



ORIGINAL RESEARCH ARTICLE

**MECHANICAL PROPERTIES OF GOAT HOOF FIBER REINFORCED POLYSTYRENE COMPOSITE FOR CAR BUMPER**

**C. Nathan\*, E. B. Bwala, A. A. Barnabas and I. Y. Ayomikun**

Department of Mechanical Engineering Nigerian Army University Biu Borno State

\*Corresponding author's email Address: [\\*chindapin@gmail.com](mailto:chindapin@gmail.com)

**ARTICLE INFORMATION**

Submitted: 4<sup>th</sup> June 2024  
Revised: 2<sup>nd</sup> December 2024  
Accepted: 8<sup>th</sup> February 2025

**Keywords:**

Bumpers  
Goat Hoof  
Polystyrene  
Fibers  
Matrix

**ABSTRACT**

Natural materials are good reinforcements for composite materials due to their eco-friendliness and potentials for improved mechanical properties. This study explores the potential of goat hoof fibers as a reinforcing material in polystyrene composites for car bumpers. Different % composition mixes of goat hoof fibers and polystyrene matrix were used as samples A-F. Samples A(100% polystyrene and 0% goat hoof), sample B(90% polystyrene and 10% goat hoof), sample C(80% polystyrene and 20% goat hoof), sample D (70% polystyrene and 30% goat hoof), sample E (60 polystyrene and 40% goat hoof), sample F (50 polystyrene and 50% goat hoof). The samples were then moulded into different shapes depending on the type of test to be conducted on the samples. The test conducted on sample composition mixes are tensile test, impact test, flexural test and hardness. The results of the experiments conducted on sample D (70% polystyrene and 30% goat hoof) gave the following results (14.9MPa, 75.23KN, 71.3MPa, 56.92KN/m<sup>2</sup>) and for sample E (60% polystyrene and 40% goat hoof) gave the following results (11.66MPa, 69.2KN, 71.2MPa, 51.4KN/m<sup>2</sup>) and for sample C (80% polystyrene and 20% goat hoof) gave the following results (10MPa, 70.9KN, 70.9MPa, 46.2KN/m<sup>2</sup>) respectively. The results of the values obtained by samples D, E and C composition mixes gave values that compare reasonable with the values obtained by the conventional car bumpers.

© 2025 Faculty of Engineering, University of Maiduguri, Nigeria. All rights reserved.

**1.0 Introduction**

Composite is a heterogeneous substance consisting of two or more materials which does not lose the characteristics of each component but brings about new desirable properties, naturally occurring composites are tendon, bone, bamboo, rock, and many other biological and geological materials (Mallick, 2007). Composites, particularly polymer-matrix composite laminates are increasingly used for elements capable of absorbing energy from impact loads while undergoing deformation (Morello et al, 2011). Materials with high impact resistance are required for a great number of applications (Chatys et al, 2013) including controlled mobile systems (Takosoglu, 2016). For example, unmanned aerial vehicles such materials are also desirable for elements of an automotive bumper system protecting the front and rear ends of a motor vehicle which need to withstand small impact loads during a collision (Roy et al, 2014). Composite materials play an important role in modern industry through the design and manufacture of advanced materials capable of attaining higher stiffness/density and strength/density ratios. These ratios allow composite materials to be used in various applications where the weight and strength of the structure are highly significant in design parameters (Felix et al, 2017). Impact resistance in composites is the study of the effects of damage induced by striking a foreign body on a material and the factors affecting it, which are generally recognized as the most severe threat to composite structures (Kroschwitz, 2005). Any material that is to be used for car bumper must be able to absorb more energy on collision, it should have good rust resistance, it should have high strength and light in weight for easy to manufacture in large quantity and should be of low cost (Felix et al, 2017). A good quality bumpers should be able to protect more serious and expensive damage when two cars crash. Since bumper is an exterior part of passenger cars to protect the cars from more expensive damage (Julian, 2016).

