positioned between two heat flux sensors, which are used to determine the amount of heat that is transferred through the material. Because of the sensors, precise and accurate measurements of thermal conductivity may be obtained across a wide range of sample thicknesses and material compositions. In accordance with the ASTM C5183 standard, thermal conductivity measurements are carried out with the help of the heat flow meter test equipment. The processes and standards for properly assessing the thermal conductivity of insulating materials are outlined in this standard. This standard ensures that the findings obtained are consistent and reliable. A standardised foundation for evaluating the thermal performance of various polymer composites under controlled conditions is provided by the measurements, which are carried out in accordance with ASTM.

The heat flow meter is an extremely useful instrument in the field of research and development due to its capacity to accurately measure a broad variety of sample thicknesses while also retaining its precision. The thermal conductivity of polymer composites may be evaluated by scientists and engineers using this method, which allows them to examine how different compositions and manufacturing procedures impact the material. It is crucial to have this knowledge in order to develop materials that fulfil certain thermal performance standards,

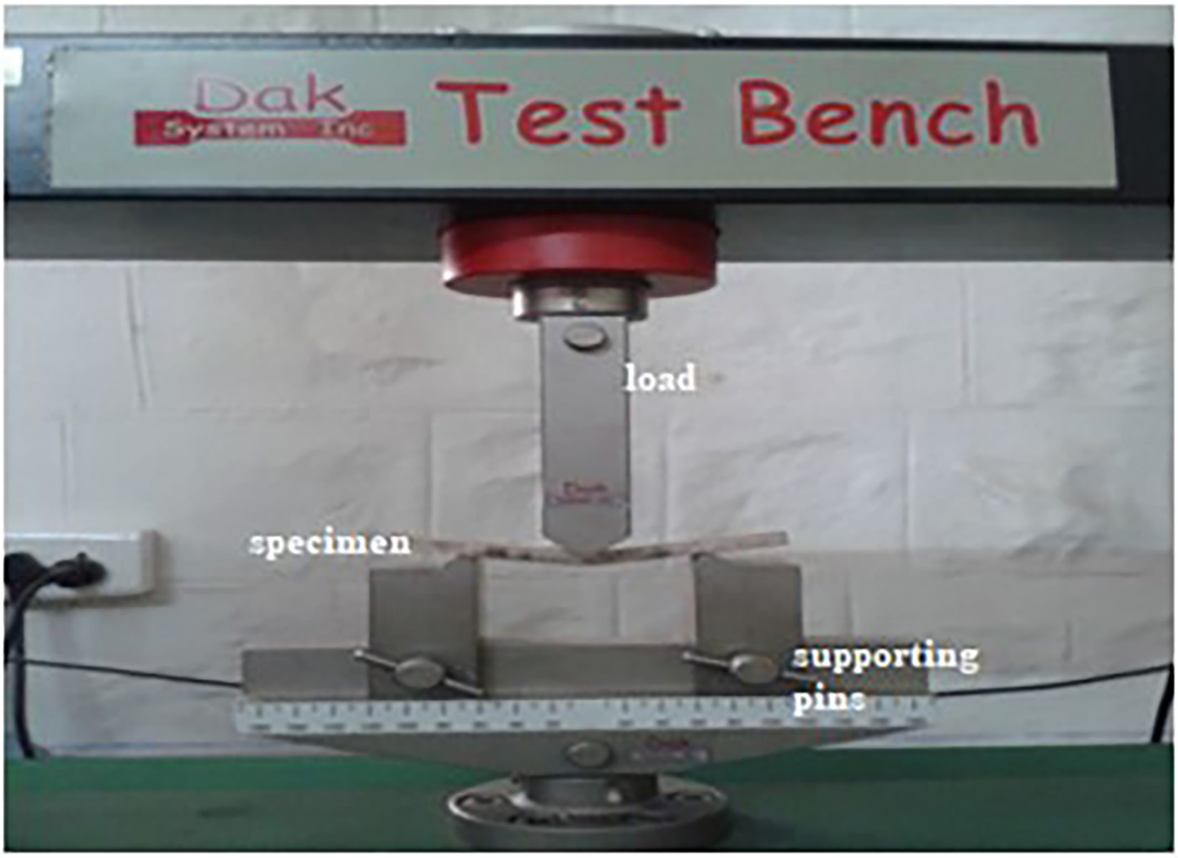

Figure 2: Experimental setup of interlaminar shear stresses (ILSS).

whether it be for the purpose of insulation, electronic packaging, or any other application where heat management is an important aspect.

