International Journal of Engineering, Sciences, Technology and Management
Published online November 26, 2015 (http://www.scienceresearchlibrary.com)

Vol. 01, No. 01, pp. 23 - 29

Research Article **Open Access**

PERFORMANCE OF BLENDED HYBRID FIBER EPOXY/POLYESTER COMPOSITES

G.Naveen Kumar*[1], Y.V.Mohana Reddy[2], K.Hemachandra Reddy[3]

[1]Department of Mechanical Engineering, S.K.University College of Engineering & Technology, SV Puram, Kadiri Road,Anantapuramu-515655, Andhra Pradesh, India

[2]Department of Mechanical Engineering, G Pulla Reddy Engineering College, Nandyal Road, Kurnool - 518 007, Andhra Pradesh, India.

[3]Department of Mechanical Engineering, Jawaharlal Nehru Technological University Anantapur, Anantapur-515002, Andhra Pradesh, India

Received: July 14, 2015 / Accepted : October 21, 2015

Abstract

Hybrid fiber are touted with the help of mercerization technique in order to promote the properties of host Sansevieria cylindrica (Sc) and Sisal(Sl) hybrid fibers in the blend composites followed by synthesized and tested. The developments of high performance composite materials employed from locally available-sources. The objective of this research was to evaluate the mechanical performance (tensile, bending and impact strength) of blended Epoxy (Ey) and Polyester (Pr) in the ratio of 85/15(Wt./Wt.) filled with Sansevieria cylindrica(Sc) at different compositions (3,5,10,20 and 30wt%), using the extrusion and hot press molding technique. Results showed that Sc10: Ey/Pr (75/15) mixture was found better performance among the composites prepared. Because of the suitability of Sansevieria cylindrica (Sc) as filler in Ey/Pr blended composite as shown in our previous work, and yet Sansevieria cylindrical is subjected to hybridize with sisal (Sl) short fibre in Ey/Pr blended composite to achieve superior mechanical performance. Dielectric strength was increased gradually up to 30wt% of Sc fiber content. Thus due to good immiscibility of epoxy/polyester brought a windfall on dielectric strength, water sorption capacity, degradation behaviour such as simulating weathering and soil buried test and yet proved cost effective, co-friendly and state of art blended composites are always go hand in hand.

Keywords: Sansevieria cylindrica fiber, Sisal fiber, Hot press molding, Hybrid blend composite, Mechanical properties

*Corresponding authors: naveenkumargurrijala84@gmail.com

Introduction

Usage of natural fibers in the composite circuit is ubiquitous as they become bear fruit due its inborn qualities such as lignocellulose, natural, annually renewable and biodegradable fibres. Because of its user-friendly these fibers have gone one step ahead as it becomes substitute for synthetic counterparts. Therefore, demand for natural fibers will be increasing day by day in the years to come.

The polymer blending offers possibility of adjusting the cost performance balance and tailoring the technology to make products for specific end use applications; extends engineering resin's performance; improves specific properties, viz. impact strength and solvent resistance; and provides means for industrial and consumer plastics waste recycling[1-4]. Combination of polymer blends with wood and other cellulose materials appears quite promising on the basis of balanced performance, re-utilization of plastic wastes and recyclables after the end use. Also there have been limited reports on the usage of polymer blends and alloys as polymeric, the published work [5-7] was mainly based on polyolefin/polyolefin blends are the processing temperature for each polymeric is below 200ºC such as polystyrene (PS)/high-density polyethylene(HDPE)[8] and polyvinylchloride(PVA)/ low-density Polyethelene(LDPE) blends[9]. Among various polymer blends and alloys, modification of epoxy and polyester matrix combinations are attractive route to promote the performance of the thermosetting matrix; because their blends are expected to improve impact, tensile, flexural and moisture resistance properties and the low cost polyester with excellent mechanical, thermal and barrier properties of epoxy. One example is the Selar® RB resin launched by DuPont Co. This laminar blend was reported to provide up to 100 fold improvement in the barrier to permeation of such organic solvents as toluene, relative to the pure epoxy. The materials can be used for fuel tank and solvent containers [10-20]. Various polyolefin-based compatibilizers have been widely attempted in the literature, but very few blend reports were seen on epoxy/polyester combinations.

This paper present effort on addressing such issues by selecting novel fibres called short Sansevieria cylindrica Fibre (Sc) and Sisal (Sl) to reinforce on Ey/Pr blended system. *Sansevieria* (genus) *cylindrica* (species) is a plant which belongs to *Agavaceae* family and it was invented by Bojer Ex Hook. Sc is 2 fold lesser in size and 1.2 times lesser density when compared with sisal fibre and what's more decrease in size and density brings out excellent interface that will suit for specific applications. It is also clear from the perusal of the literature that the blend systems reinforced with novel and innovatives with different fibres have been little explored and hence there is a need to explore this aspect [21-26]. Aim and the objective of this study is to fabricate light weight, high strength composite that suits for today's transportation systems which is windfall in fuel economy. Present work, work done on adding Sl and Sc fibres as fillers on Ey/Pr blended composites were prepared to assess the effect of mercerization and immiscible behaviour of blends on mechanical, dielectric strength, simulating weathering, soil degradation and water sorption behaviour of composites.

