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Role of natural fibres: Rubber/polyester composites reinforced with sansevieria cylindrica, waste silk, jute and drumstick vegetable fibres (*Moringa oleifera*)

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ABSTRACT

Despite thermoset polymers have been widely used as engineering components, adhesives and matrix fibre reinforced composites due to their versatile mechanical properties compared to those of thermoplastics polymer, they virtually brittle and vulnerable to crack. Addition of ductile materials such as rubber microsized natural fibres are added in these polymers would help in gaining tensile and flexural strength, corrosion resistance, toughness and water absorption properties. Aim of this work is to investigate the tensile, flexural and dielectric properties of composites made by reinforcing Sansevieria cylindrica as a new natural fibre into a rubber based polyester matrix. The fibres were extracted by retting and manual processes have been used to fabricate the composites. These composites were tested for the properties which mentioned above and compared with those of established composites like waste silk, drumstick vegetable fiber and jute made under the ASTM conditions. The composites were fabricated up to a maximum volume fraction of fibre of 0.35 for impact testing, tensile, flexural and dielectric testing. It was observed that the tensile properties were increased with respect to volume fraction of fibre for Sansevieria cylindrica fibre composite and are also more than those of silk and drumstick composites and comparable to those of jute composites. The flexural strength of Sansevieria cylindrica fibre composite is more than that of waste silk composite and is closer to drumstick fibre composite with respect to the volume fraction of fibre, where as the flexural modulus is much higher than those of jute, drumstick vegetable fibre composites and also very much closer to silk fibre composites. The dielectric strength of Sansevieria cylindrica fibre composite was increased with increase in volume fraction of fibre in the composite unlike the case of waste silk, jute and drumstick tree vegetable fibre composites. The dielectric strength being a unique feature of Sansevieria cylindrica fibre composite can be suggested for electrical insulation applications.

KEYWORDS

Mechanical properties;
Dielectric strength;
Rubber;
Polyester;
Natural fibers.

INTRODUCTION

Natural fibers are an attractive research area because they are eco-friendly, inexpensive, abundant and renewable, lightweight, low density, high toughness, high specific properties, biodegradability and non-abrasive to processing characteristics, and lack of residues upon incineration. Therefore, natural fibers can serve as reinforcements by improving the strength and stiffness and also by reducing the weight of the resulting biocomposite materials although the properties of natural fibers vary with their source and treatments. Cellulosic fibres like sisal, coconut (coir) and bamboo in their natural form as well as several waste cellulosic products such as shell flour, wood flour and pulp have been used as reinforcing agents of different thermosetting and thermoplastic composites[1-4]. Several authors have reported the chemical composition, properties of sisal fibres and their composites by incorporating the fibre in different matrices before and after treatment by different methods[5]. It was observed that the mechanical process yields good quality of fibre compared to retting process, even though the yield is more in the later case. The mechanical properties of sisal, banana and hemp fibre composites using novolac resin, with and without maleic anhydride treatment were reported[6]. It was observed that the properties like Young's modulus, flexural modulus and impact strength increases with maleic anhydride treatment. The mechanical behavior of high impact polystyrene reinforced with short sisal fibres was investigated[7]. Higher values of quasi-static fracture toughness were exhibited by the composites in comparison to the plain matrix up to a fibre content of about 10 wt% of sisal. A composite laminate based on natural flax fibre and recycled high density polyethylene was manufactured by a hand lay-up and compression moulding technique[8]. The tensile and impact properties of the composites were assessed and observed that improvements in strength and stiffness combined with high toughness can be achieved by varying the fibre volume fraction and controlling the bonding between layers of the composite. Composites of an aliphatic polyester with natural flax fibres are prepared by batch mixing and the effect of processing conditions on fibre length distribution and the dependence of the composite mechanical properties on fibre content were investigated[9]. A 30% increase in strength is observed when natural fibres (25 vol.%) are substituted by fibres containing acetate groups. The properties such as tensile strength, modulus, tear strength and elongation at the break of bamboo fibre-reinforced natural rubber composites with and without the presence of a bonding agent, was studied[10]. The presence of bonding agent gave shorter curing time and enhanced mechanical properties. Some studies were carried out on the flexural behavior of bamboo-fibre reinforced mortar laminates[11]. The flexural strength value was improved to greater than 90 MPa for the laminates with reformed bamboo plate on the bottom as a tensile layer and fibre-reinforced mortar sheet on the top as a compressive layer. The mechanical and thermal properties of composites on alkali treatment of jute fibres were also studied. These composites exhibited significantly enhanced properties compared to virgin polypropylene. HDPE-henequen fibre composites were prepared with a 20% volume of fibre content and the tensile, flexural and shear properties were studied. The comparison of the properties of the composites showed that the Silane treatment and the matrix–resin pre-impregnation process of the fibre produced a significant increase in tensile strength but only the silane treatment of the fibre produced a significant increase in flexural strength and shear properties where as the tensile and flexural modulii remained relatively unaffected. Rubber seed oil is fast gaining its place in the composite world as a renewable material for a number of industries. Rubber seed oil is an unsaturated triglyceride made of fatty acid chain attached to a glyceride unit. The fatty acids contain double bonds, allylic carbons, ester groups, and the carbon to ester or olefinic groups. These functional groups can be used to tailor the oil structure such that it contains specific functional groups (such as polyol and oxirane), useful as starting raw material for polymer industries. Previous research studies have shown that rubber seed oil is a potential raw material for alkyd resins used as binders for surface coatings industries[12-22].

