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Mechanical Properties of Polymer Composites Reinforced with Short Sisal Fibre

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A B S T R A C T

In the present investigation, composites are prepared with natural fibre i.e. sisal fibre and polymer i.e. polyester resin. The samples are prepared with a simple hand lay-up method. The content of fibre varies from 0 wt. % to 8 wt. %. The properties evaluated are different mechanical properties. The properties under investigation are tensile strength, flexural strength, compressive strength and hardness. All the properties are experimentally evaluated as a function of fibre content. From the experimental results, it is found that the inclusion of short sisal fibre in the polyester resin improves the different mechanical properties of the composites. Properties like tensile strength, flexural strength, compressive strength and hardness increase as the content of fibre in the polyester matrix increases for the complete range of filler loading. Among all the properties, the maximum increment took place for the tensile strength followed by compressive strength and flexural strength, It is observed that the inclusion of sisal fibre in the polyester resin does not effect much the hardness of the composites as only a small increment in hardness is registered.

Keywords: Polymer matrix composites, polyester, sisal fibre, mechanical properties.

1. Introduction

Natural fibre-polymer composites (NPCs) are gaining popularity across diverse applications due to their environmental and cost benefits compared to traditional petroleum-based materials. Organic waste and residues from industrial and agricultural activities are often underutilized, typically managed through methods like landfilling, composting, or anaerobic digestion. Using these organic by-products in NPCs offers an environmentally friendly alternative with greater value. Natural plant fibres are increasingly seen as a sustainable option for composite fillers. The mechanical and physical attributes of natural fibre composites (NFCs) vary widely and include factors such as dimensional stability and mechanical strength. These properties are influenced by fibre characteristics, the bonding between fibre and matrix, the type of matrix used, production techniques, and any added materials. Additionally, the performance of NFCs can be affected by the conditions under which they are used. Recent interest in natural fibres has surged due to their advantages over traditional reinforcement materials. Natural fibres are cost-effective, lightweight, biodegradable, and non-abrasive, making them a compelling choice for composite applications. This shift aligns with a broader trend towards sustainable materials and practices, offering an eco-friendly alternative while maintaining or enhancing performance characteristics. Among the long list of natural fibres, sisal fibre is of interest to the scientific community because of its multiple advantages.

Sisal fibre has been established as a potential reinforcement material in combination with different thermoset and thermoplastic polymers. Mechanical properties of sisal fibre-reinforced polymer composites depend on various factors which include fibre loading, length of fibre and orientation of fibre. Maurya et al. [1] worked on epoxy reinforced with short sisal fibre and evaluated the mechanical properties of the composites as a function of fibre length. They used four different lengths of fibre ranging from 5 mm to 20 mm with an increment of 5 mm and kept the fibre loading constant at 30 wt. %. Rao et al. [2] fabricated sisal fibre-reinforced polyester composites by varying the content of fibre from 10 volume % to 40 volume %. They used the hand lay-up method for composite fabrication and evaluated the tensile and flexural strength of the composites. In their analysis, they found that tensile and flexural strength both the properties increase linearly with an increase in the content of fibre. Mahato et al. [3] used sisal fibre with vinyl ester polymer and fabricated the samples using the hand lay-up method. They used sisal fibre of length 50 mm in their investigation. NaOH is used by them for modifying the surface of sisal fibre. They fixed the concentration of NaOH used at 2 % and varied the time of treatment. They fabricated the samples with treatment sisal fibre for different durations and also with different weight fractions.