MATERIAL AND METHODS

Materials

Epoxy and hardener (Aradur LY-556 /Araldite HY-951) and used in this study is a commercially available, supplied by Huntsman, Switzerland. Polyester/accelerator/catalyst was supplied by Polyolefin Co. Limited, Singapore. Sc fibre was extracted from the *Sansevieria cylindrica* plant was obtained from the Enumuladoddi forest, near Kalyanadurg, Anantapur (AP) India. The Sisal was collected and subjected to extract fibre from the leafs from the local market at Guntakal; Anantapur, India. The extracted fibre was dried at 80°C in a vacuum oven for 24h prior to the preparation of the composites.

Extraction of the Sc and Sl from the Plant

Duo natural fibers were extracted from the Sansevieria cylindrica and Sisal plants. Leafs were cut and decomposed in a water pot for about one month. Rinsed and washed several times making sure all lignin, hemi-cellulose, lignocellulose materials should be separated and repeated the same until fair fibres gets separated after removing from the water. The fibres were washed thoroughly several times with distilled water and allowed to dry in the sun for about 1day.

Alkali Treatment of Sc and Sl

Two glass trays separately toped with a 5% NaOH solution and further Sc and Sl fibres were added to the tray and allowed to soak in the solution for about 4 hours. As result of that removed all left over lignin, hemi-cellulose 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 60ºC for 1 h. The fibres were cut into 20mm length with a sharp scissors [14].

Mercerization of Sisal and *Sansevieria cylindrica* fibres

In order to mercerize *hybrid* fibres, a small apparatus which allowed desired tensions to be applied to the fibres was developed [26]. A bundle of *hybrid* fibres was soaked in 0.5% NaOH solution under ambient condition with desired tensions (from 0g to 120g weight per fibre) for 2h separately. One end of the fibre bundle was slightly stretched while mounting in the mercerization apparatus to minimize the shrinkage of the fibres during the soaking in NaOH solution. After soaking for 2h, fibres were rinsed several times with distilled water to remove the excess NaOH solution from the fibre surface, neutralized with acetic acid, rinsed with distilled water and finally dried in air. During the air drying, the same tensions used during mercerization were applied to the fibres.

Fabrication of Blended/nanocomposites

Then pre-calculated amount of epoxy/polyester (i.e. 85/15; w/w ratio) were mixed together in a suitable beaker. Hardener/accelerator/catalyst/promoter (100:10/2/2/2) parts by weight was added to the modified epoxy/polyester mixer. A glass mould with required dimensions was used for making sample on par with ASTM standards and it was coated with mould releasing agent enabling to easy removal of the sample. A layer Sc was placed in the glass mould after pouring the 25% of the total modified blend solution, and then remaining solution was poured over this fiber. Brush and roller were used to impregnate composite. The closed mold was kept under pressure for 24 hrs at room temperature. To ensure complete curing the blended composite samples were post cured at 80ºC for 1 hr and the test specimens of the required size were cut out from the sheet. Composites were prepared by compounding with extrusion and hot press machine. The processing temperature is maintained at 180ºC and the pressure was almost all constant. The extruded composites were hot pressed under 10MPa for 5min at 180 ºC into sheets of suitable thickness for making the specimens as per ASTM standard. Sheet size and thickness were dependent on the testing methods used in this study. The relative amounts (%wt) of reinforcing materials Sc and Sl were doped on Ey/Pr blend matrix mentioned in the **Table1**.

Table 1 Relative Amount (%wt) of Reinforcing Materials Sansevieria cylindrica (Sc) and Sisal (Sl) and Epoxy/Polyester Blended Hybrid Composites.

Fillers as reinforcing materials (%)	Ey/Pr matrix (%)	Blend Composites
None	Ey/Pr:85/15	Ey/Pr
Sc:3	Ey/Pr :82/15	Sc3
Sc :5	Ey/Pr :80/15	Sc5
Sc :10	Ey/Pr :75/15	Sc10
Sc :20	Ey/Pr :65/15	Sc20
Sc :30	Ey/Pr :55/15	Sc30
Sc :10 Sl:10	Ey/Pr :65/15	ScSlEy/PrBHC
Sc :10 Sl:20	Ey/Pr :55/15	ScSlEy/PrBHC -1
Sl:30	Ey/Pr :65/15	SlEy/Pr

Determination of Mechanical Properties of the Composites

Tensile properties of the composites were determined using a UTM testing machine(Instron, Series-3369) with across head speed of 5mm/min. Tensile strength, three point bending tests were carried out on par with ASTM D 53455 and ASTM-53452, respectively. All the tests were performed in a displacement controlled mode on a closed-loop servo-hydraulic MTS testing machine. Impact strength of samples was measured on Zwick impact strength testing machine (ZIS 250) according to ASTM D

53433. All the tests were accomplished at a room temperature of 22 ºC. At least five samples were tested for each composition and results were averaged.