In spite of very large quantity of work has been published on various natural fibres and its composites, an effort has been made in the present work to introduce a new couple of natural fibres at one go as reinforcement in one polyester resin in the development of new composite materials for lightweight structures. Few studies were already reported on the exploration, extraction and tensile properties of *Sansevieria cylindrica* fibre but nobody was compared with established fibres like waste silk, jute and drumstick vegetable fibre. The *Sansevieria cylindrica*, abundantly available and renewable in nature and yet obtained from local sources. This economical source compared to other natural sources is still underutilized. The overall objective of this work is to extract the fibres by retting and mechanical procedures and incorporating them into polyester resin matrix to prepare the composites at various volume fractions of fibre. The resulting composites were tested and characterized to evaluate the tensile, flexural and dielectric properties.

EXPERIMENTAL

Matrix

Polyester (Ecmalon 9911, Ecmas Hyderabad, with 2% cobalt accelerator, catalyst 50% methyl ethyl ketone peroxide (MEKP) in 10% DMA solution, ratio of the resin/accelerator/catalyst:100/2/2. The resin has a density of 1335 kg/m^3, Young's modulus of 450 MPa, tensile strength of 15.3 MPa and elongation at break of 3.3%.

Extraction of fibres

Sansevieria cylindrica was collected from Enumuladoddi forest division, nearby Kalyanadurg, Anantapur, Andhra Pradesh, India, waste silk was collected from silk sari weaver at Dharmavaram, nearby Anantapur, Andhra Pradesh, India as it is a hub for silk saris manufacturing., jute and drumstick tree vegetable fibres extracted in the laboratory using retting and mechanical extraction procedure which was explained in detail in the earlier work are collected from various local sources[12]. Fibres were extracted from the Sansevieria cylindrica plant, leafs were cut and decomposed in a water pot for about one month. Removed from the pot, making sure all lignin, hemi-cellulose, lingo-cellulose materials should be separated when it is washed and repeated the same until fair fibres gets separated. The fibres were washed thoroughly with distilled water and allowed to dry in the sun for about 1day. Glass trays separately toped with a 5% NaOH solution and further natural fibres were added to the tray and allowed to soak in the solution for about 4 hours. As result of that left over waste removed viz. lignin, hemicellulose and lingo-cellulose which act as antidote in building adhesiveness, interface and bonding. The fibres were washed with water to remove the excess quantity of NaOH sticking to the fibres. Finally the fibers were washed with distilled water and dried in a hot oven at 60°C for 1 h. The fibres were cut into 20mm length with a sharp scissors[14].