Contrary to that, Huang et al [4] found that the mechanical properties show increasing decreasing trends with an increase in fibre content. They fabricated sisal fibre-reinforced composites with polyester up to 15 volume % fibre content. They used close mould techniques for composite fabrication. In their analysis, they found that tensile strength, flexural strength and impact strength increase with filler content up to 10 volume percentage and with further increase in fibre content, the values start to show decreasing trends. When sisal fibres were incorporated into polypropylene polymer, Hasmi et al. [5] observed continuous increasing trends in all the mechanical properties under investigation. Also, they reported to achieve significant improvement in the mechanical properties. In their work, tensile strength increases from 31.26 MPa to 48.99 MPa and flexural strength increases from 48.03 MPa to 64.51 MPa when fibre weight fraction increases from 0 wt. % (pure PP) to 30 wt. %. Rohit et al. [6] incorporated sisal fibre in low-density polyethene and fabricated composites by the melt mixing method and varied the fibre content from 5 wt. % to 20 wt. %. They observed that tensile strength increases with fibre content up to 15 wt. % and then starts showing a decreasing trend with a further increase in fibre content. On the other hand, impact strength continues to increase with fibre content and maximum impact strength achieved at maximum fibre content. Uppal et al. [7] studied mechanical properties like tensile strength, flexural strength and impact strength of the chopped sisal fibre-reinforced polyester composites. From their thorough investigation, they found that the inclusion of chopped sisal fibre in the polyester resin improves the various mechanical properties of the composites under investigation and makes the composite suitable for building construction products and automotive applications. Sahu et al. [8] fabricated composites by manual method with a constant content and length of fibres as 16 wt. % and 15 mm, respectively. Mechanical tests on the prepared samples were performed in terms of tensile, flexural, impact and hardness.

It has been seen that reinforcement of sisal fibre enhances the mechanical properties of the polymeric resin. Further improvement in properties can be achieved by using surface-modified sisal fibre. The influence of the concentration of chemicals used and the time of treatment on sisal fibre and its properties have been studied and reported by various researchers. Sisal fibre was mainly treated with NaOH and silane to provide successful results but in recent research work, various other chemicals are also been explored over sisal fibre. The promising chemicals are peroxide, acetylation, potassium permanganate, baking soda and ultrasonication. Zhu et al. [9] used NaOH solution treatment over sisal fibre. The concentration of solution used was 10 % by weight. The duration of treatment was chosen as 3 hours in their investigation. Later they evaluated the tensile strength, flexural strength and impact strength of the composites and reported that all the properties decreased when treated fibres were used. Their analysis is different from the study reported by various other scientists. Against that, Krishnaiah et al. [10] reported achieving higher tensile and thermal properties when sisal fibre was treated with NaOH and incorporated in the PP matrix. They also reported that when NaOH treatment is combined with ultrasound treatment, tensile and thermal properties are further improved. FTIR and SEM analysis confirm that treated fibre has fewer traces of amorphous material like hemicellulose, lignin and other waxy material. Naushad et al. [11] also used the combination of PP and sisal fibre and they used NaOH with maleic anhydride grafted PP and found that the tensile and flexural properties increased. MAPP supported the increment in properties. Kaewkuk et al. [12] fabricated three sets of sisal fibre/ polypropylene composites by varying the fibre content from 10 wt. % to 30 wt. %. They used alkaline and heat treatment methods to modify the surface of the fibre. They also added maleic anhydride grafted polypropylene compatibilizer and studied the effect of interfacial adhesion and fibre content on various physical, mechanical and thermal properties of the composites. When treated fibres were Mourya et al. [13] studied the tribological behaviour of short sisal fibre-reinforced epoxy composites. They performed two body abrasion tests by the pin-on-disc method. They used four different parameters for evaluating the wear rate, specific wear rate, frictional force and coefficient of friction of the developed material. The parameters selected by them are fibre loading, external load, speed and sliding distance.