Water Absorption Test

Sample of a dumbbell specimens were used for the measurement of water absorption. Specimens were kept in the desiccators at room temperature after being oven-dried at 105ºC for 24h. Then, the specimens were weighed before being immersed in distilled water. Mass of the sample was recorded prior to immersion. The specimens were periodically taken out of the water, surface dried with absorbent paper, reweighed and immediately put back into the water. Water absorption was evaluated on par with ASTM D 5229/D 5229M-92.

Simulated Weathering Test

The blended composites were treated by using a simulated weathering tester from Q-panel Co. (model Q.U.V., USA). The weathering test was performed in alternating cycles of sunshine over 4h (65±2 ºC) and dews and condensation 2h (65±2 ºC). This treatment was carried out for a period of about 720h.

Soil Degradation Test

Cellulose possesses the tendency to be degraded when buried in soil (having at least 25% moisture). For this purpose, the composite samples are weighed individually and buried in soil for 1-16weeks. There after, samples were carefully withdrawn, washed with distilled water, and dried at 105 ºC for 20min and kept for 24h and then weigh is recorded. Finally weight loss of various degraded samples is calculated.

Dielectric Strength

Specimens were made as per the ASTM D 149 to measure the dielectric strength. The specimens having dimensions of 120mmx120mmx3mm are reinforced with fibres in a single direction along 120mm length. The dielectric break down voltage is determined at five points for each specimen and average value is considered for analysis. The points selected are distant enough so that there is no flashover. The test is carried out at 50Hz frequency and room temperature. Digital micrometer of 0.001mm least count is used to find the thickness of the specimen at break down point and the test was repeated for all specimens fabricated from different kinds of fibres.

RESULTS AND DISCUSSIONS

TENSILE STRENGTH AND ELONGATION AT BREAK

Tensile properties such as tensile strength and elongation at break(Eb) of the Sc Ey/Pr blended composites containing 3%,5%, 10%, 20% and 30% Sc as filler were measured and the results are presented in the **Figure 1** & **2,** respectively. It is observed that with an increase in filler content from 3% to 10%, the tensile strength gradually increased but the tensile strength of the composites is found to decrease with increasing filler loading by weight fraction from 20% to 30 %(wt/wt). This may be due to lack of stress transfer from the matrix Ey/Pr to Sc filler. The elongation at break of the composite shows a similar trend as shown for the 10% Sc sample for tensile strength performance and maximum elongation at break. An increase of the elongation at break of the composites increases the toughness and ductility of the composite [20]. The composite might be present as moderate physical-mechanics adhesion (better known as inter-diffusion that allows a kind of bonding between two polymers surfaces via diffusion of the macromolecules both polymers [3].

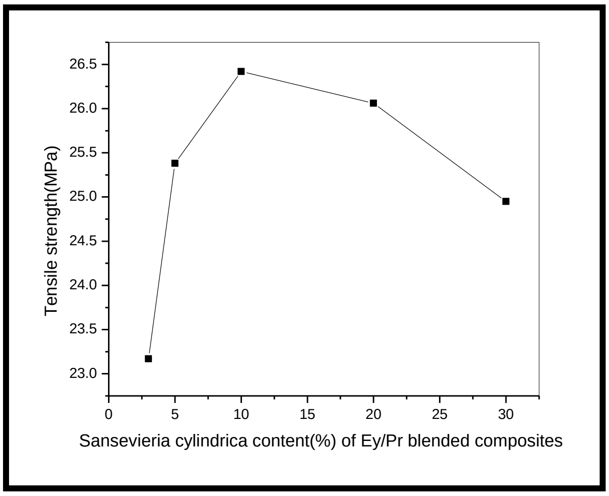

Figure 1 Tensile strength (MPa) of the blended composites.