Composite preparation

Unidirectional composites were prepared using polyester matrix to assess the reinforcing capacity and dielectric strength of various natural fibres considered in the present study. Polyester and rubber were added by predetermined ratio of 85:15 respectively and mixed thoroughly with spatula about 45min to see a complete blend of it. The quantity of accelerator and catalyst added to resin at room temperature for curing was in the ratio of resin/accelerator/catalyst by (i.e.100/2/2 respectively) by weight/weight. Hand lay-up method was adopted to fill up the prepared mould with an appropriate amount of polyester resin mixture and fibres, starting and ending with layers of resin. Care has been taken to minimize fibre movement to yield good quality, unidirectional fibre composites. Therefore, at the time of curing, a compression pressure of 0.06 MPa was applied on the mould and the composite specimens were cured for 24 h. Fibre configuration and volume fraction are two important factors that affect the properties of the composite. In this work, the configuration is limited to unidirectional and continuous fibres equal to the length of the specimen 160 mm in case of impact strength testing, 100 mm for flexural testing and 120 mm for dielectric testing and the composite samples were prepared with five different volume fractions of various fibres. The composites are also post cured for 2 h at 70ºC after removing from the mould for flexural testing.

Instron Universal Testing machine (IUTM, seris-3369) was used for measuring tensile and flexural strength. The unidirectional composite specimens were made as per the ASTM D638M to measure the tensile properties. The length, width and thickness of the specimen were 160, 12.5 and 3 mm, respectively. Three point bend tests were performed in accordance with ASTMD618 test method I, procedure A to measure flexural properties. The samples were 100 mm long by 20 mm wide by 3 mm thick. In three point bend test, the outer rollers are 64 mm apart. A three point bend test is chosen because it requires less material for each test and eliminates the need to accurately determine center-point deflections with test equipment. The flexural modulus and the maximum composite stress were calculated using the relationships given in our earlier paper[21]. Five identical samples were prepared for each volume fraction of fibre and all the specimens were tested at a strain rate of 0.5 mm/min. The composite specimens were made as per the ASTM D149, to measure the dielectric strength. The specimens having dimensions of 120 x 120 x3 mm are reinforced with fibres in a single direction along 120 mm length. The dielectric breakdown voltage is determined at five points for each specimen and the average value is considered for the analysis. The points selected are distant enough so that there is no flashover. The test is carried out at 50 Hz frequency and room temperature. Digital micrometer of 0.001 mm least count is used to find the thickness of specimen at break down point and the test was repeated for all specimens fabricated from different kinds of fibres.

RESULTS AND DISCUSSION

Tensile

The density of the *Sansevieria cylindrica* fibre was very less compared to the established fibres like drumstick, silk, jute, coir and banana, which was an attractive parameter in designing lightweight material[22]. The diameter of different fibres under consideration varied between 200 and 300 μm. Ultimate tensile strength and modulus of *Sansevieria cylindrica* fibre reinforced composites, along with drumstick, silk and jute composites are presented in TABLE 1. The effect of volume fraction of fibre on tensile strength and modulus for *Sansevieria cylindrica* fibre reinforced composites in comparison to drumstick, silk and jute composites are presented in Figure 1 and 2. It is observed that the tensile strength of all fibre reinforced composites considered in the present study increases with volume fraction of fibre in the order of silk, jute, *Sansevieria cylindrica* and drumstick. At a volume fraction of fibre

TABLE 1 : The tensile properties of *Sansevieria cylindrica* fiber composites along with the other natural fibers reinforced composites at 0.35 volume fraction of fiber.

