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Investigation of Physical and Mechanical Properties of Sansevieria Zelanica Fibre Reinforced composites with Epoxy and Polyester Resins

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Abstract – *Natural fibre-reinforced composites are the most cost-effective and environmentally friendly alternative to industrial applications, due to their higher mechanical properties for industrial applications. This research used the Sansevieria zeylanica (Ceylon Bowstring Hemp) natural fibres, and investigated the physical and mechanical properties of Sansevieria zeylanica -SZ- (Ceylon Bowstring Hemp) fibres and SZ fibre reinforced composites .Part of extracted fibres with water retting method have treated with 5% NaOH solution (Alakali treatment). Then, these fibres were tested for their important physical and mechanical characteristics. Alkali-treated SZ fibres showed higher fibre bundle tenacity (28.47%) and single fibre strength (9.16%), and higher moisture absorbency (5.43% in moisture regain) properties. However, the breaking elongation of alkali treated fibres was lower (17.18%) than that of untreated fibres. Composite samples were prepared using various fibre weight ratios: 20%, 30%, 40%, and 50% and resins. Mechanical and physical properties of these composites were investigated. It showed that the alkali-treated SZ fibre-based composites gave higher tensile strength (47.2 MPa with Epoxy and 30.99 MPa with Polyester), hardness (78.86HRB with Epoxy and 72.54HRB with Polyester), impact strength (0.0754 J/m^2 with Epoxy and 0.0715 J/m^2 with Polyester), and flexural strengths (183MPa with Epoxy and 103.66MPa with Polyester) at the 40% fibre ratio than with the other ratios. However, compressive strength exhibited good behaviour in all the tested fibre ratios. Thus, the moisture absorption of composites showed significantly lower values with all tested composites. Further, Epoxy resin based reinforced composites have indicated much better physical and mechanical properties.*

Keywords: Epoxy resin, Fibre reinforcement composites, Polyester resin, Sansevieria zeylanica fibre, Textile composites,

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1. INTRODUCTION

The fibre reinforced polymer composites have potential applications in various areas such as in aerospace, construction, automotive, and sports etc. as they have shown important properties such as specific stiffness and strength, good fatigue performance and damage tolerance, corrosion resistance, low thermal expansion, nonmagnetic properties and low energy consumption during fabrication and eco-friendly products (Adeniyi et.al. 2020 Subramanium et.al. 2022, Balaji et.al. 2020). In developing the fibre reinforced composites, natural fibres have acquired higher positions compared to using synthetic fibres, as natural fibres show high specific strength, no abrasion during processing, abundance, availability as renewable resources, biodegradable, low cost, minimum health hazards and low density (Adeniyi et.al. 2020, Subramanium et.al. 2022, Balaji et.al. 2020, Widyasanti et.al. 2020).

Sansevieria zeylanica (Ceylon Bowstring Hemp) is a type of non-conventional leaf fibre. Sansevieria is a genus of roughly 70 species with a wide range of species, from succulent desert plants like Sansevieria pinguicula to tropical plants with thinner leaves. The Sansevieria zeylanica-SZ- (Ceylon Bowstring Hemp) is a very common type abundantly available in Sri Lanka and it is grown as an ornamental plant in homes. In recent years, there has been a growing interest in the use of natural fibres as the reinforcing components in composites for various industrial applications as mentioned. The SZ fibres can be utilized as reinforcement fibre in the polymer composites to be used in various applications. However, there was no research work found with SZ leaf fibre for composites. However, some research works were found with other Sansevieria verities (Widyasanti et.al. 2020, Hariprasad et.al. 2022). In these few reports, it was found that other varieties of Sansevieria fibres have given higher mechanical properties. Based on this fact, this research work was formulated to use SZ fibres to develop composites.

The objective of this research was to investigate the physical and mechanical properties of SZ fibre and the SZ fibre reinforced composites made with epoxy and unsaturated polyester resins. For this objective, SZ fibres were alkali treated and used for composites with various fibre weight ratios such as 20%, 30%, 40% and 50%.