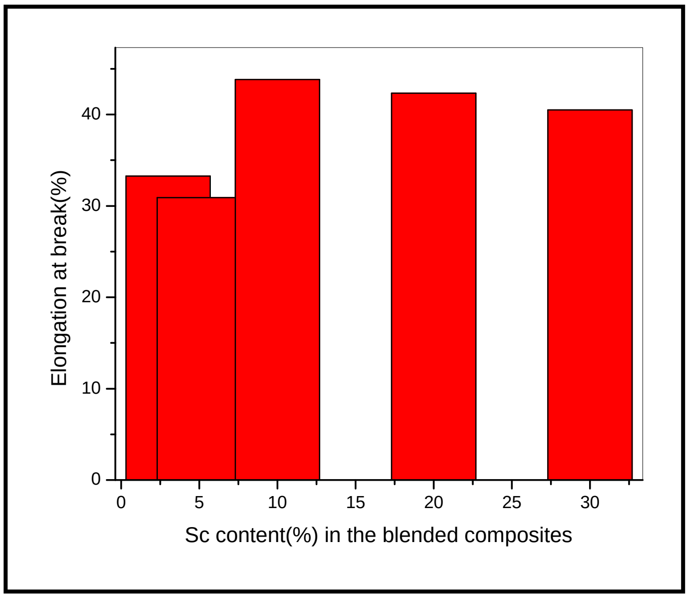

Figure 2 Elongation at break (%) of the composite

BENDING STRENGTH

The bending strength of the different composites is depicted in **Figure 3,** in which, enhancement of tensile strength, the trends for bending strength enhancement of the blended composites were observed. The most obvious reason for the identical results of the tensile and bending properties is due to Sc fiber content in different proportions. Bending strength increases up to 10% Sc and thereafter remains constant.

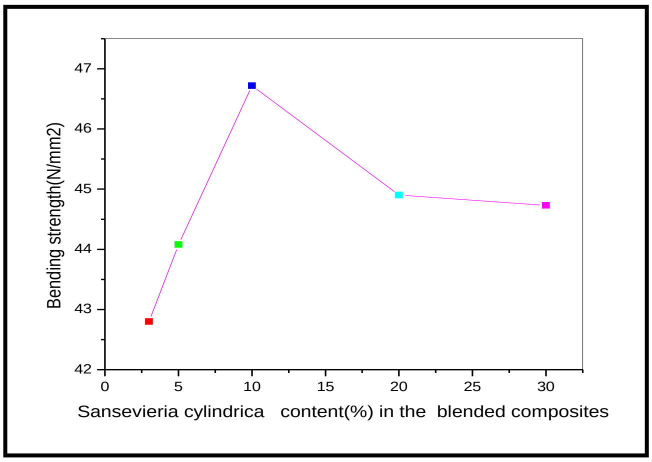

Figure 3 Bending strength of the composites

IMPACT STRENGTH

On considering the impact strength of the composites as shown in **Figure 4**, is an increasing trend with increasing Sc content from 3% to 10% is observed, followed by a decreasing trend. It is envisaged that as the size of the reinforcer becomes smaller, greater interaction between the reinforcer and matrix could result in better and more efficient stress transfer which intern could increase the impact strength of the composite [24]. The optimum reinforcer content varies with the nature of the reinforcer and matrix, reinforcer aspect ratio, reinforcer /matrix interfacial adhesion etc. the low value at high reinforcer content may be due to the presence of so many reinforcer ends in the composites, which could cause crack initiation and hence potential composite failure [8]. In view of the above results, it is noted that the composite of 10% Sc content exhibits better mechanical behaviour.

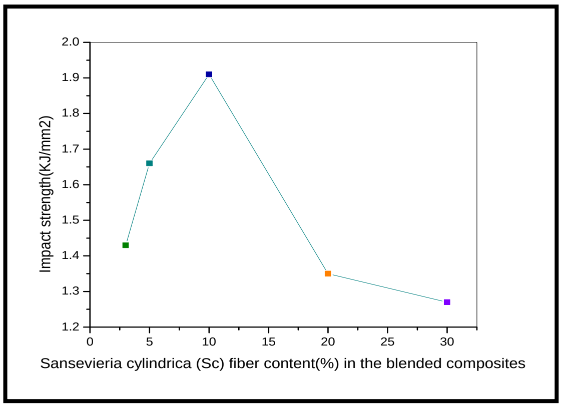

Figure 4 Impact strength of the blended composites.

TENSILE AND BENDING MODULUS

The tensile and bending modulus of the Sc Ey/Pr blended composites increases with increasing filler loading as compared with 85/15: Ey/Pr pure blends(**Figure 5**), while the filler loading more than 10% Sc has adverse effect on tensile strength, at the same time, it has a direct proportional effect on tensile modulus and bending modulus. Both effects may due to the high stiffness of the Sc short fibre composites.

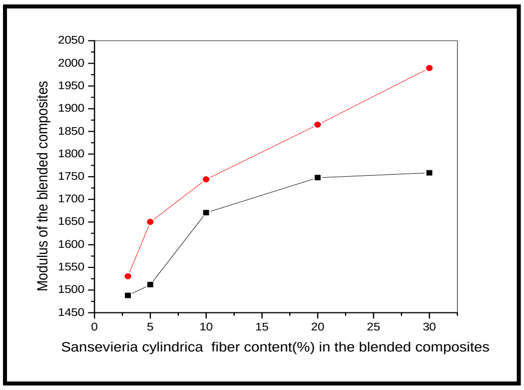

Figure 5 Tensile modulus and bending modulus of the composites.