The hoof wall is the weight-bearing and protecting structure surrounding the distal phalanx of the goat. During impact, the hoof wall repetitively withstands conclusive forces and transmits the forces to the bones and joints of the limb. During impact, the hoof wall must resist excessive abrasion in order to protect the interior structure (Jing *et al*, 2020). The reactional forces on the hoof during impact involve two dynamic processes, low impact loads at high vibration frequency characterize by the collision of the hoof with the ground, followed by high forces at low frequency which are largely attributable to the onset of the collision of the torso with the limb (Behnke *et al* 2018; Thomson and Peterson, 2008). Investigation of the surface strains of the hoof wall under different locomotion conditions indicate that the wall is loaded principally in compression (Douglass *et al*, 1996). Mechanical test of the equine hoof wall indicate that the wall is stiffer in compression than in tension. (Jing *et al*, 2020). The effect of hoof wall viscoelasticity on the mechanical properties have been evaluated with the result suggesting that the stiffness increased with stain rate, while the fracture resistance was unaffected by strain rate (Kasapi and Gosline, 1996). The major objective of this research work is to determine the mechanical and physical properties of goat hoof fiber reinforced polystyrene composite material for the production of car bumpers. The goat breed slaughtered at the slabs and restaurants was the Sokoto Red with weight of 25kg – 50kg. The total number of butchers involved in slaughtering was 26. Daily slaughter at the two slabs was 65 goats/day: While average slaughter at the twelve restaurants was 19goats/day with average of 26 slaughter days in a month. Total goats slaughtered daily in Sagamu township estimated at 84 goats which was undertaken by 21 butchers and slaughter can be extend to late hours in the evening depending on the customer's demand. Some of the butcher's also render slaughter services to the restaurants at fee. A total of 120 pairs of goat horn and 556 quadruple pairs of goat hoof were sampled for the hoof and horn. The samples waste weighed produced 16065.76kg hoof meal and 2702.73kg horn meal (Sule *et, al* 2020).

Felix *et, al* (2017) carried out an analysis on the application of Glass Fiber Reinforced Composite in the production of light weight Car Bumper (A case study of Mechanical Properties) and obtained Tensile strength to be 3.9 MPa, Impact Strength of 100 kN/m<sup>2</sup> and 60% of weight compared to steel. Equally Julian (2016) performed research on the use of Natural Fiber Composites for Bumper Materials. The research found out that carbon charcoal gave an impact of 67.14 kN/m<sup>2</sup>, Banana Stem 15.75 kN/m<sup>2</sup> and wedd 12.50 kN/m<sup>2</sup> and the compressive strength of 22.50 kPa, 11.98 kPa, and 15.38 kPa respectively. In addition, Sulove (2019) investigated the Mechanical Properties of a recycled polypropylene/Talc composites for car bumper application and found out that the tensile strength of samples 1-3 are 20.4MPa 118.2MPa and 20.7 MPa. The flexural strength at 1.44 was found to be 31.2 MPa, 31.5MPa and 36 MPa for samples 1-3. Subsequently, Vipul *et al* (2020) worked on the design optimization of hybrid Bio composite Materials and found out the Tensile strength gave the value of 49.28Mpa and the flexural strength 152.21MPa and the density to be 1.142g/cm<sup>3</sup>. It can also be seen that Olorunnishola and Adubi (2018) compared and analyzed the blend of Natural Jute and Glass Fibers with synthetic Glass Fibers Composites as car Bumper Materials. The result showed that the hardness sample 1-3 gave the values of 62.9 kN/m<sup>2</sup>, 63.8 kN/m<sup>2</sup>, 64 kN/m<sup>2</sup> respectively and the impact results are 12.0 MN/m<sup>2</sup>, 10.8MN/m<sup>2</sup>, and 12.2MN/m<sup>2</sup> respectively for samples 1-3. The aim of the study is to determine the Mechanical properties of polystyrene and goat hoof mix in different proportion as composite materials and compare them with standard properties of car bumpers.