In the last five years, the study on sisal fibre as reinforcement has grown interest again and is explored with various polymers for their different properties. In that context, the prime work conducted in the last four years is discussed in detail. Sahu and Gupta [14] investigated the effects of eco-friendly treatments and coatings on the mechanical and physical properties of sisal fibre composites. Their study aimed to enhance the performance of these composites while maintaining sustainability. The research revealed that treatment significantly improved the tensile strength of sisal composites by 24%, providing enhanced structural stability. Flexural strength increased by 20%, demonstrating greater resistance to bending forces, which is crucial for load-bearing applications. Bhagat and Ghosh [15] investigated the performance properties of polypropylene (PP) and sisal fibre composites, focusing on composites with near-critical fibre lengths. Their study aimed to understand how fibre length influences the mechanical properties of these composites and to predict their performance. Ayalew and Wodag [16] conducted a study on chemically treated sisal fibre/polyester composites, focusing on how chemical treatments affect the mechanical and physical properties of these composites. The study found that chemical treatment significantly enhanced the tensile strength of the sisal fibre composites, with an improvement of 22% compared to untreated fibres. Olhan et al. [17] investigated the mechanical, thermal, and viscoelastic properties of sisal fibre-based structural composites, with a focus on their suitability for automotive applications. The study combined experimental methods with finite element modelling (FEM) to analyze the performance of these composites. Sanfilippo et al. [18] examined the impact of sodium bicarbonate treatment on sisal fibres and their subsequent effect on geopolymer composites. The study aimed to enhance the performance of sisal fibres when used in geopolymer matrices. Naik et al. [19] explored the use of microwave-assisted alkali treatment to enhance sisal fibres for use in composite materials intended for non-structural building applications. The study focused on improving the mechanical properties and overall performance of the sisal fibres and their composites. The results showed that the microwave-assisted alkali treatment increased the tensile strength of the treated sisal fibres by 28%, and flexural strength improved by 22%. The uniqueness of the present work is to develop a green composite at a low cost for light-duty structural applications using polyester as the base matrix and sisal fibre in short form as reinforcing material. Based on the literature survey, the sisal fibre was first modified using a moles concentration NaOH solution before reinforcing it into the polyester. The effect of the sisal fibre loading on different mechanical properties has been investigated.

2. Materials and Method

Unsaturated isophthalic polyester supplied by Carbon black composites, Mumbai India, is the matrix material in the present investigation. Polyester resin is used with its corresponding accelerator i.e. cobalt accelerator and catalyst i.e. MEKP catalyst. The advantage of polyester resin composites is that they can be cured in a variety of ways without altering the physical properties of the finished part. Their advantages include low viscosity, low cost, and fast cure time. The sisal fibre used in the present work was obtained from the local market as it is used in rural areas for making cord, met etc. The fibre was extracted from the leaf of the plant Agave-Sisalana which is available in plenty in the Southern part of India. Among the various natural fibres, sisal fibre is the most promising to be used as reinforcement in polymer composites as it is relatively inexpensive and commercially available. In the present investigation, sisal fibre is used in its short form. An approx. 4 mm length of sisal fibre is used for composite fabrication. The use of short fibres as reinforcement in composites is getting commercial importance, particularly in low-load secondary structure applications. Short fibre reinforced composites offer better stiffness, heat distortion temperature and strength in comparison to the base polymer. Sisal fibres were treated with aqueous solution of NaOH before being used as a reinforcement material. The different sets of composites prepared are shown in Table 1.

Table 1 - List of polyester-based composites filled with short sisal fibre

S. No.	Composition
1	Neat Polyester
2	Polyester + 2.5 wt. % short sisal fibre
3	Polyester + 5 wt. % short sisal fibre
4	Polyester + 7.5 wt. % short sisal fibre
5	Polyester + 10 wt. % short sisal fibre

The tensile strength of the composites is measured with a computerized Instron 3382 universal testing machine by ASTM D638 procedure by applying uni-axial load through both ends at a crosshead speed of 0.5 mm/min. Static uniaxial compression tests and flexural tests on specimens are carried out using the same Instron 3382 universal testing machine. The method by which the compression test is conducted is ASTM D695. The flexural strength is measured by a point bend test carried out by ASTM D2344-84. In the present investigation, he hardness test was performed using a PosiTector SHD Shore hardness Durometer following ASTM D-2240.

