

## Research Article

V. Jagadeesh\*, DR. K. Venkatasubbaiah, and A. Lakshumu Naidu

# Experimental study on mechanical behavior of natural hybrid composites filled with ground nut shell ash

<https://doi.org/10.2478/mme-2019-0029>

Received Oct 05, 2017; revised Jun 10, 2018; accepted Nov 20, 2018

**Abstract:** Nowadays, natural fiber reinforced polymer composites are widely used because of their advantageous properties like minimum density, maximum specific strength, low cost and easy availability. Manufacturing of natural fiber composite is easy as compared to the conventional methods. In the present scenario, due to an increasing interest in environmental consciousness with greenhouse effect, various industries have initiated the use of eco-friendly materials and are replacing hazardous materials with such eco-friendly materials. The present work aims to determine the tensile strength of okra and jute fibers reinforced in Epoxy LY-556 and XIN-100IN Resins. Okra fibers are developed from the stem of the plant of the Malvaceae family. Their use as reinforcement in polymer composites requires the basic knowledge of their mechanical properties. Jute fibers are developed from the best jute plants. The conclusions are based on their mechanical properties and behavior.

**Keywords:** Composite materials, natural fibers, polymers, mechanical properties, environmental

## 1 Introduction

Since 1900s, natural fibers have become quite popular as the strengthening material for composites. Currently, fiber composites are being employed in numerous applications as a replacement for the conventional composites due to their properties like minimum density, maximum specific strength, low cost and easy availability [1]. Natural fibers are a bio and renewable material. Natural fibers

can originate from plants, animals, and minerals. Mineral fibers are avoided in several countries as these are found to inflict health problems in humans. Plant fibers are mostly polysaccharide based fibers; polysaccharide is the major component while manufacturing this fiber. Plant fibers are obtained from stem, leaves, bast, seeds, and fruits. Banana, jute, kenaf, flax, palm are some examples of plant fibers. Animal fibers are mostly super molecule based fibers; they're obtained from wool or hair of animals [2]. Alpaca and silk are some examples of animal fibers.

Plant fibers have a higher mechanical behavior than animal fibers except for silk fiber; silk fiber has higher strength, however, the value of the fibers in silk fiber is very high as compared to plant fibers. Jute fiber comprises 59–71.5% cellulose, 13.6–20.4% hemi cellulose and 11.8–13% Lignin in their chemical compositions. Okra fiber consists of 67.5% of cellulose, 15.4% of hemi cellulose and 7.1% of lignin as its major chemical properties.

The frictional grip between fiber and matrix plays an important role in the natural fiber composites. The matrix material transfers the load to the stiff fibers through shear stress at the interface of the composite. If the bonding between the matrix and fiber is poor, the fabric might weaken and a life time of composites are ablated [3]. If there is robust adhesion between the fiber and matrix, sensible mechanical properties can be obtained. Mechanical properties are not solely dependent upon the fiber-matrix interaction; it also depends upon the matrix and fiber together [4–9].

With passage of time, the orientation of fiber jointly influences the mechanical properties of a cloth. Fiber alignment and size can jointly create problems in the mechanical properties of a composite. Fiber properties are dependent on the placement of the fibers; at completely different locations, fibers can have the various properties. As a result of this, there may be alteration in the properties of the fiber. Even with using the same procedure, but having different alignments, fibers don't offer equivalent mechanical properties [4].

\*Corresponding Author: V. Jagadeesh: Andhra University, Department of Mechanical Engineering, India; Email: Varanasi.jagadeesh@gmail.com

DR. K. Venkatasubbaiah, A. Lakshumu Naidu: Andhra University, Department of Mechanical Engineering, India

## 1.1 Lady's Finger Fiber Applications for Potential Use as Reinforcement in Composite Materials

In the process of making efforts for widening the number of species from which plant fibers are developed and used as a filler (possibly with some reinforcement effect) for polymers, a reasonable method for local fibers may be made available that does not involve unsustainable costs for transportation. Cellulosic fibers are extracted from plants and they are mostly suitable for polymer reinforcement purposes. This includes, for example, jute, flax and hemp, which are hard fibers and quite well benefitting industrially [5].