Hybrid Composites

As a link to previous work [24], *Sansevieria cylindrica* (Sc) has been chosen as another filler to prepare hybrid composite with Sisal (Sl) in Ey/Pr and, thereafter, two hybrid composites, ScSlEy/PrBHC and ScSlEy/PrBHC -1 were prepared by the formulation of 10%Sc, 10%Sl with 65/15: Ey/Pr and 10%Sc, 20% Sl with 55/15: Ey/Pr respectively. There is considerable enhancement of the tensile behaviour exhibited by the hybrid composites, as shown in **Figure 6**. The highest tensile strength (2.77MPa), maximum elongation at break value (46%) and young's modulus (EM) (1.59GPa) have been produced by the hybrid blended composites ScSlEy/PrBHC and there is no significant results obtained by another composite ScSlEy/PrBHC -1 as shown in **Figure7**, which proved that the BS and IS values of the hybrid composites are significantly higher than those of the other composites. The enhancement of the hybrid composites may be caused due to better compatibility of the two fibers and Ey/Pr matrix in particular ScSlEy/PrBHC blended composites. The remarkable behaviour on elongation at break (**Figure 8**) of the hybrid blended composite supports the increased fiber/ matrix adhesion and better fiber dispersion which demonstrated hybrid reinforcing effect as well as the positive hybrid effect [14]. Further research is required for better interpretation of the activities of hybridization in the hybrid composite during extrusion and hot press molding process.

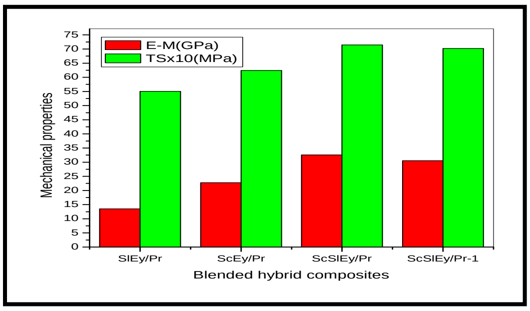

Figure 6 Mechanical properties of hybrid composites

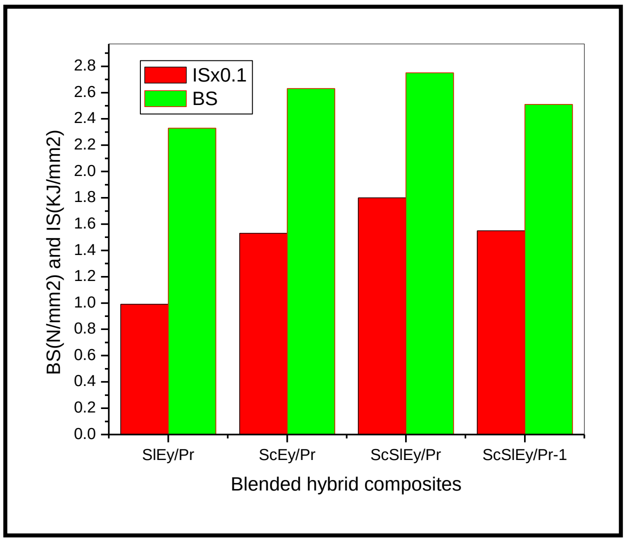

Figure 7 Bending strength (BS) and impact strength (IS) of the hybrid composites.

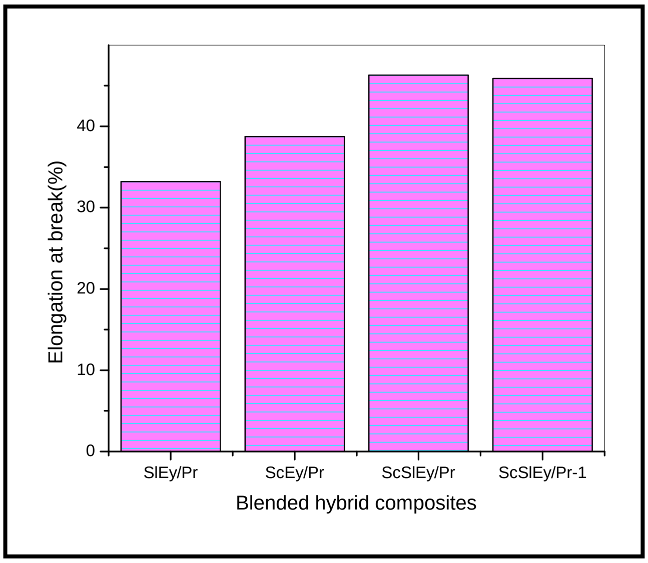

Figure 8 Elongation at break of the blended hybrid composites.

Water Sorption Test

The influence of water environment on the sorption characteristic of ScEy/PrBC composites has been studied by immersion of distilled water at 28ºC. The effect of fiber loading on the sorption behaviour is evaluated. The results of the water up take are shown in the **Figure 9** as water up take versus soaking time. In fact it is observed that initially the absorption is linear, subsequently gradual and finally reaches a plateau. It is evident that the initial rate of water absorption and equilibrium uptake of water increases with increasing fibre content. Therefore, the water uptake is found to increase with fiber loading, owing to the increased cellulose content [9]. Hence, as expected, as the samples uptake the highest amount of water compared with the other samples depending on the filler loading in the composites. The lowest uptake of water by the composites indicates that more OH groups of cellulose content in the fibers of the composites are being blocked by their interaction with the Ey/Pr matrix, hence hindering them from being accused by water [15].It is also worth noticing that the dielectric strength of Sc fibre composites (**Figure10**) 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 Sc fibre composites investigated in the present research work, the composite can certainly be considered for electrical insulation applications.