3. Results and Discussion

The tensile strength of all the polyester/sisal fibre samples is measured by a universal testing machine and is shown in Figure 1. From the figure, it is visible that the tensile strength of the composites is higher than that of the neat polyester. Also, the tensile strength increases with fibre loading for the complete range of fibre loading.

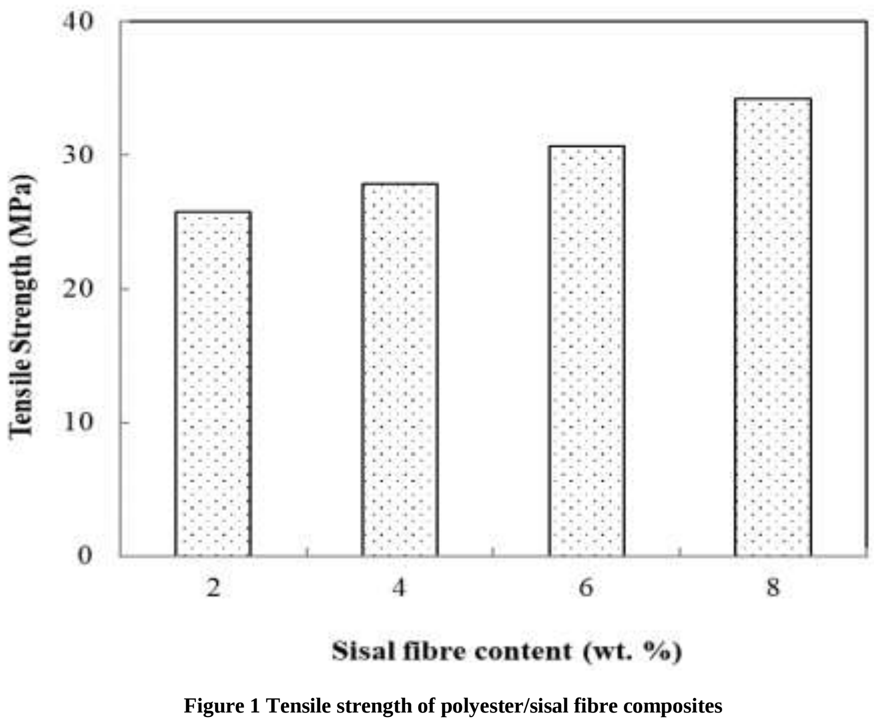

Figure 1 Tensile strength of polyester/sisal fibre composites

The tensile strength of unfilled polyester is 23.4 MPa which increases marginally to 25.8 MPa for a fibre loading of 2 wt. %. For a fibre loading of 8 wt. %, the tensile strength increases appreciably and reaches a value of 34.2 MPa registering an increment of 46.15 %. The tensile strength of the composite increases with fibre loading mainly because of the high strength value of fibres. Also, when fibres are incorporated into the polymer matrix, they form a bonding which helps in increasing the resistance against tensile loading and thus improves the tensile strength of the material. It is also observed that the increment is appreciable for low fibre loading of 8 wt. %. This is mainly because of the modification of the surface of the sisal fibre with an aqueous solution of NaOH. Surface-modification of sisal fibre results in the formation of active sites over the fibre surface and makes the surface of the fibre rough for creating mechanical linkages with the polymer matrix. The surface modification enhances the mechanical interlocking between the two phases and thus increases the overall tensile strength of the composite material.

4.2.2 Flexural strength

The flexural strength of the composites under investigation is present in Figure 2. It is clear from the figure that the inclusion of sisal fibre in the polyester matrix gainfully increases the flexural strength of the composite body. The flexural strength of the neat polyester is 31.7 MPa. When the 2 wt. % of sisal fibre was added to the polyester resin, and the flexural strength increased slightly and reached 32.9 MPa. When the fibre loading increases to a high value, the rate of increment of strength increases. For a fibre loading of 8 wt. %, the maximum flexural strength reached 40.1 MPa. This is an increment of 26.5 % over neat polyester. It has been seen that the trend obtained for flexural strength is similar to that obtained for tensile strength though the rate of increment is higher for tensile strength as compared to that of flexural strength.