2. METHODOLOGY

2.1 Materials

2.1.1 Fibre Extraction

Reinforcing fibres were extracted from SZ leaves using water retting method. The fibres were separated from the lignocellulosic biomass using a preferred decaying technique that does not damage the cellulose in the fibre. The microbial liberation of plant fibres from their environment is known as retting (Subramanium *et.al.* 2022), (Balaji *et.al.* 2020, Li *et.al.* 2007). The entire procedure has taken up to four weeks. The non-fibrous cementing elements, primarily pectin and hemicellulose, are consumed by retting microorganisms. The degradation of the less resistant intercellular adhesive molecules gradually softens the leaves. The fibres may be easily separated from the leaves after the fermentation has reached the suitable level. If the retting process is allowed to continue beyond this point, the quality of the fibres will deteriorate. Therefore, careful monitoring of the water retting process at regular intervals is essential to avoid fibre damage and success of the fibre extraction. Although natural retting takes longer, it is more cost effective.

2.1.2 Alkali treatment of SZ fibres

Further, the extracted fibres were washed thoroughly to remove any traces of pulp adhering to the fibres and part of the extracted SZ fibres were added to an aqueous 5% NaOH (mild alkali) bath for 1 hour. Then, small bundles of SZ leaves were immersed in a water bath with liquor in a 1:20 ratio for 1 hour. This NaOH treatment caused hemicellulose in the cellulosic fibre to swell even more, and other contaminants such as pentosans, lignin, fat and wax, ash content, nitrogenous matter, and pectin were eliminated from the fibre surface. Due to the NaOH treatment, the cellulose microfibrils remain unaltered. Surface contaminants are removed to improve mechanical qualities, fibre wetting characteristics, and fibre-matrix surface bonding in composite applications (Subramanium *et.al.* 2022, Li *et.al.* 2007, Ashik *et.al.* 2017).

Further, this process helps to improve the fibre density and also increases the surface area, which leads for better interface bonding of the SZ fibres and the resins such as epoxy and polyester. This will directly affect the mechanical properties of SPF composites. Consequently, the fibre matrix adhesion is very significant (Balakrishnan *et.al.* 2016, Li *et.al.*

2007). This will directly affect the mechanical properties of SPF composites. After completing the alkali treatment, it was allowed to dry the treated SZ fibres for 3-4 days under Sunlight.

2.1.3 Resin Matrix

Resins such as polyester with catalyst and epoxy with hardener were used in producing composites. The epoxy and hardener were used in the ratio of 2:1 by volume to form an optimal bonding with SZ fibres in the composites. In the case of polyester and catalyst, it was chosen 2% by weight of catalyst (based on the weight of the resin used) to form an optimal bonding (Ashik *et.al.* 2017, Li *et.al.* 2007). Both epoxy and polyester based composites were cured at room temperature with the curing time of 24 hours.

2.1.4 Mould for Composite Preparation

Stainless steel mould was used in the size of 25 cm x 25 cm x 0.5 cm to develop the composites. A cover plate was made to compress the fibres mat, after the epoxy or polyester resin was poured into the mould and this helps to prevent air entering to the composite mould and to easily apply even pressure during curing.

2.1.5 Fibres Batt Preparation for Composites

SZ fibres were cut about 1 cm in length and the required fibre quantities were weighed according to the fibre ratios such as 20%, 30%, 40% and 50% separately. Then, fibres were laid in random orientation according to the fibre ratios. Finally applied some pressure to the fibres for 24 hours to form fabrication batts.

2.2 Procedure

2.2.1 Testing of physical and mechanical properties of extracted SZ fibres

Following properties of extracted SZ fibres before and after mild NaOH (alkali) treatment.

(a) Staple fibre length

Staple length of fibres was measured using bundle of long fibres without considering their tips. Before measuring, fibre bundle made parallel form with hand doubling and drawing method and placed on a black velvet pad in a straight form using a ruler.