The stalk from herbaceous plants can also be used for this purpose, although these plants are less regularly used and it is not always easy to prepare effective fibers through traditional retting. Fibers prepared and developed from herbaceous plants that have been proposed for use in materials include switch grass, alpha esparto, celery and nettle; although in some cases, more as an agro-waste filler than for semi-structural purposes [6].

## 1.2 Materials and Methods

### 1.2.1 Fiber Extraction

Okra (*Abelmoschus esculents*), having the local name Dherosh, is a monocotyledon plant. The plant was collected and it was kept under water to allow microbial degradation. It is possible to allow fiber extraction after the leaves degraded within 15 to 20 days. The fibers were separated from the degraded leaves by being washed three to four times, using deionized water, then tied with ropes, dried in open air and kept in moisture-proof container afterwards [7–10].

### 1.2.2 Measurement of Tensile Strength of Okra Fibers

Measurement of tensile strength is carried out by using a Hounsfield UTM testing device equipped with a 100 N force, having a test speed of 5 mm/min. The fiber was twisted with a fixed diameter. Tensile strength of each specimen was measured according to ASTM D3822-07 [11].

### 1.2.3 Static Tests on Composites

Tensile specimens were prepared according to ASTM D 638-98, following the sample type M-II. The test speed was 5 mm/min. Flexural specimens were prepared according to ASTM D790M, 3 point loading. The specimen dimension was  $125 \times 10 \times 6$ –8 mm and support span was 96 mm.



Figure 1: Tensile test specimens

### 1.2.4 Tensile Strength of Okra Fiber Reinforced Polymer Composites

Fiber reinforced polymer (FRP) materials are composites consisting of fibers embedded in polymer matrices. These materials are suitable for a large number of diverse applications ranging from aerospace to sporting equipment. The FRP composites primarily consist of synthetic fibers like glass, carbon, aramid and Kevlar. Although the synthetic fiber reinforced composites have excellent strength and hardness, they are high cost and non-biodegradable. Because of these reasons, over the past few years, the synthetic fibers have been replaced with natural fibers. The growing interest in using the natural fibers is due to their availability, satisfactory specific strength and modulus, light weight, low cost and biodegradability. Also, the price of polymer reinforced natural fiber composite is two to three times lower than that of polymers reinforced composite with glass fibers [12].

Natural fiber reinforced composites contain plant derived fiber with plastic binder. The natural fibers like

wood, sisal, hemp, coconut, kenaf, flax, jute, abaca, banana leaf and bamboo are extensively used. The properties of natural fibers depend on the nature of the plant, locality in which it grows, age of the plant and extraction method used. The properties of the composite also depend on the direction of fibers. The bidirectional bamboo fiber reinforced composite has a higher punch shear strength and lower tensile strength than that of the unidirectional fiber composite. The mechanical strength of the natural fiber reinforced polymer composite (NFRPC) is compared with the glass fiber reinforced polymer composite [13].

## 2 Experimental Procedure

Okra fibers extracted from okra plant are used as reinforcement material. Fresh okra stems collected from farms are immersed and held in water for 20 days. The microbial degradation allows the stems to degrade sufficiently to enable fiber extraction [14]. The extracted fibers are washed several times using water. The washed fibers are dried in open air and kept in moisture proof container. Two types of chemical treatments are performed on the fibers. First, the fibers are soaked in 2% NaOH solution at 70°C for about 2.5 hours and then washed with water. In the second stage, the fibers are soaked in basic sodium sulphate (PH4) for 3 hours, then washed with water and dried in open air.