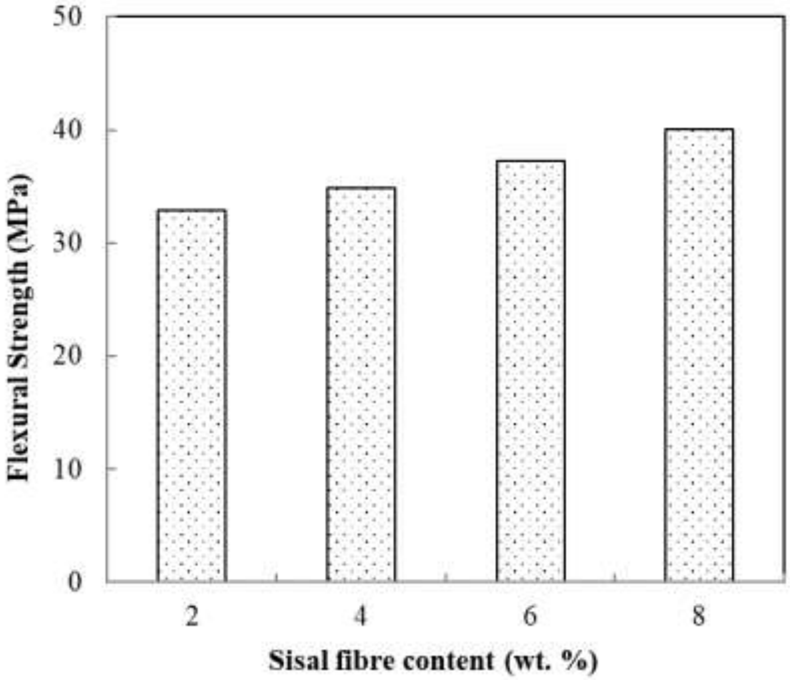

Figure 2 Flexural strength of polyester/sisal fibre composites

4.2.3 Compressive strength

The compressive strength of the polyester/sisal fibre composites under investigation is presented in Figure 3. It is visible from the figure that the inclusion of sisal fibre enhances the compressive strength of the polyester resin and the increment of compressive strength is a function of fibre loading. The compressive strength of neat polyester is 68.9 MPa. When 2 wt. % of sisal fibre is added to the polyester and the compressive strength of the composite increases to 70.8 MPa. The rate of increment of compressive strength increases for a higher loading of sisal fibre. When the content of sisal fibre increased to 8 wt. %, compressive strength reached 85.2 MPa registering an increment of 23.6 %. The improvement in compressive strength with fibre loading is due to the better adhesion and improved compatibility between the polyester matrix and sisal fibre.

4.2.4 Hardness

Figure 4 shows the hardness of the polyester composites reinforced with surface-modified short sisal fibre. It is observed from the figure that the inclusion of sisal fibre in the polyester resin enhances the hardness of the polymer reasonably. The hardness of pure polyester is measured at a Shore-D value of 73.2. With 2 wt. % sisal fibre, the Shore-D value rises to 73.9 showing a negligible increment. When the sisal fibre content reaches 8 wt. %, the hardness increases to 76.4, showing a small improvement of 4.37 %. The increase in hardness is due to the rearrangement of the polymer chain due to the inclusion of the sisal fibre. Hardness measures localized deformation under specific conditions. Adding sisal fibre makes the polyester less likely to deform plastically and acts as a barrier to dislocation movement in the matrix. This results in the improvement of hardness in the composite material. It is also observed that the improvement is very little which is mainly because sisal fibre is not a hard substance so, during micro-indentation, its inclusion does not affect hardness much.