(b) Fibre bundle strength

This was measured using a standard Pressley fibre bundle tester according to the ASTM D1445-05 Standard test method.

(c) Single fibre strength

Strength of a single filament was measured using a standard Tensile Strength tester at dry state according to the ASTM D3822 standard.

(d) Moisture Regain and Moisture Content

These were determined according to the ASTM D2495-01standard.

2.2.2 Preparation composites

Treated fibres were combed and cut into nearly 10mm length to make composites based on the literature survey (Adeniyi *et.al.* 2020, Subramanium *et.al.* 2022, Balaji 2020, Balakrishnan 2016, Widyasanti *et. al.* 2020). Thereafter, cut fibres were hand-laied up in multi-direction in the prepared stainless-steel mould (size of 25cm x 25cm x 0.5cm) as a fibre web. In preparation composites, 20%, 30%, 40% and 50% fibre ratios (weight % basis) have been considered and accordingly, first the fibre batt was laid and pressed. After 1 day, the fibre batt was removed, and its weight was obtained. Again, the batt was laid in the mold and prepared resin (Unsaturated Polyester with hardener or Epoxy with catalyst) was poured carefully on to the batt to fill up 100% volume. After that, the mould was allowed to cure under pressure according to their curing times.

2.2.3 Testing of physical and mechanical properties of SZ fibre reinforced composites

Following physical and mechanical properties of composites prepared with Unsaturated Polyester and Epoxy resins under selected fibre ratios were measured.

(a) Tensile strength of composites

The tensile strength of composites was measured using a standard Tensile Strength tester suitable for composite testing and done according to the ASTM-D3039 –Standard.

(b) Hardness of composites

This was measured using a standard Rockwell Hardness Tester using ASTM- D0785-03 standard. Hardness was measured in HRB in a hardness tester with a ball as the indenter.

(c) Compressive strength test

This was measured using Universal material Tester with suitable grips and done according to the ASTM-D5024-01 standards.

(d) Flexural strength test

The three point bending principle was used in measuring the flexural strength of prepared composite samples using the ASTM-D5023-01 standard. For these experiments, a standard tensile strength tester with suitable accessories was used.

(e) Impact resistant test

To measure the impact resistance of the prepared composites was done using standard Pendulum test method following Izod test principle. This was carried out according to the ASTM-D256 – 04 standard.

(f) Moisture absorbency test

Moisture absorbency of prepared composites was measured according to the ASTM D5229 standard to determine their Moisture Regain and Moisture Content of them.

3. RESULTS AND DISCUSSION

3.1 Physical and Mechanical properties of extracted SZ fibres

3.1.1 Staple length of SZ fibres

Staple length of fibres (without fibre tips) was measured with the help of a meter ruler. First, the fibres were laid on black paper. It is important to ensure the fibres are laid straight and parallel to avoid errors in measuring fibre length. The length of laid fibres was measured with avoiding the tips of the laid fibre bundle in straight and parallel form. and takes it as the average for usable fibre length. The measured staple fibre length of SZ fibre was s 30 cm. which was important in laying the fibres in a web to form the composites and also to obtain the better physical and mechanical properties of reinforced composites.

3.1.2 Fibre bundle tenacity

Tenacity test results of alkali treated and intreated fibres, which were obtained using the Pressley bundle tester, are given in Table 1. According to these results, the alkali-treated SZ fibres showed a 28.47% higher bundle tenacity than untreated fibres. As the NaOH treatment removes waxes, oils, hemicellulose, lignin, and other impurities, it leads to a closer packed cellulose polymer chains, and also the release of internal tension to increase the bundle tenacity. Furthermore, the alkali treatment also roughens the surface of the fibre and improves fibre-matrix adhesion (Widyasanti *et. al.* 2020, Li *et.al.* 2007, Ashik *et.al.* 2017). These changes will provide benefits in composite manufacturing. Further, the standard deviation and CV% of Fibre bundle tenacity of alkali treated fibres were 0.428 and 1.83% respectively.