### 2.1 Physical, Mechanical Behavior of Jute Fiber Reinforced Polymer Composites

There has been greater interest in the use of natural fibers with Jute Fiber Reinforced Polymer Composites over the last few decades in order to replace synthetic fibers in composite applications. Jute fiber is a promising reinforcement for use in composites apart from other natural fibers, on account of its characteristics like reasonable cost, availability and its renewable nature with high specific properties and no health risk. It needs very less energy consumption for processing. A great deal of work has been published regarding the reinforcing potential of jute fiber on polymer composites. Properties of FRP composites are determined by many factors, such as the properties of the fibers, orientation of the fibers, concentration of the fibers, properties of the matrix and fiber-matrix interface. By increasing the volume content of reinforcements, the strength and stiffness of a composite can be increased to a point [15]. If the volume content of reinforcements is too high, there will not be enough matrix to keep them sepa-

rate, and they can become tangled. Similarly, the arrangement or orientation of the fibers relative to one another within the matrix can affect the performance of a composite. There are many factors to be considered when designing with composite materials. In order to obtain the favored material properties for a particular application, it is important to know how the material performance changes with different factors [16].

## 2.2 Jute Fiber Reinforced Composites

### 2.2.1 Jute Fiber

Jute fiber is generally developed from the stem of a jute plant. It is an annual plant that grows to 2.5–4.5 m and flourishes in monsoon climates. Jute is a lingo-cellulosic fiber, as its major chemical constituents are lignin and cellulose. The main significance of this fiber is that it possesses good thermal and electrical conductivity properties and biological degradation. Proneness to mildew and moths and ability to protect from different climatic conditions are determined by cellular constitution and morphology. The chemical composition of jute fiber has been reported by many researchers. Jute fibers can be easily extracted and prepared in fiber and fabric forms with good thermal and mechanical properties apart from other natural fibers. The natural properties of jute fiber, such as low density, high tensile modulus and low elongation at break and its specific stiffness and strength comparable to those of glass fiber, draws the attention of the world [17]. It has been used in various applications of daily needs like ropes, beds and bags since past 10 decades. Many applications of this fiber with good quality can create more jobs in small scale industries. There are more applications of this fiber, for example, in the auto, aerospace, and packaging sectors.

### 2.2.2 Jute in Various Forms

#### (1) Raw Jute

Jute is a long, soft, and shiny fiber obtained from the bark of a jute plant. Commercially, the smallest unit of raw jute is known as reed. The fibers are classified depending upon their grade. In general, the length and diameter of the reed varies from 6–20 microns to 1–4.5 m. Raw jute can be processed into different forms like yarn or mats. Raw jute is primarily used in the manufacturing of hessian, sacking

cloths, cords, ropes, bags, handicrafts, and miscellaneous fabrics [18].

## (2) Jute Fiber

Jute in the form of short fiber is shown in Figure 2 and Figure 3. Composites made from short fiber are used widely in non-load bearing applications to obtain complex geometry in aerospace and automobile industry [19].



Figure 2: Raw jute fiber



Figure 3: Short jute fiber

## (3) Woven Jute Fiber Mat

Woven mat reinforced composites are gaining popularity due to their balanced properties in mat plane as well as their ease of handling during fabrication. The woven configuration of the mat leads to a synergetic effect on the

improvement of wear resistance of the composites. Woven mat composites belong to a class of two dimensional textile composites where the warp and weft fiber tows are woven into each other to form a layer. The laminated composite prepared from the woven mat that has good properties in mutually orthogonal directions as well as better out of plane impact resistance than the multidirectional laminate. Woven mat composites have found wide range of applications in automotive, defense, and aerospace industries [20].