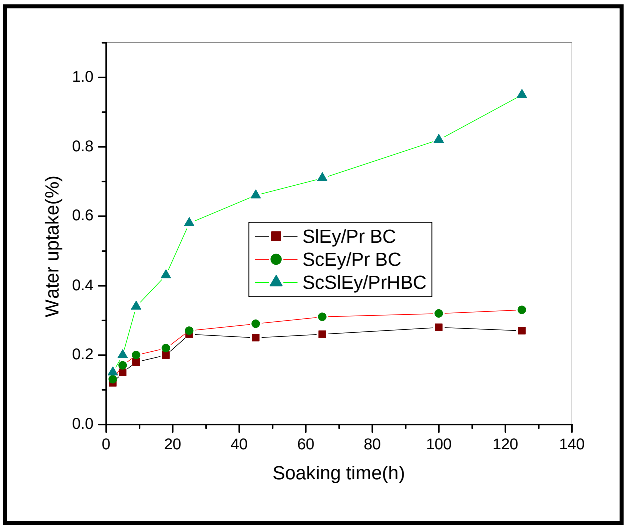

Figure 9 Water uptake of the composites.

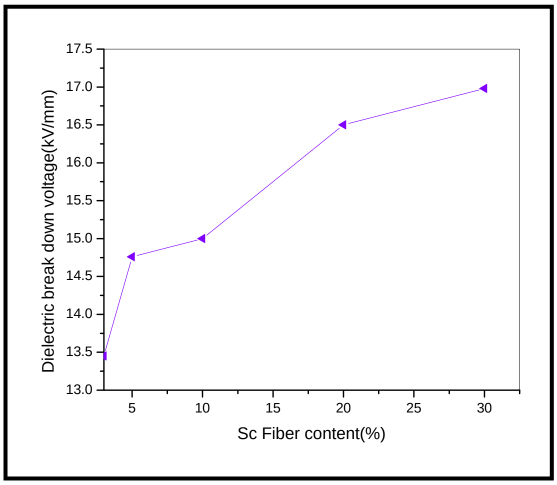

Figure 10 Effect of Sc fiber content on dielectric strength.

Simulating Weathering Effect

The three types of composites Sc composites(ScEy/PrBC), *Sisal(Sl)* composite(SlEy/PrBC) and Sc/Sl hybrid composite(ScSlEy/PrBHC) were exposed to accelerating weathering tester over a period of about 720h to study the degradation properties. The loss of weight and tensile properties (TS & Eb) of the samples due to weathering is shown in the **Table 2.** The loss of TS of the ScEy/PrBC composite is about 7.4% while that of the SlEy/PrBC is about 7.7% and for the hybrid composites ScEy/PrBC is about 5.3%. Similarly Eb loss is 25% for the ScEy/PrBC sample and 24% and 21.5% for the ScEy/PrBC and ScSlEy/PrBHC samples, respectively.

Table 2 Loss of Weight and Mechanical Properties of the Composites Due to Simulating Weathering

Weathering time(h)	Weight loss (%)			Loss of TS (%)			Loss of Eb (%)		
	ScC	SlC	ScSlBHC	ScC	SlC	BnScBHC	ScC	SlC	BnScBHC
24	1.5	3.3	1.9	1.8	1.5	1.4	1.9	2.2	1.9
48	3.4	5.1	2.3	2.4	1.6	3.9	3.4	4.5	3.7
72	5.2	7.5	5.9	1.6	3.4	1.2	6.8	8.1	5.2
96	7.0	9.6	6.4	3.2	4.5	2.1	9.5	10.8	8.6
120	8.9	12.5	5.1	3.9	4.6	2.1	14.1	14.2	11.6
240	10.9	13.4	8.7	3.5	4.2	2.2	18.1	20.2	16.6
480	12.8	16.0	9.4	5.2	6.2	4.3	23.0	26.5	21.2
720	15.4	18.0	10.2	7.4	7.7	5.3	25.0	24.0	21.5

Soil Degradation

Composites such as *Sansevieria cylindrica* (Sc) fibre composite(ScEy/PrBC), composite Sisal(Sl) SlEy/PrBC and Sl fiber/ *Sansevieria cylindrica* hybrid blend composite (ScSlEy/PrBHC) were buried in soil (25% water) for a period of 16 weeks in order to study the effect of environmental condition on the degradability of the samples. Weight loss and tensile properties (TS and Eb) of the composite samples were periodically measured and the results are given in **Table 3.** Minimum weight loss is for the blended hybrid composites (ScSlEy/PrBHC) (7.0%) as compared with other composites samples. Also, TS and Eb loss due to degradability is minimum for the hybrid composites at the maximum period of observation.