Name of the composite	Volume fraction of fibre	Ultimate tensile strength (MPa)	Tensile modulus(GPa)
Neat rubber/polyester	0.000	16.5(±1.230)	0.56(±3.423)
Sansevieria cylindrica	0.355	71.4(±3.670)	1.82(±4.729)
Silk	0.358	68.0(±4.130)	1.72(±5.015)
Jute	0.354	59.5(±3.026)	1.31(±1.634)
Drumstick	0.350	122.2(±6.956)	1.22(±6.520)

Note: Value represented in bracket is standard deviation.

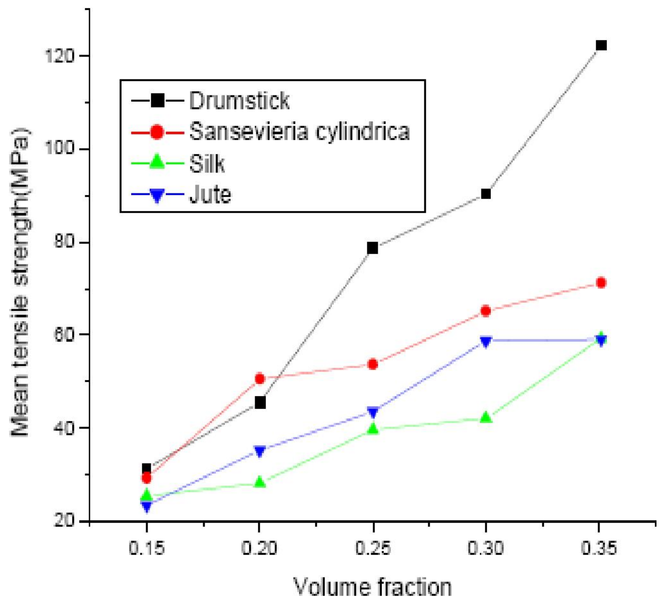

Figure 1 : Effect of volume fraction of fiber on the mean tensile strength of various natural fiber rubber/polyester composites

0.35 approximately in the composite, the tensile strength of *Sansevieria cylindrica* fibre composite is about 5%, 20% higher than those of silk, jute composites respectively. This enhancement is attributed to the strength and stronger bonding of *Sansevieria cylindrica* fibre with the polyester matrix compared to drumstick, silk, jute. The tensile modulus of all composites considered in the present study increases with volume fraction of fibre in the composite in the order of Jute, silk, *Sansevieria cylindrica*, drumstick. It is also observed that the tensile modulus of *Sansevieria cylindrica* fibre composite is 39%, 6% higher than those of jute and drumstick composites, respectively, and comparable to that of silk composite at the same volume fraction of fibre (0.35).

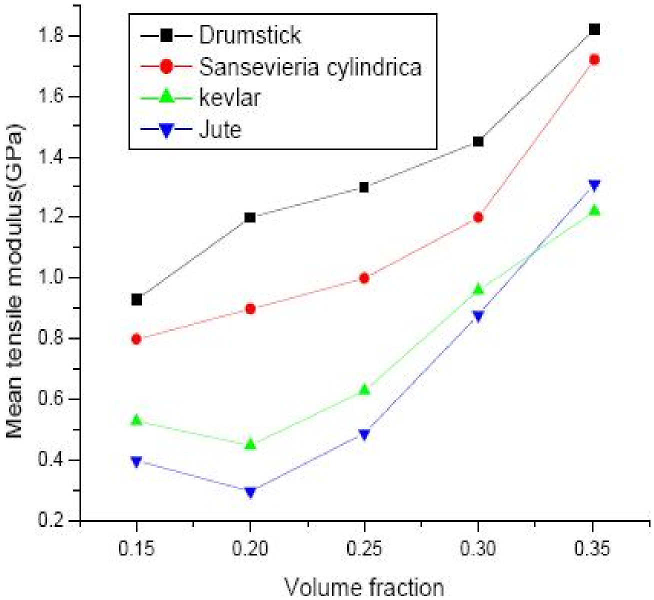

Figure 2 : Effect of volume fraction of fiber on the mean tensile modulus of various natural fiber rubber/polyester composites