## (4) Needle-punched Nonwoven Jute Fiber

Needle-punched nonwoven fiber mat is another form of jute. The use of needle-punched nonwoven mats is beneficial in polymer reinforced composites as these materials improve the mechanical properties such as toughness and strength with light weight. These nonwoven fiber mat has an important quality that offers excellent z-directional properties that minimizes the delamination problem. The entanglement or interlocking of fibers in needle punched nonwoven mats results in a three dimensional fiber reinforcing structure. Nonwoven mat is widely used as geotextile, filtration, medical goods, aviation and defense applications. These materials have been identified for the use of many engineering applications including abrasive composite materials [21, 22]. In search of manufacturing varied products by using jute fiber, successful efforts have been made to use this natural and eco-friendly technical fiber in the field of geotextile, floor covering, and filtration. The research on the needle-punched nonwoven fiber based polymer composites has been completed. However, the potential utilization of needle-punched nonwoven jute fiber as reinforcement in polymer composites has hardly been reported [23].



Figure 4: Woven jute fiber mat



**Figure 5:** Woven jute fiber mat Figure

### 2.3 Chemical Treatment

Jute and okra fibers are marinated in 5% NaOH solution for half an hour. Then, these fibers are cleaned several times with distilled water, followed by immersing the fibers in a very dilute HCl in order to remove the NaOH content. NaOH treated fibers are kept in an oven at 70°C for an hour to eradicate the moisture extant in the fibers [24].

### 2.4 Preparation of Composite

Two epoxy based matrix materials were prepared, Epoxy resin (LY556) mixed with hardener (HY951) was one matrix material and another matrix material was epoxy (XIN 100 IN) mixed with hardener (XIN 900 IN). The epoxy and hardener were mixed in 10:1 ratio. Okra fibers are oriented in bidirectional (0° and 90°) and jute fibers are oriented in unidirectional for preparing the composite. After the mixing of epoxy and hardener, 5 wt.% of groundnut shell ash were incorporated into the matrix material. While mixing, the forming of air bubbles were prevented. Four composite materials were prepared by conventional hand-layup method [25].

### 2.5 Experimentation

For experimentation process, we had already undergone different processes for better reinforcement of materials. We had commercially bought the available ARALDITE LY 556, and along with this, the hardener HY 951 was used as matrix material in the fabrication of material.

### Experimentation:

The universal testing machine is used to determine the mechanical properties like strength, stress, and strain elongation of the given standard specimen made up of different combinations. A universal testing machine is used to test the tensile stress and compressive strength of materials. It is named after the fact that it can perform many standard tensile and compression tests on materials, components, and structures. Here, we have to check the strength of the clay and resin composite, which is in a standard cylindrical shape for the measuring of tensile strength. We have taken four specimens:

1. Okra uni-directional using Epoxy Resin (LY 556) along with hardener (HY 951)
2. Okra uni-directional using Epoxy Resin (XIN-100IN) along with hardener (XIN-900IN)
3. Jute orthogonal using Epoxy Resin (LY 556) along with hardener (HY 951)
4. Jute bi-directional using Epoxy Resin (XIN-100IN) along with hardener (XIN-900IN)

### 2.6 Raw Material Used

- Okra fiber and jute fiber
- Epoxy Resin (LY 556) along with hardener (HY 951)
- Silica mold relief spray
- Epoxy Resin (XIN-100IN) along with hardener (XIN-900IN)

### 2.7 Mold Preparation

GI Sheet boxes of size 25 x 20 x 5 mm were used for the molding process. The molded sheets were transformed into a square box such that the mixture of resin and hardener were poured in it. Through the **HAND LAY-UP technique**, the prepared mold was transferred to the mold cavity taking care that the mold cavity should be thoroughly filled. Levelling was done to uniformly fill the cavity with the help of rollers support. Before that, the molding gel was used, as it would act as layer between the molds and the box without giving any sticky nature to it. Because it leads to changes in the properties of the composite material, curing was done at room temperature for approx. 24 hours. After curing, the mold was opened and the slab was taken out of the mold and cleaned.