Table 3 Loss of Weight and Mechanical Properties of the Blended Composites Due to Soil Degradation.

Degradation time(weeks)	Weight loss (%)			Loss of TS (%)			Loss of Eb (%)		
	ScC	SlC	ScSlBHC	ScC	SlC	ScSlBHC	ScC	SlC	ScSlBHC
1	3.5	3.6	1.2	3.4	2.5	3.8	3.5	4.5	3.2
2	5.2	5.9	3.9	5.8	7.5	4.3	6.0	6.8	3.7
4	8.1	8.3	5.2	9.3	11.1	7.6	8.3	10.2	8.6
8	9.1	11.2	7.9	9.3	11.4	8.5	12.1	13.2	12.5
16	10.1	13.5	7.0	12.7	14.4	9.3	19.1	22.0	18.7

Abbreviation: ScC= Composite blend formulated by 10% Sansevieria cylindrica fibre and Ey/Pr: 75/15(w/w); SlC= Composite blend formulated by 20% Sl and Ey/Pr: 65/15(w/w); ScSlBHC= blended composite formulated by10% Sc,10% Sl and Ey/Pr: 65/15(w/w);

CONCLUSIONS

The results of the study showed that extrusion and hot press molding process could be used to produce Sc short fiber Ey/Pr blended composites with remarkable mechanical properties. From the above experimental observations it is clear that tensile properties decreased as the % of the filler increased a trend which completely followed our earlier work with *Sansevieria cylindrica* [21]. However, the results demonstrated that the prepared composite with 10% content of Sc exhibits better mechanical properties. Dielectric strength was observed remarkable at 10% of Sc. The results also indicate that it is possible to enhance mechanical performance of hybrid fibre reinforced composites through hybridization of betel nut fibre and *Sansevieria cylindrica* with Ey/Pr matrix at optimized ratio (Sc10:Sl10: Ey/Pr: 65:15) of the fiber matrix formulation. The results discussed above can be used to prepare composites/hybrid composites using Sc and Sl in Ey/Pr blends, which may be find diverse applications as structural materials where strength and cost considerations are important.

Acknowledgements

Authors would thank for both Dept. of Pharmacy and Dept. of Polymer science and Technology at S.K.University, Anantapur for providing laboratories and other facilities.

References

Ashok Kumar, M., Hemachandra Reddy, K., Mohana Reddy, Y.V., Ramachandra Reddy, G. and Venkata Naidu S.(2010). Improvement of Tensile and Flexural Properties in Epoxy/Clay Nanocomposites Reinforced with Weave Glass Fiber Reel, International Journal of Polymeric Materials, **59**:854–862.

Ashok Kumar, M., Ramachandra Reddy, G., Siva Bharathi, Y., Venkata Naidu, S. and Naga Prasad Naidu, V. (2010). Frictional Coefficient, Hardness, Impact Strength and Chemical Resistance of Reinforced Sisal-Glass Fiber Epoxy Hybrid Composites, Journal of Composite Materials, **46**(26):3195-3202.

Utracki, L.A. (2003). Introduction to the Polymer Blends. In Utracki, L. A. (Ed.), Polymer blends hand book, Vol. 1. pp.15-21 Kluwer Academic Publishers, Dordrecht.

Simonsen, J. and Rials, T.G. (1996). Morphology and Properties of Wood Fiber Reinforced Blends of Recycled Polystyrene and Polyethylene, Journal of Thermoplastic Composites**,** **9**(3):292-302.

Xu, B., Simonsen, J. and Rochefort, W.E. (2001). Creep Resistance of Wood Filled Polystyrene/ High Density Polyethylene Blends, Journal of Applied Polymer Science, **79**(3): 418-425.

Prachayawarakorn, J., Khamsri, J., Chaochanchaikul, K., Sombatsompop, N.(2006). Effect of Compatibilizer Type and Rubber Wood Saw Dust Content on the Mechanical, Morphological and Thermal Properties of PVC/LDPE Blend, Journal of Applied Polymer Science, **102**(1): 598-606.

Akkapeddi, M. K. (2003). Commercial Polymer Blends, In: Utracki, L.A., (Ed.) Polymer blends hand book, Vol.2, P.1034(Chapter14) Kluwer Academic Publishers, Dordrecht.

Jiang, C., Fillippi, S. and Magagnini, P. (2003). Reactive Compatibilizer Precursors for LDPE/PA6 Blends, II: Maleic Anhydride Grafted Polyethylene, Polymer,**44** (8):2411-2422.

Chiono, V., Filippi, S., Yordanov, H., Minkova, L. and Magagnini, P. (2003). Reactive Compatibilizer Precursors for LDPE/PA6 Blends, III: Ethylene-Glycidylmethacrylate Copolymer, Polymer, **44** (8):2423-2432.