4. RESULTS AND DISCUSSION

Presented and extensively described in this part are the findings of the tests that were conducted. The results of the tensile tests conducted on treated sisal fibre reinforced composites are presented in Table 1, which offers a detailed summary of the findings. In order to provide a comprehensive comparison between the various orientations, these results have been painstakingly documented. In order to guarantee the dependability and precision of the findings, we carried out three separate trials for each specimen orientation while we were doing the Interlaminar shear strength testing. This method produces a strong dataset for analysis while also reducing the amount of unpredictability. ILSS experiments were carried out in order to determine the extent to which the orientation of the fibres of the composites has an effect on the mechanical characteristics of the composites. It was found that the 90-degree (unidirectional) orientation had the maximum Interlaminar shear strength among the other orientations that were tested against it. It may be deduced from this that the composite material's load-bearing capability is greatly improved when the fibres are aligned in a single direction. Because of the unidirectional arrangement, the stress may be distributed more evenly over the length of the fibre, which is one of the factors that contributes to the higher Interlaminar shear strength qualities that are seen. By doing an analysis of the outcomes of a number of different experiments, we are able to assert with absolute certainty that the 90-degree orientation is superior to other orientations in terms of Interlaminar shear strength. This discovery is essential for applications that demand the highest possible tensile strength, as it will direct the design and manufacturing processes of sisal fibre reinforced composites in order to maximise their mechanical performance.

The ILSS of treated sisal fibre reinforced composites is depicted in Figure 3, which displays the composites in their various orientations. The 90^0 orientation, which is unidirectional, is the one that exhibits the highest ILSS among these combinations which was shown in the Table 2.

The resulting thermal conductivity values for treated sisal fibre reinforced composites are presented in Table 3, which displays the findings for various orientations. As part of this, we run three separate tests on specimens to determine their heat conductivity. Particularly among these, the 90^0 orientation, which is unidirectional, demonstrates the highest flexural strength.

The thermal conductivity of treated sisal fibre reinforced composites is depicted in Figure 4, which represents the varied orientations of these composites. When it comes to them, the 90^0 orientation, which is unidirectional, demonstrates the highest thermal performance.

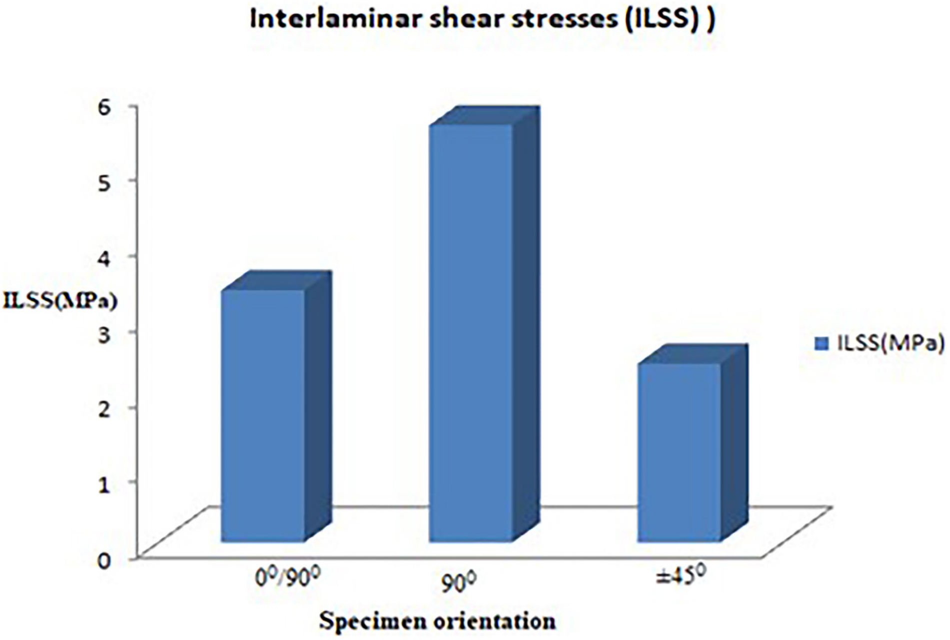

Figure 3: Graphical representation of the interlaminar shear stresses (ILSS) test results.

Table 2: Interlaminar shear stresses (ILSS) test results of different specimen orientation.