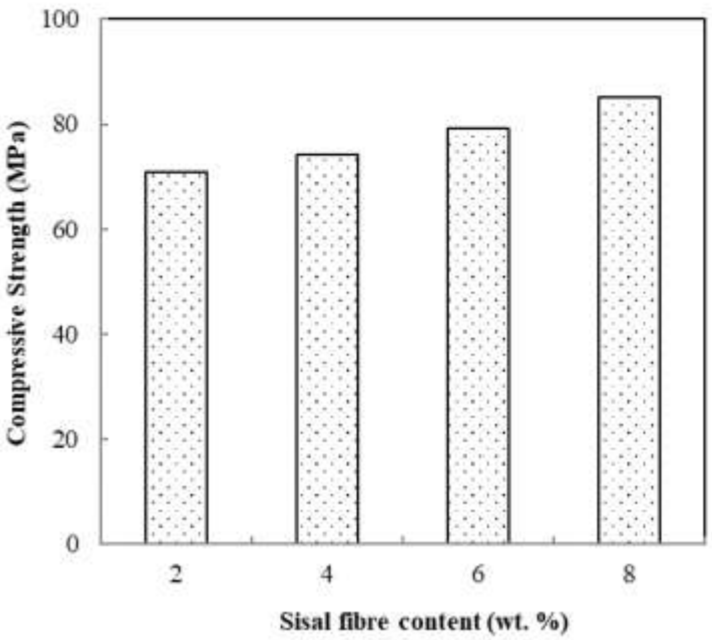

Figure 3 Compressive strength of polyester/sisal fibre composites

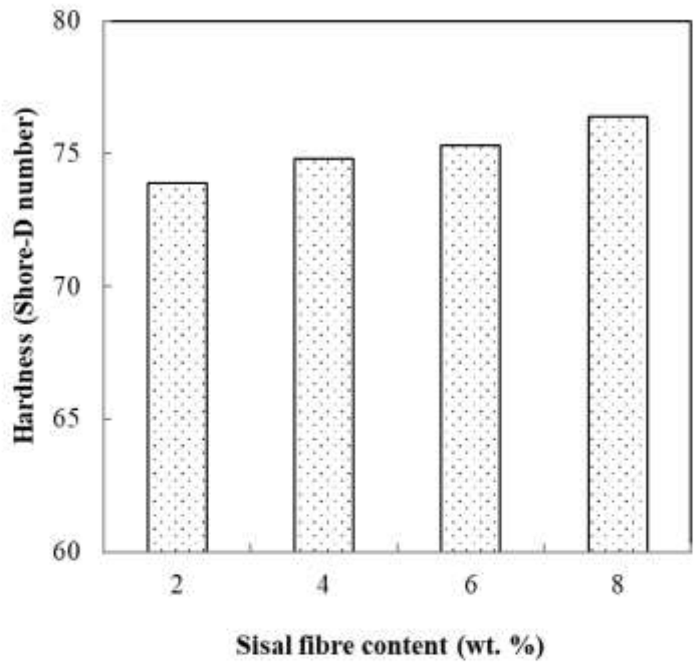

Figure 4 Hardness of polyester/sisal fibre composites

5. Conclusion

This present investigation on particulate sisal fibre/polyester composites has led to the following conclusions:

1. On increasing the fibre content, the tensile strength of the polyester-based composites increases substantially. For maximum fibre reinforcement of 8 wt. % gives the maximum value of tensile strength.

2. The flexural strength of the fabricated composite increases with an increase in fibre content. The highest flexural strength is obtained for the composite prepared with 8 wt. % of the sisal fibre. The increment in flexural strength over neat polyester is reported to be 26.5 %.
3. The compressive strength of the fabricated composite increases with the increase in fibre content. The maximum value of compressive strength for polyester composite is for 8 wt. % sisal fibre where the maximum value reported is 85.2 MPa.
4. The effect of fibre loading on the hardness of the composite is marginal in the current work. For a fibre loading of 8 wt. %, the improvement in hardness is reported to be only 4.37 % which is a very low value as compared to the other mechanical properties.

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