Yordanov, C. and Minkova, L. (2005). Fractionated Crystallization of Compatibilized LDPE/PA6 Blends, Europian Polymer Journal, **41**(3):527-534.

Filippi, S., Yordanova, H., Minkova, L., Polacco, G., Talarico, M.(2004). Reactive Compatibilizer Precursors for LDPE/PA6 Blends, IV: Maleic Anhydride and Glycidyl methacrylate Grafted SEBS, Macromalecule Material engineering,. **289**(6):512-523.

Rozman, H.D., Musa, L. and Abubakar, A. (2005). The Mechanical and Dimensional Properties of Rice Husk Unsaturated Polyester Composites, Polymer Plastic Technology and Engineering, **44**:489-500.

Varada Rajulu, L., Ganga Devi, G. and Babu Rao, G.(2003). Miscibility Studies of Epoxy/Unsaturated Polyester Resin Blend in Chloroform by Viscosity, Ultrasonic Velocity and Refractive Index Methods, Journal of Applied Polymer Science, **89**(11): 2970–2972.

Benny Cherian, A., Lity Alen Varghese, and Eby Thomas Thachil.(2007). Epoxy-Modified, Unsaturated Polyester Hybrid Networks, European Polymer Journal, **43**(4):1460-1469.

Nikhil Gupta, L., Tien Chih Lin, and Michael Shapiro.(2007). Clay-Epoxy Nanocomposites: Processing and Properties, Journal of Minerals, **12**:127-131.

Blanton, T. N., Majumdar, D. and Melpolder. S. M. (2000). Microstructure of Clay-Polymer Composites. JCPDS-International Centre for Diffraction Data, Advances In X-Ray Analysis, **42**:457-462.

Jawahar, P. and Balasubramanian, M. (2004). Alkali Resistance of Polyester-Clay Nanocomposites. International Symposium of Research Students on Materials Science and Engineering, December 20-22, 2004, Chennai, India.

Varada Rajulu, A., Babu Rao, G. and Lakshminarayana Reddy, R. (2001). Chemical Resistance and Tensile Properties of Epoxy/Polycarbonate Blend Coated Bamboo Fibers, Journal of Reinforced Plastics and Composites**, 20**: 200-206.

Asma Yasmin, Jandro Abot, L. and Isaac Daniel, M. (2003). Processing Of Clay/Epoxy Nanocomposites By Shear Mixing, Scripta Materialia, **49**: 81–86.

Varada Rajulu, A., Babu Rao, G. and Lakshminarayana Reddy, R. (2000). Chemical Resistance and Tensile Properties of Epoxy/Polymethylmethacrylate Blend Coated Bamboo Fibers, Indian Journal of Fiber and Textile Research, 2: 295-297.

Sreenivasan,V.S., Ravindran,D., Manikandan,V. and Narayanasamy, R.(2010). Mechanical Properties of Randomly Oriented Short Sansevieria Cylindrica Fibre/Polyester Composites, Materials and Design, (in press) doi:10.1016/j.matdes.2010.11.042.

Ashok Kumar, M., Hemachandra Reddy, K., Ramachandra Reddy, G., Venkata Mohana Reddy, Y. and Subbarami Reddy, N. (2010). Synthesis, Mechanical & Thermal Properties of Clay /Epoxy Nanocomposites Reinforced with Short Woven Glass Fiber Reel**,** Nano Science and Nano Technology, 4(2):2010(in press).

Ashok Kumar, M., Hemachandra Reddy, K., Ramachandra Reddy, G., Venkata Mohana Reddy, Y. and Subbarami Reddy, N. (2010). Tensile, Thermal Properties & Chemical Resistance of Epoxy/Hybrid Fibre Composites (Glass/Jute) Filled with Silica Powder, Indian Journal of Macromolecules, **6**(2):2010(in press).

Ashok Kumar, M., Ramachandra Reddy, G., Hemachandra Reddy, K., Venkata Mohana Reddy, Y., Ranga Reddy, P. and Subbarami Reddy, N.(2011). Fabrication and Performance of Hybrid Betel Nut (Areca catechu) Short Fibre/ Sansevieria cylindrica (Agavaceae) Polypropylene Composite, Indian Journal of Material Science (in press).

Sreenivasan, V.S., Somasundaram, S., Ravindran, D., Manikandan, V. and Narayanasamy, R.(2011).Microstructural Physico-Chemical and Mechanical Characterization of Sansevieria cylindrica Fibres: an Exploratory Investigation, Materials & Design, **32**/1 (2011), 453-461.

Jun T. Kim, Anil N. Netravali, Mercerization of Sisal Fibers: Effect of Tension on Mechanical Properties of Sisal Fiber and Fiber-Reinforced Composites, Composites Part A: Applied Science and Manufacturing,(in press) doi:10.1016/j.compositesa.2010.05.007.