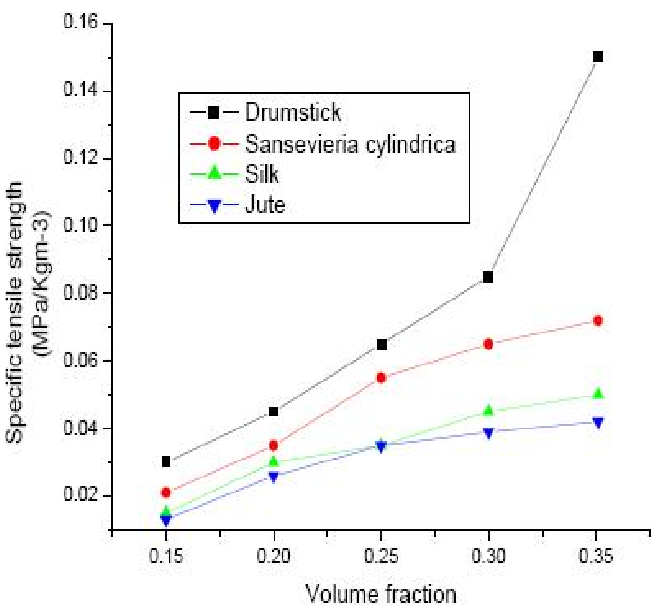

Figure 3 : Effect of volume fraction of fiber on the mean specific tensile strength of various natural fiber rubber/polyester composites

This is due to lower percentage strain of *Sansevieria cylindrica* fibre composite compared to jute and silk composites. The effect of volume fraction of fibre in the composite on the specific tensile strength and modulus are also shown in Figures 3 and 4. The specific tensile strength increases linearly with volume fraction of fibre. As the volume fraction of fibre increases in the composite the specific tensile strength of *Sansevieria*

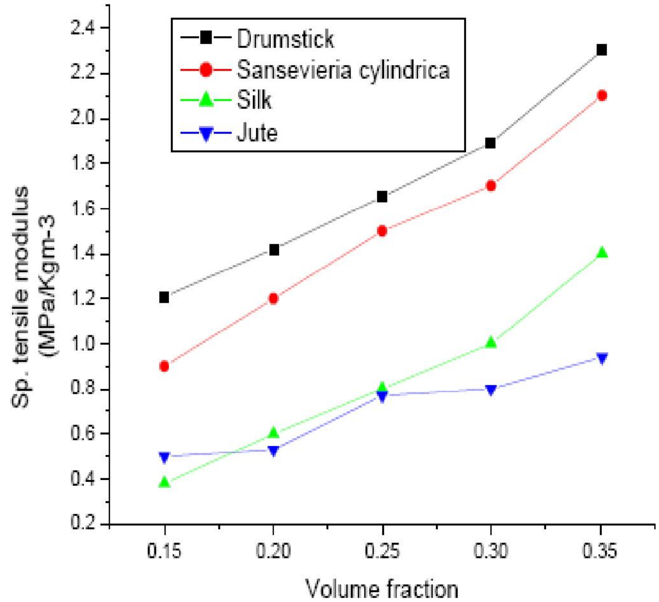

Figure 4 : Effect of volume fraction of fiber on the specific tensile modulus of various natural fiber rubber/polyester composites

cylindrica fibre composite is higher than those of silk and jute composites in the present study. The specific tensile modulus also increases linearly with volume fraction of fibre for all fibre composites considered in the study.

Flexural properties

Ultimate flexural strength and modulus of *Sansevieria cylindrica* fibre reinforced composites, along with silk, drumstick and jute composites at approximately 0.35 volume fraction of fibre, are presented in TABLE 2 for comparison. The effect of volume fraction of fibre on flexural strength and modulus for *Sansevieria cylindrica* fibre reinforced composites in comparison

TABLE 2 : The flexural properties of fibre composites, along with other natural fibre reinforced composites at 0.35 volume fraction of fibre.