Table 1: Tenacity variations of treated and untreated SZ fibre bundles

Fibre treatment	Bundle strength (lb)	Bundle weight (g)	Pressley Index (lb/mg)	Tenacity (g/tex)
Untreated	5.600	0.966	5.797	31.073
Alkali-treated	5.833	0.783	7.447	39.920

3.1.3 Single fibre strength of alkali treated and untreated SZ fibres

The single fibre strength of alkali-treated and untreated fibres are given in Table 2. According to the results, it can be observed that breaking force has increased by 9.16% and but, breaking elongation has reduced by 17.18% after alkali treatments. The reason could be that the alkali treatment removes the hemicellulose and other impurities, and make fibrils, which leads to closer packing of polymer chains in the fibres. This will improve the strength of single SZ fibres and also cause to reduce the breaking elongation. Further, the standard deviation and CV% of breaking force of alkali treated fibres was 0.0812% and 1.45% respectively.

Table 2: Single fibre strength and breaking elongation of SZ fibres

Fibre treatment	Breaking force (gf)	Breaking Elongation (%)
Untreated	2.337	1.572
Alkali-treated	2.551	1.302

3.1.3 Moisture absorption of alkali-treated and untreated SPRFs

Moisture absorption was determined in terms of moisture content and moisture regain. The following Table 3 depicts these results for alkali-treated and untreated SZ fibres. According to the results in Table 3, moisture absorption increased after alkali treatment (i.e. 5.43% increase in moisture regain and 5.01% increase in moisture content) and gave comparatively high values. The reason for this could be that the alkali treatment changes the fibre structure during moisture absorption, then, the cellulose polymer chains in SZ fibres may be pushed apart by the absorbed water molecules, allowing for more absorption.

Table 3: Moisture absorption of treated and untreated SZ fibres

Fibre treatment	Moisture regains (%)	Moisture content (%)
Untreated	9.40	8.59
Alkali-treated	9.91	9.02

Based on the physical and mechanical properties of the extracted SZ fibres tested, the 5% mild alkali treated SZ fibres can be used to develop composites to obtain good mechanical properties for industrial uses.

3.2 Physical and Mechanical properties of SZ fibre reinforced composites

Composites were prepared using mild NaOH treated SZ fibres, polyester resin and epoxy resin separately with different fibre ratios such as 20%, 30%, 40%, and 50% and using the prepared stainless-steel mould. Following physical and mechanical properties were tested.

3.2.1 Tensile strength and breaking force variations of SZ reinforced composites

Fig.1 and 2 show the tensile strength (in MPa) and breaking force (in N) variations of epoxy and polyester based SZ fibre reinforced composites prepared with different fibre ratios. According to fig.1, tensile strength show positive correlations to the fibre ratio between 10%-40%, but, these vales have reduced 26.53% in tensile strength and 15.07% in breaking load at 50% fibre ratio. Thus, epoxy-based composites show higher tensile strength and breaking force compared to the polyester-based composites under all tested fibre ratios. The reason would be the higher tensile strength reported by epoxy resin as 73 MPa than the tensile strength of polyester resin itself as 40 MPa (Widyasanti *et. al.* 2020).