## 2.8 Preparation of Composite

The preparation of the polymer matrix composite was done at room temperature. The required ingredients of resin, hardener and groundnut shell ash were mixed together thoroughly in a beaker and the mixture was turned into a thick paste. The required mixture of resin and hardener were made by mixing them in 10:1 parts in a beaker, by stirring the mixture by a rod, taking care that no air should be entrapped inside the solution.

## 2.9 Groundnut Shell Ash

Groundnut shells were kept in a muffle furnace at 500°C temperature for ½ hour to burn completely. After this, the burned groundnut shells were pulverized into ash. It was sieved to achieve filler particles smaller than 300 µm. Then, the filler was dried in an oven at a temperature of 250°C for 3 hours.

## 3 Chemical Treatment of Okra Fibers

Okra fibers were immersed in 5% NaOH for 30 min. The fibers were then cleaned several times with distilled water, followed by immersing the fibers in very dilute HCl in order to remove the NaOH adhering to the surface of the fibers. Finally, the fibers were again washed several times with distilled water and dried in an oven maintained at 70°C for 1 hour.

**Table 1:** Types of Resin

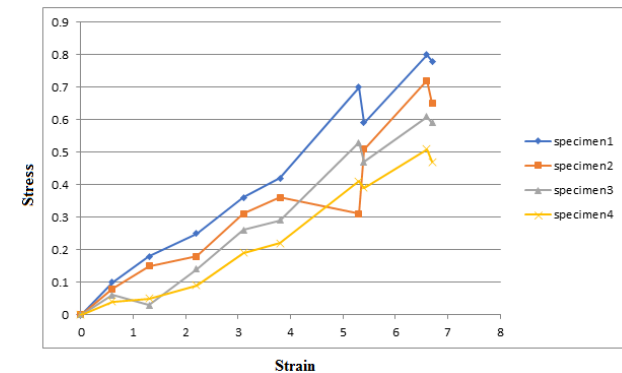
S.NO	SAMPLE	TYPE OF FIBER	RESIN	HARDENER
1	TEST SPECIMEN 1	Okra Unidirectional	LY 556	HY 951
2	TEST SPECIMEN 2	Okra Unidirectional	XIN-100IN	XIN-900IN
3	TEST SPECIMEN 3	Jute Orthogonal	LY 556	HY 951
4	TEST SPECIMEN 4	Jute Bi-directional	XIN-100IN	XIN-900IN

## 4 Mechanical Tests

### 4.1 Tensile Test

**Table 2:** Tensile test specimen loads

S.NO	SPECIMEN	LOAD AT BREAK (KN)	LOAD (KN)	UTS (mm)
1	I	2.69	2.6989	10.01
2	II	3.21	3.2171	11.7
3	III	2.58	2.5898	10.7
4	IV	2.47	2.4701	8.65



**Figure 6:** Diagram of stress and strain specimens



**Figure 7:** Tensile test specimens



Figure 8: Tensile test machine

## 4.2 Compression Test

Compression test is used to obtain the mechanical properties and is the basis for acceptance or refusal of brittle non-metallic and other materials that have very low strength in tension like concrete, wood and masonry. Compression test could be used to obtain the mechanical properties of metals; however, it is not preferred due to the following. It is difficult to apply a truly axial load in compression, which would lead to non-uniform stresses.

Friction between the machine head and the sample affects the results causing stresses to have a small inclination. Eccentricity may cause instability. Long samples are prone to buckling, therefore, the length of the specimen must be limited. Using small samples results in inaccuracies in results and using large samples requires testing machines with large capacities.

The results were plotted in a tabular column. The load values were taken into consideration, where the specimen was about to break before sustaining of the load. The failure analysis was done to the specimen.