Name of the Composite	Volume fraction of fibre	Ultimate flexural strength (MPa)	Flexural modulus(GPa)
Neat rubber/polyester	0.000	68.12(±3.150)	1.56(±3.423)
Sansevieria cylindrica	0.351	91.89(±1.200)	3.32(±4.729)
Silk	0.355	103.0(±4.570)	2.52(±5.015)
Jute	0.356	98.13(±6.011)	3.55 (±1.634)
Drumstick	0.352	129.26(±3.233)	2.25(±6.520)

Note: Value represented in bracket is standard deviation.

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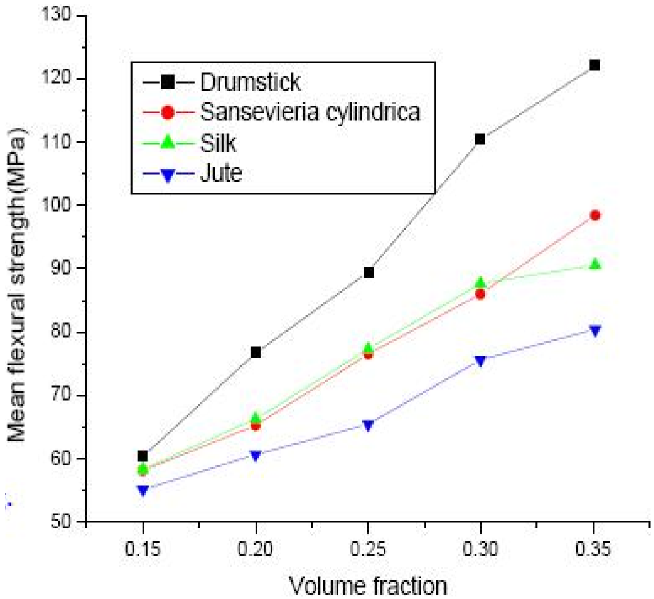

Figure 5 : Effect of volume fraction of fiber on the mean flexural strength of various natural fiber rubber/polyester composites

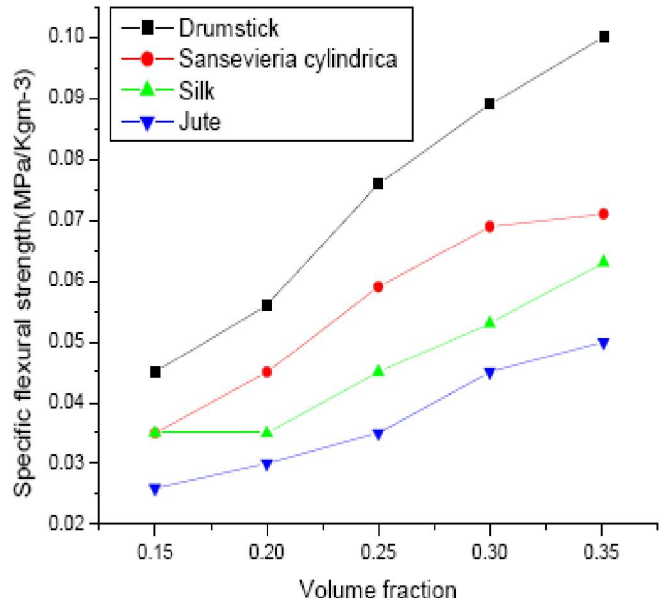

Figure 7 : Effect of volume fraction of fiber on the specific flexural strength of various natural fiber rubber/polyester composites