SPECIMEN ORIENTATION	NO. OF TRIALS	ILSS (MPa)
$0^0/90^0$	T1	3.325
	T2	3.450
	T3	3.253
	Avg	3.343
90^0	T1	5.651
	T2	5.522
	T3	5.421
	Avg	5.531
$\pm 45^0$	T1	2.376
	T2	2.385
	T3	2.355
	Avg	2.372

Table 3: Results of the thermal conductivity tests.

SPECIMEN ORIENTATION	NO. OF TRIALS	TEMPERATURE (°C)	THERMAL CONDUCTIVITY (W/m*K)
$0^0/90^0$	T1	60	0.124
	T2	60	0.109
	T3	60	0.117
	Avg	60	0.350
90^0	T1	60	0.128
	T2	60	0.139
	T3	60	0.129
	Avg	60	0.396
$\pm 45^0$	T1	60	0.112
	T2	60	0.135
	T3	60	0.124
	Avg	60	0.371

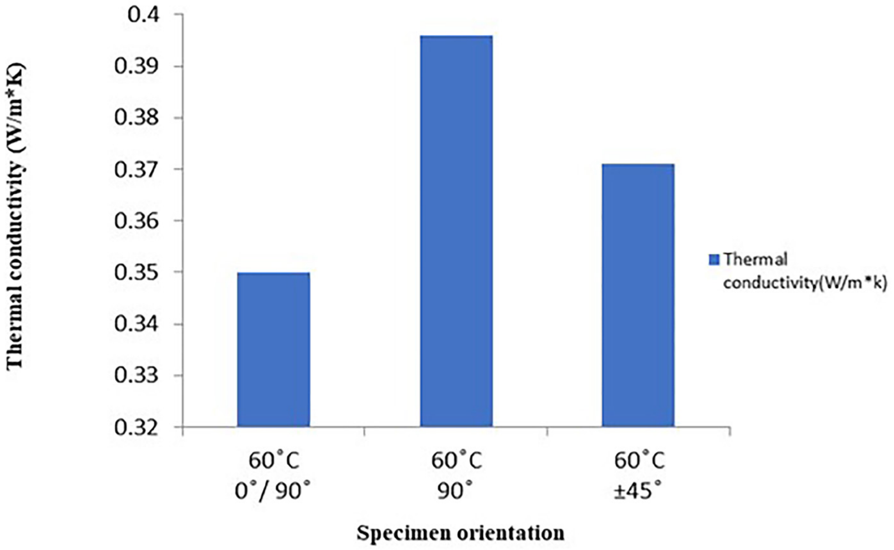

Figure 4: Graphical representation of the thermal conductivity results.

5. CONCLUSIONS

As part of the current research, three distinct types of fibre orientations were examined in accordance with ASTM standards in order to ascertain the influence that these orientations have on the mechanical and thermal characteristics of treated sisal fibre reinforced epoxy composites. For the purpose of accommodating various kinds of loads, these orientations were particularly selected: 0 degrees to react to axial loads, ± 45 degrees to react to shear loads, and 90 degrees to react to side loads or side loads. This all-encompassing testing strategy makes it possible to get a full understanding of the ways in which the performance of the composite is affected by the orientation of each fibre under a variety of loading circumstances. Several notable discoveries were made as a result of the concluding inquiry on the influence of fibre orientation on the treated sisal fibre reinforced epoxy composites. The interlaminar shear strength (ILSS) turned out to be one of the most important mechanical parameters that was examined. Based on the findings, it was determined that the 90-degree orientation (unidirectional) had the greatest ILSS value, which was measured at 5.531 MPa respectively. The unidirectional alignment of the fibres, which improves stress transmission and load-bearing capacity, is responsible for this enhanced performance, which may be linked to the improved performance. Not only did the study concentrate on the mechanical qualities of the composites, but it also looked at how they behaved in terms of temperature. Sisal fibres are well-known for their strong thermal insulation capabilities due to their intrinsic characteristics. It was determined how the thermal conductivity of the treated sisal fibre reinforced composites varied depending on the orientation of the composites. Based on the findings, the orientation of 0 degrees and 90 degrees (bidirectional) produced the lowest value of heat conductivity, which was 0.396 watts per metre Kelvin. Due to the fact that it has a low thermal conductivity, the bidirectional orientation is very good in preventing the transfer of heat, which makes it an ideal choice for applications that require thermal insulation.

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