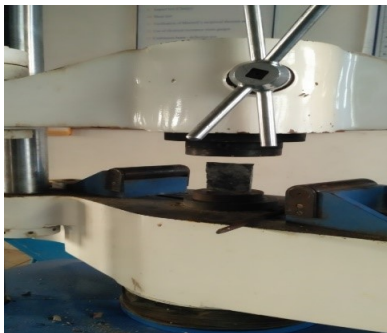


Figure 9: Compression Test

Table 3: Load values for the Compression Test

S. No	Sample	Peak load (KN)
1.	SPECIMEN 1	22.0
2.	SPECIMEN 2	27.0
3.	SPECIMEN 3	15.8
4.	SPECIMEN 4	29.7

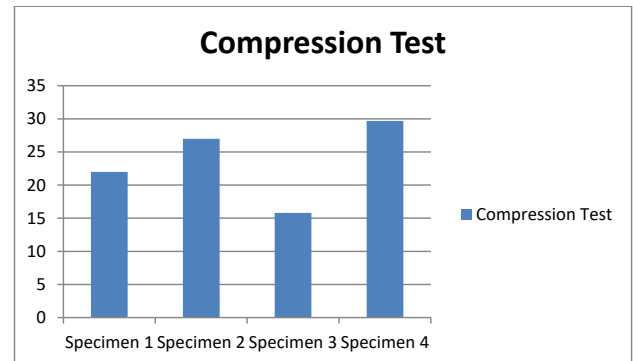


Figure 10: Load values for the Compression Test

## 4.3 Hardness Test

Hardness is a characteristic property of a material; it is not a fundamental physical property. It is a measure of how resistant solid matter is to various kinds of permanent changes when a compressive load is applied. Hardness is dependent on ductility, elastic, stiffness, plasticity, strain and so on.

According to our analysis, Specimen 3 is having a higher hardness number when compared to the other three specimens at 60 KN (L-Scale) and 100 KN (M-Scale) respectively. Higher the hardness number, lower the temperature to quench it.

## 4.4 Impact Test

Impact strength is the capability of a material to withstand a suddenly applied load and is expressed in terms of energy. Impact strength is the resistance of a material to fracture under dynamic load. The impact strength is calculated as the ratio of impact absorption to test specimen cross-section. Izod impact test and Charpy impact test are used for the measurement of impact strength in order to measure the impact energy required to fracture a sample.

According to our analysis, the **impact test** was carried out on four specimens and the respective impact strengths were calculated and tabulated, as shown in Figure 14. The results predicted that there was no significant change in

**Table 4:** Hardness Test Readings

S.NO	SPECIMEN	INDENTOR USED	LOAD	RHN	AVERAGE	LOAD	RHN	AVERAGE
1.	SPECIMEN-I	DIAMOND	60	49	50.2	100	54	53
				50			53	
				51			53	
				50			52	
				51			53	
2.	SPECIMEN-II	DIAMOND	60	53	53	100	52	51
				52			51	
				53			51	
				54			50	
				53			51	
3.	SPECIMEN-III	DIAMOND	60	52	52.4	100	53	53.4
				52			53	
				53			54	
				53			54	
				52			53	
4.	SPECIMEN-IV	DIAMOND	60	40	40.8	100	52	52
				41			52	
				41			53	
				40			51	
				42			52	



**Figure 11:** Hardness testing machine

the impact strength on Izod scale. The results showed that the impact strength on Specimen 3 and Specimen 4 was



**Figure 12:** Specimen tested for hardness

high when compared to the Specimens 1 and 2. The impact nature of the specimens is less when compared to metals and other materials as the specimens are most tangential toward brittle nature.