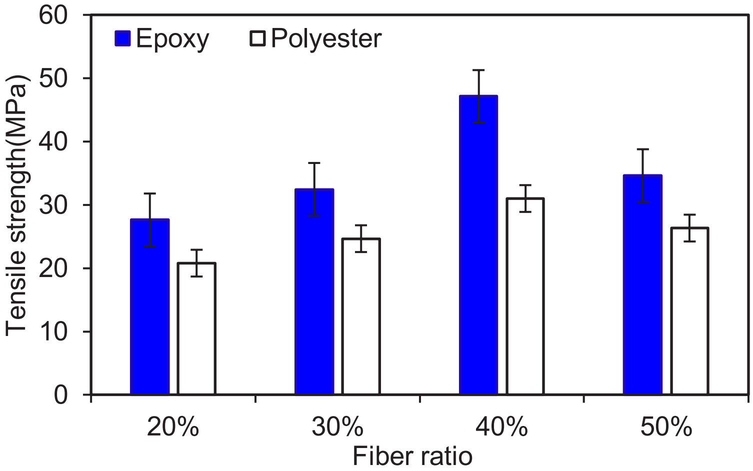

Fig. 1. Tensile strength variations of SZ reinforced composites with resins

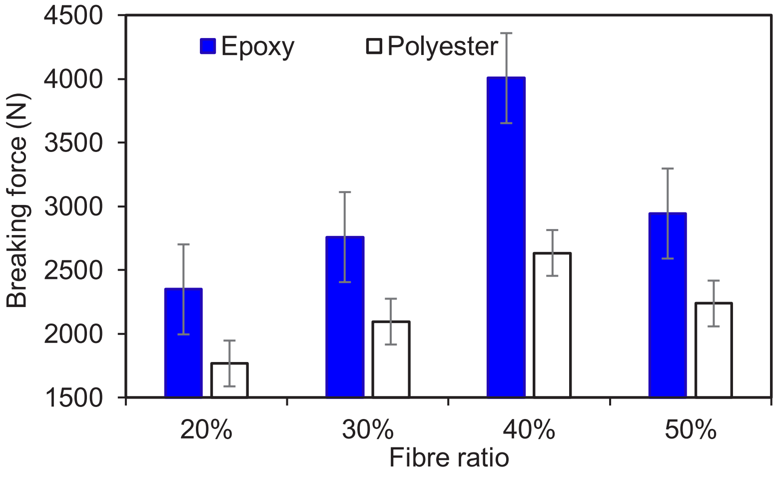

Fig. 2. Breaking force variations of SZ reinforced composites with resins

Therefore, it is recommended to use epoxy resin-based composites with a 40% fibre weight ratio to obtain higher tensile strength in SZ fibre reinforced composites.

3.2.2 Variations of Hardness of SZ reinforced composites

Fig. 3 shows the hardness of the prepared composites. Hardness was measured in HRB units. The 40% composites had the highest Hardness among the treated SZ fibre composites, indicating the good distribution of the fibre into the matrix minimized the voids and a robust interfacial bond between the SZ fibre and polyester or epoxy resin, however, beyond this, hardness was reduced at the 50% fibre ratio, indicating lower interfacial bonding between fibre and resin. In doing the test with Rockwell hardness tester, it was observed that both the intender and body of the intender penetrated to the composite samples, which shows that there is not enough hardness in composites due to an insufficient amount of matrix in the composites and therefore, no results were indicated during the test with both resins used. The reason for this could be that with the 50% fibre ratio, there may be voids in the composite structure. Therefore, it may be poor interfacial bonding between fibre and resins, which results in poor resistance to forces applied on composites. This is indicated in Fig.3 as no data was recorded in the testing. Further, epoxy resin-based composites showed higher hardness values compared to Polyester-based composites. This is because epoxy resin has a higher modulus than polyester resins, as indicated in the literature (Subramanium *et.al.* 2022). Therefore, Epoxy-based SZ composites with a 40% fibre ratio show good resistance to shape deformation due to applying loads in hardness testing.