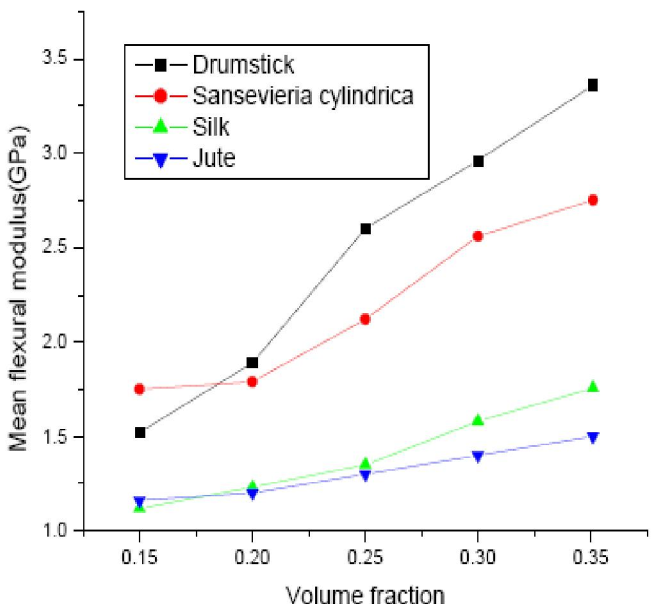

Figure 6 : Effect of volume fraction of fiber on the mean flexural modulus of various natural fiber rubber/polyester composites

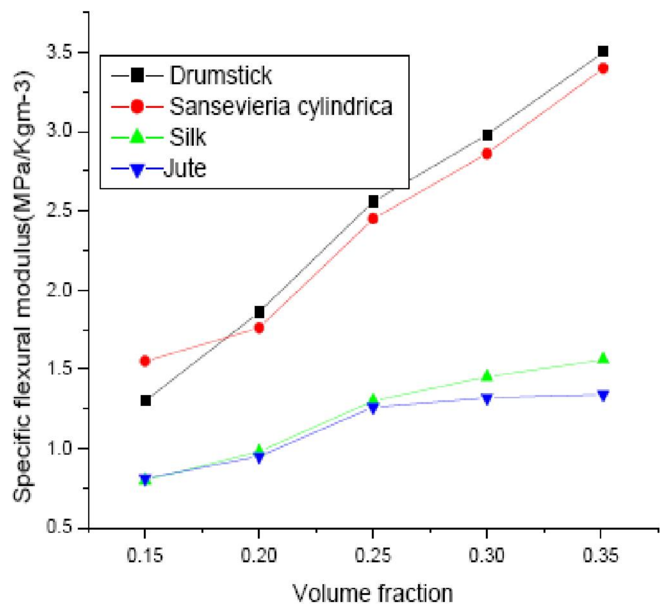

Figure 8 : Effect of volume fraction of fiber on the specific flexural modulus of various natural fiber rubber/polyester composites

to silk, drumstick and jute composites are presented in Figures 5 and 6. It is observed that the flexural strength of all fibre reinforced composites considered in the present study increases with volume fraction of fibre in the order of jute, *Sansevieria cylindrica*, silk and drumstick up to 0..35 volume fraction of fibre. The flexural modulus of all composites considered in the present study increases with volume fraction of fibre in the composite in the order of jute, silk, *Sansevieria cylindrica* and drumstick. It is also observed that the flexural modulus of *Sansevieria cylindrica* fibre composite is 47% and 32% more than those of jute and silk fibre composites, respectively, unlike flexural strength and is also very close to that of drumstick composite at 0.35 volume fraction of fibre in the composite. This is due to higher flexural stiffness of *Sansevieria cylindrica* fibre composite compared to jute and silk fibre composites. The effect of volume fraction of fibre in the composite on the specific flexural strength and modulus are also shown in Figures 7 and 8. The specific flexural strength and modulus increases linearly with volume fraction of fibre. As the volume fraction of fibre increases in the composite the specific flexural strength of *Sansevieria cylindrica* fibre composite is considerably higher than that of jute composite and is very close to silk composite in the present study. The specific flexural modulus also increases linearly with volume fraction of fibre for all fibre composites considered in the study and the specific flexural modulus of *Sansevieria cylindrica* fibre composite is 82% and 80% more than those of jute and silk fibre composites, respectively, which is due to lower density of the *Sansevieria cylindrica* composite compared to other composites.