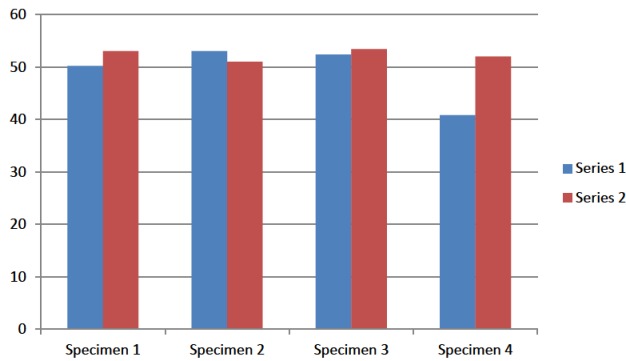


Figure 13: Number of specimen tested for hardness

Table 5: Samples' impact strength on Izod

S.NO	SAMPLE	IMPACT STRENGTH ON IZOD (J/MM <sup>2</sup> )
1.	SPECIMEN SAMPLE 1	0.0248
2.	SPECIMEN SAMPLE 2	0.0241
3.	SPECIMEN SAMPLE 3	0.0512
4.	SPECIMEN SAMPLE 4	0.0509

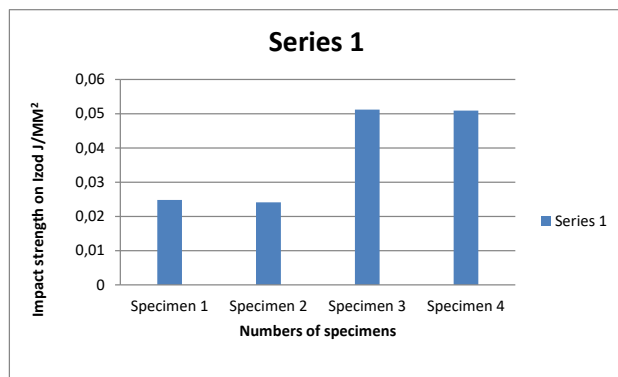


Figure 14: Impact strength on Izod

## 5 Conclusions

In the present work, the natural fibers are extracted from different local sources. A laboratory study has been carried out to determine the mechanical properties and their behavior. The comparative analysis has been conducted between okra and jute fibers. The conclusions drawn are mentioned below:

1. The Specimen 1 possesses maximum stress according to the stress-strain curve and Specimen 4 has minimum stress with reference to the tensile test experiments.

2. The compression test yields maximum value for Specimen 1 and minimum value for the remaining specimens.
3. The hardness number is maximum for the jute orthogonal fiber.
4. The impact strength is maximum for Specimen 3 and minimum for other specimens.
5. This natural hybrid composite can be useful for few biomedical engineering applications.

## References

- [1] Srinivas, K. A., Naidu, A. L. and Raju Bahubalendruni, M. V. A.: A Review on Chemical and Mechanical Properties of Natural Fiber Reinforced Polymer Composites, *International Journal of Permeability Engineering* 13(2), 189, 2017.
- [2] Wambua, P., Ivens, J. and Verpoest, I.: Natural fibres: can they replace glass in fibre reinforced plastics?, *Composites Science and Technology*, 63(9), 1259–1264, 2003.
- [3] Barone, J. R.: Polyethylene/keratin fiber composites with varying polyethylene crystallinity, *Composites Part A: Applied Science and Manufacturing*, 36(11), 1518–1524, 2005.
- [4] Barone, J. R. and Schmidt, W. F.: Polyethylene reinforced with keratin fibers obtained from chicken feathers, *Composites Science and Technology*, 65(2), 173–181, 2005.
- [5] Rutherford, T. A. and Hawk, P. B.: A study of the comparative chemical composition of the hair of different races, *Journal of Biological Chemistry*, 3(6), 459–489, 1907.
- [6] Lee, S. M. et al.: Novel silk/poly (butylene succinate) biocomposites: the effect of short fibre content on their mechanical and thermal properties, *Composites Science and Technology*, 65(3), 647–657, 2005.
- [7] Xie, Yanjun, et al.: Silane coupling agents used for natural fiber/polymer composites: A review, *Composites Part A: Applied Science and Manufacturing*, 41(7), 806–819, 2010.
- [8] McKittrick, J., et al.: The structure, functions, and mechanical properties of keratin, *Jom*, 64(4), 449–468, 2012.
- [9] Martínez-Hernández, A. L., et al.: Dynamical-mechanical and thermal analysis of polymeric composites reinforced with keratin biofibers from chicken feathers, *Composites Part B: Engineering*, 38(3), 405–410, 2007.
- [10] Yu, Y. et al.: Structure and mechanical behavior of human hair, *Materials Science and Engineering: C*, 73, 152–163, 2017.
- [11] Cheng, S. et al.: Mechanical and thermal properties of chicken feather fiber/PLA green composites, *Composites Part B: Engineering*, 40(7), 650–654, 2009.
- [12] Naidu, A. L. and Ramana Rao, P. S. V.: A Review on Chemical Behaviour of Natural Fiber Composites, *International Journal of Chemical Sciences*, 14(4), 2016.
- [13] Cao, J. and Leroy, F.: Depression of the melting temperature by moisture for  $\alpha$ -form crystallites in human hair keratin, *Biopolymers*, 77(1), 38–43, 2005.
- [14] Naidu, A. L., Jagadeesh, V. and Raju Bahubalendruni, R. V. A.: A review on chemical and physical properties of natural fiber reinforced composites, *Journal of Advanced Research in Engineering and Technology*, 8(1), 56–68, 2017.