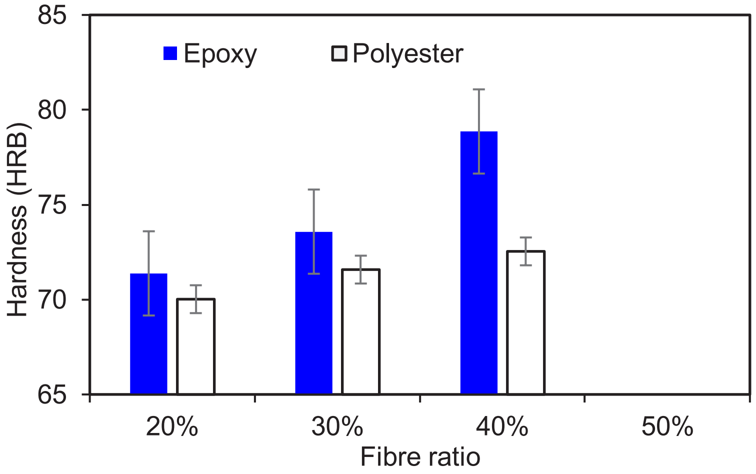

Fig. 3. Variations of hardness of SZ reinforced composites with resins

3.2.3 Flexural strength variations of SZ reinforced composites

Fig.4 shows the flexural strength variations of the prepared composites. According to the results obtained, it can be observed that increase in flexural strength with the increasing of fibre ratio from 20% to 40%, but beyond that, it decreased at 50% in both epoxy and polyester resin-based composites.

With the increasing fibre volume, the interfacial bonding between the resin and fibre increases to 40%, but after 40%, higher fibre volume may not be well dispersed within the resin due to the lower volume of resin available in the composite compared to the 40% fibre ratio. At a 50% fibre ratio, when applying a bending force on to the composite during the flexural test, first the fibres may be stressed and then broken. Because, if there is not enough space between fibre and resin, with higher fibre volume at a 50% fibre ratio, less space will be there to stress transfer (Hariprasad *et.al.* 2022). When compared with epoxy and polyester resin-based composites, flexural strength of Polyester resin is lower than epoxy resin, because, flexural strength of polyester resin itself is lower than epoxy resin (Subramanium 2022, Ashik 2017). Therefore, it is recommended to use the 40% fibre ratio for composites with SZ fibre reinforcement and Epoxy resin to obtain higher flexural strength.

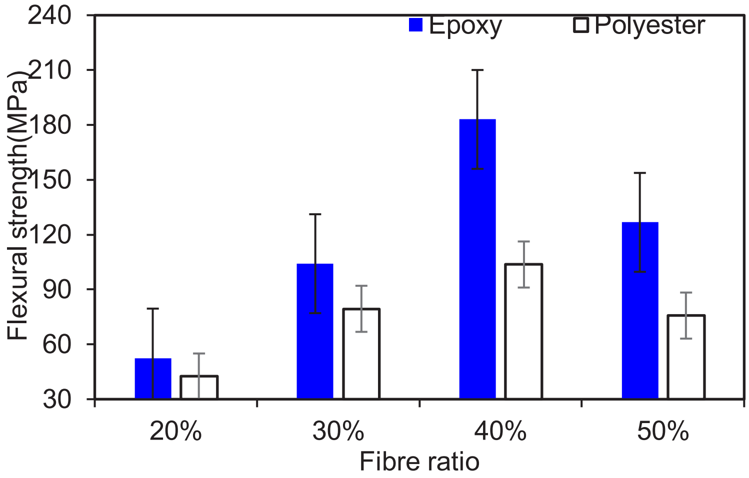

Fig. 4. Variations of flexural strength of SZ reinforced composites with resins

3.2.4 Impact strength variations of SZ reinforced composites

Impact resistance is the ability of a material to withstand a shock loading or an applied stress at high speed. Impact behaviour is an important mechanical property of engineering materials that are used for many applications including interior and exterior components of automobiles, buildings, aircraft and many more. It depends on several parameters such as strength, elastic modulus, length and orientation of fibres, and fibre-matrix interfacial bond strength (Subramanium *et.al.* 2022, Adeniyi *et.al.*2022). Fig.5 shows the impact resistance of tested composites.

According to Fig.4, impact resistance has increased up to 40% fibre ratio and then, it decreased to 50% fibre ratio. This is because of increasing interfacial bonding between fibre and resin up to 40%. But, with a higher the fibre ratio at 50% and comparatively lower resin volume at 50% fibre ratio, it resulted in poor interfacial bonding between fibre and matrix and it may cause to develop voids in the composite. Thus, at 40% fibre ratio, it showed a greater absorption ability of the amount of energy to inhibit fracture development during testing to give the highest impact resistance.