Dielectric properties

The effect of volume fraction of fibre on dielectric strength of various natural fibre reinforced polyester composites is shown in Figure 9. It is observed that the dielectric strength of all composites decreases with increase in volume fraction of fibre in the composite except in *Sansevieria cylindrica* fibre composite. The rate of decrease of dielectric strength is more in case of jute composite compared to silk and drumstick fibre composites as the volume fraction of fibre increases in the composite. It is also interesting to notice that the dielectric strength of *Sansevieria cylindrica* fibre composites increase with increase in volume fraction of fibre. This is a very rare phenomenon which is not observed in many of the natural fibre composites. Hence, based on the availability and good dielectric strength of *Sansevieria cylindrica* fibre composites investigated in the present research work, this can be considered as one of the potential electrical insulation materials.

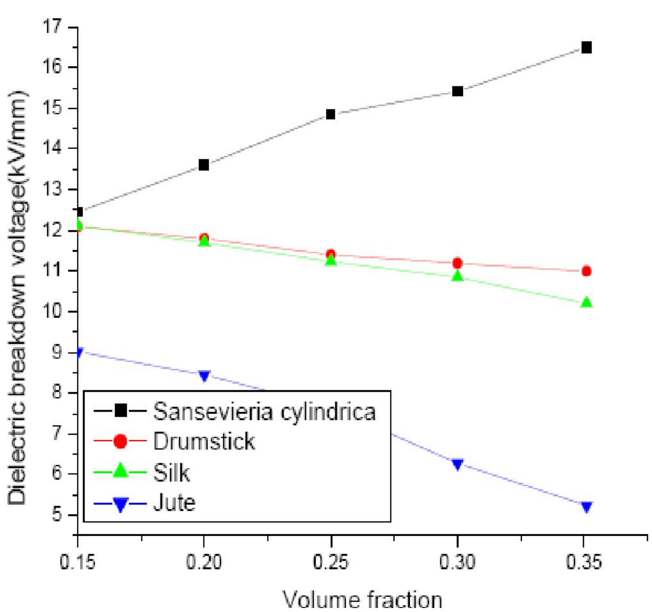

Figure 9 : Effect of volume fraction of fiber on dielectric strength of various natural fiber rubber/polyester composites

CONCLUSIONS

The process of extraction of *Sansevieria cylindrica* fibre is simple and results in an excellent quality, quantity and lengthy fibre useful for fabrication of large composite components. The lower density of *Sansevieria cylindrica* fibre is also an interesting parameter in designing lightweight materials compared to other fibres considered in the present study. The mean tensile strength of Sansevieria cylindrica fibre composite at highest volume fraction of fibre in the present study is much higher than those of silk and jute composites and comparable to that of drumstick composite. It is also concluded that the mean tensile modulus of Sansevieria cylindrica fibre composite is higher than those of jute and silk fibre composites and comparable to that of drumstick composite at highest volume fraction of fibre. As the volume fraction of fibre increases in the composite the specific tensile strength of Sansevieria cylindrica fibre composite is also higher than those of silk and jute composites in the present study.

The flexural modulus of Sansevieria cylindrica fibre composite is much higher than those of jute and silk fibre composites unlike flexural strength and is also very close to that of drumstick composite as the volume fraction of fibre increases up to 0.35 in the composite, and the same trend is also observed in specific flexural modulus with respect to volume fraction of fibre in the composite. It is also worth noticing that the dielectric strength of Sansevieria cylindrica fibre composites increases with increase in volume fraction of fibre in the composite in the present study. This is a very rare phenomenon which is not observed in many of the natural fibre composites. Hence, based on the availability, cheaper and good dielectric strength of Sansevieria cylindrica fibre composites investigated in the present research work, the composite can certainly be considered for electrical insulation applications in addition to fabrication of lightweight materials used in automobile body building, packaging industry, partition panels, etc.

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