- [15] Naidu, A. L. and Raob, D. N.: Studies on Characterization and Mechanical Behavior of Natural Clay, *Int. Journal. of Multidisciplinary and Current Research*, July, 2013.
- [16] Yang, L. et al.: Preparation and characterization of novel super-artificial hair fiber based on biomass materials, *International Journal of Biological Macromolecules*, 99, 166–172, 2017.
- [17] Naidu, A. L., Raghuvver, D. and Suman, P.: Studies on Characterization and Mechanical Behavior of Banana Peel Reinforced Epoxy Composites, *International Journal of Scientific & Engineering Research*, 4(6), 844–851, 2013.
- [18] Oladele, I. O., Olajide, J. L. and Ogunbadejo, A. L.: The influence of chemical treatment on the mechanical behaviour of animal fibre-reinforced high density polyethylene composites, *American Journal of Engineering Research*, 4(2), 19–26, 2015.
- [19] Chakradhar, K. V. P. et al.: Epoxy/polyester blend nanocomposites: effect of nanoclay on mechanical, thermal and morphological properties, *Malaysian Polymer Journal*, 6(2), 109–118, 2011.
- [20] Naidu. A. L., Sudarshan. B., and Krishna, K. H.: Study on Mechanical Behavior of Groundnut Shell Fiber Reinforced Polymer Metal Matrix Composites. *International Journal of Engineering Research and Technology*, 2(2), 1–6, 2013.
- [21] Prasanna, G. V. and Subbaiah, K. V.: Modification, flexural, impact, compressive properties & chemical resistance of natural fibers reinforced blend composites, *Malays. Polym. J.*, 8(1), 38–44, 2013.
- [22] Chakradhar, K. V. P., et al.: Blended epoxy/polyester polymer nanocomposites: Effect of “nano” on mechanical properties, *Polymer-Plastics Technology and Engineering* 51(1), 92–96, 2012.
- [23] Prasanna, V. G. and Venkata Subbaiah, K.: Modification of tensile, compressive properties & Chemical resistance of hybrid biocomposites, *International Journal of Nanomaterials and Biostructures*, 2(9), 2013.
- [24] Prasanna, G. V. and Subbaiah, K. V.: Hardness, tensile properties and morphology of blend hybrid biocomposites, *Journal of Engineering Research* 2(1), 21–29, 2013.
- [25] Suman, P., Lakshumu, N., Rao Ramana, P. S. V.: Processing and mechanical behaviour of hair fiber reinforced polymer metal matrix composites, *International Journal of Mechanical and Production Engineering Research and Development*, 469–478, 2016.