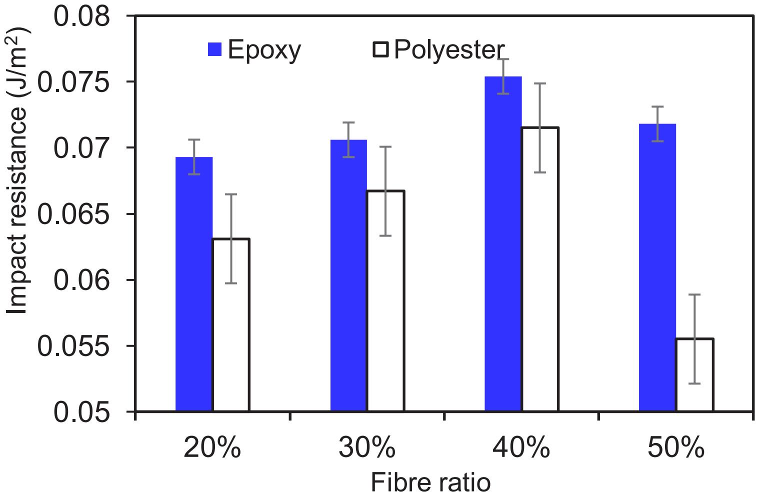

Fig. 5. Impact strength variations of SZ reinforced composites with resins

Further, it was understood that the 50% fibre ratio showed inadequate interfacial bonding, which causes micro space between the filler and the matrix, which will make crack propagation in the samples under impact force. In addition to that, epoxy resin- based composites have given higher impact resistance at all the tested fibre ratios compared to the polyester-based composites. This is because, the polyester resin has lower modulus and impact strength than Epoxy resins. Therefore, it is recommended to use 40% fibre ratio of SZ fibres with epoxy resins in developing the fibre reinforced composites for impact strength value.

3.2.5 Compressive strength variations of SZ reinforced composites

During the compression testing procedure, both the polyester and epoxy composites samples did not crack under the maximum force of 10KN under the 5 mm/min to 100mm/min speed. Therefore, it was concluded that SZ fibre reinforced composites with 20 – 50% fibre ratios, made using epoxy and polyester resins, exhibit good compressive strength. This may be due to good toughness reported in the resin materials as well as the multi directional laying of the reinforcement fibres in the composite preparation.

3.2.6 Moisture absorption of SZ reinforced composites

Fig.6 and 7 show the moisture regain and moisture content variations of composites with the used fibre ratios. Moisture absorption property was measured using these terms.

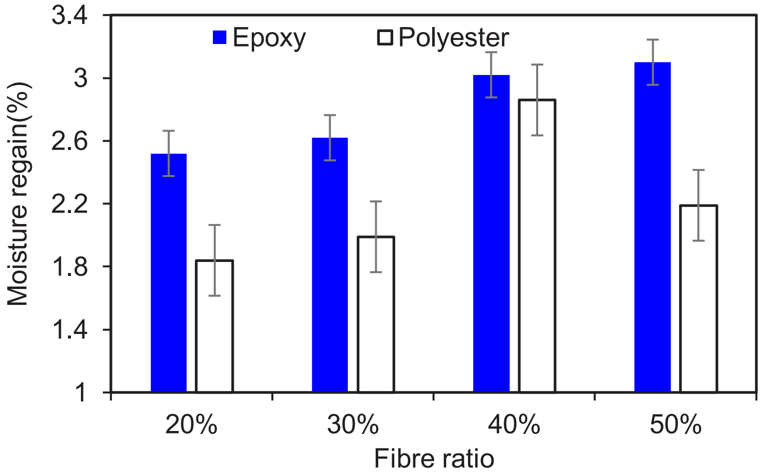

Fig. 6. Moisture regain variations of SZ reinforced composites with resins

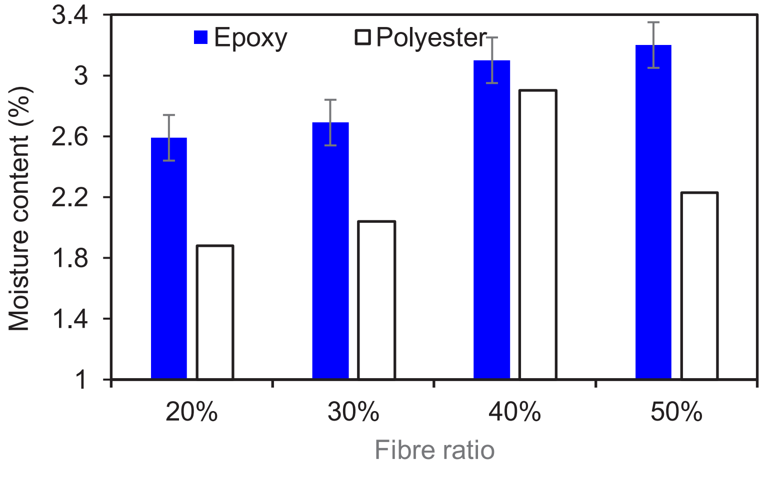

Fig. 7. Moisture content variations of SZ reinforced composites with resins

According to Figures 6 and 7, moisture absorbency increased with the amount of SZ fibres included in the composite, in the case of using epoxy resins. This is because of the moisture absorption of both the SZ fibre, which is much higher, and Epoxy. Thus, epoxy-based composites showed comparatively higher moisture absorbency than polyester resin-based composites. Because, according to the literature, epoxy itself has a moisture regain of 3% and that of polyester is 1%. However, polyester-based composites have shown maximum absorption with 40%, due to the moisture absorption by the SZ fibres. After that, it reduced to 50% fibre ratio. This may be due to the lower resin volume available in the composites with a 50% fibre ratio than the 40% fibre ratio composites.

However, comparing these values with the moisture absorption of alkali treated SZ fibres given in Table 3, it was observed that significantly lower moisture absorption are given with the composites made with both types of resin. This behaviour is very important in certain applications of SZ fibre reinforced composites.

4. CONCLUSION

In this investigation, the physical and mechanical properties of alkali treated and untreated SZ fibres and the composites made from alkali treated SZ fibres were experimented. These composites were prepared with Epoxy and Unsaturated Polyester resins separately using fibre ratios such as 20%, 30%, 40% and 50%.

Alkali-treated SZ fibres showed higher fibre bundle tenacity (28.47%), single fibre strength (9.16%), and higher moisture absorbency (5.43% in moisture regain) properties than untreated SZ fibres. However, the breaking elongation of alkali treated fibres was lower (17.18%) than that of untreated fibres., due to developing the fibrils and it leads to closer packing of polymer chains in the fibre. With the alkali-treated SZ fibre-based composites, the tensile strength (47.2 MPa with epoxy and 30.99 MPa with polyester), hardness (78.86HRB with epoxy and 72.54HRB with polyester), impact strength (0.0754 J/m^2 with Epoxy and 0.0715 J/m^2 with Polyester), and flexural strengths (183MPa with epoxy and 103.66MPa with polyester) were higher at the 40% fibre ratio than with the other ratios. However, compressive strength exhibited good behaviour in all the tested fibre ratios. Thus, the moisture absorption of composites showed significantly lower values both in epoxy and polyester based composites (3.02% with Epoxy and 2.86% with Polyester) with all tested fibre ratios. Thus, the moisture absorption of composites showed significantly lower values both in epoxy and polyester-based composites (3.02%with epoxy and 2.86% with polyester resins) in all tested fibre ratios. Additionally, epoxy resin-based reinforced composites demonstrated superior physical and mechanical properties compared to polyester resin-based composites. Therefore, it is recommended to use alkali-treated SZ fibre reinforced composites made with a 40% fibre ratio and epoxy resin, for composites, which are suitable for industrial applications such as cladding boards, automobiles, aircraft, home appliances, and aeronautical appliances. Thus, the results obtained from this research work show similar patterns of variations, in line with the previous research works on other Sansevieria fibre reinforced composites.

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