## 2. Materials and Methods

### 2.1 Materials

#### 2.1.1 Composite Matrix Material: Polystyrene (PS)

Polystyrene was chosen because is commonly used thermoplastic polymer that offers good mechanical properties, such as high strength and stiffness. It is lightweight, which is crucial for automotive applications to minimize the overall weight of the car. Additionally, polystyrene has good Impact resistance, making it suitable for use in car bumpers that are subjected to significant external forces during collision. Another significant advantage of polystyrene is it a cost-effective. Plate 1 shows the polystyrene used for the experiment and plate 2 shows six (6) composition mixtures of polystyrene and goat hoof used for the experiment. The percentage composition mixtures in plate 2 are labelled from A-F. Table 1 gives the percentage composition mixtures by weight that are seen plate 2. A, B, C, D, E and F (100% polystyrene and 0% goat hoof, 90% polystyrene and 10% goat hoof, 80% polystyrene and 20% goat hoof, 70% polystyrene and 30% goat hoof, 60% polystyrene and 40% goat hoof, 50% polystyrene and 50% goat hoof ) respectively (Ibitoye, 2024).



**Plate 1:** Polystyrene



**Plate 2:** Composition Mixtures

**Table 1: Composition Mixtures**

S/N	Polystyrene (%)	Goat Hoof (%)	Sample Label
1	100	0	Sample A
2	90	10	Sample B
3	80	20	Sample C
4	70	30	Sample D
5	60	40	Sample E
6	50	50	Sample F

### 2.1.2 Reinforcing Material: Goat Hoof Fiber (GHF)

Goat hoof fiber was selected as the reinforcing material for the composite due to its unique properties. Natural fibers, such as goat hoof fiber have gained attention in the recent years as an eco-friendly alternative to synthetic fibers. They offer several advantages, such as high specific strength, low density, biodegradability and renewability. It was noted that goat hoof exhibits good mechanical properties such as high tensile strength, stiffness and impact resistance; these properties make it an ideal candidate for reinforcing the polystyrene matrix, enhancing the composite's overall mechanical performance. Additionally, the use of goat hoof fiber offers environmental benefits by reducing dependency on non-renewable resources and contributes to the reduction of carbon footprint compared to traditional synthetic fiber-reinforced composite. Plate 3 shows the sample of goat hoof used in the experiment before crushing and plate 4 shows the pulverized goat hoof used in the experiment. Different percentage composition of the pulverized goat hoof were used in the experiment as shown in table 1 (Ibitoye, 2024).



**Plate 3:** Goat Hoof Sample



**Plate 4:** Pulverized Goat Hoof sample

### **2.1.3 Conventional Bumper Samples**

Three conventional/standard car Bumpers were used for this research: Bumper sample for Toyota Corolla LE Labelled as CBSA, Bumper sample for Mercedes Benz C class as CBSB, Bumper sample of Honda 86 as CBSC.

### **2.1.4 Procedure for Sample Preparation**

Goat Hoof Fiber (GHF) was used as the reinforcing material. In order to achieve this, samples of goat hoofs are collected from the Slaughter slab in Zaria Local Government Area of Kaduna State. The collected goat hoof samples were then washed off of hair and rumen digester with borehole water. The hoofs were boiled in water at boiling point to remove the bony structure attached to the sole of the hoof (Dina et al, 2023) and sun-dried for twenty-one days. Dried samples were then weighed using a weighing balance and the weight of the dried sample of goat hoof fiber was measured to be 125 grams with tolerance value of  $\pm 0.2$ . Afterwards, the samples were milled using fabricated local burr mill grinder as originally adopted by Odugbose & Sule (2014) and was sieved using a sieve of 300 $\mu$ m aperture.

## **2.2 Methods**

### **2.2.1 Tensile Test**

The Tensile Test were performed on the samples according to ASTM D3039 standard. The specimens were tested using a calibrated AUTOGRAPH-AGS-2003 testing Machine with speed of 5mm/min (Felix et al, 2017)

### **2.2.2 Flexural Strength Test**

The specimens were tested by a calibrated AUTGRAPH AGS-2003 testing machine. The flexural strength was conducted according to the ASTM D790 (3-point bending standard). The specimens with desired dimensions and velocity of 5 mm/min were tested. The testing was conducted for various span length of 100mm, 80mm and 60mm (Felix et al, 2017).

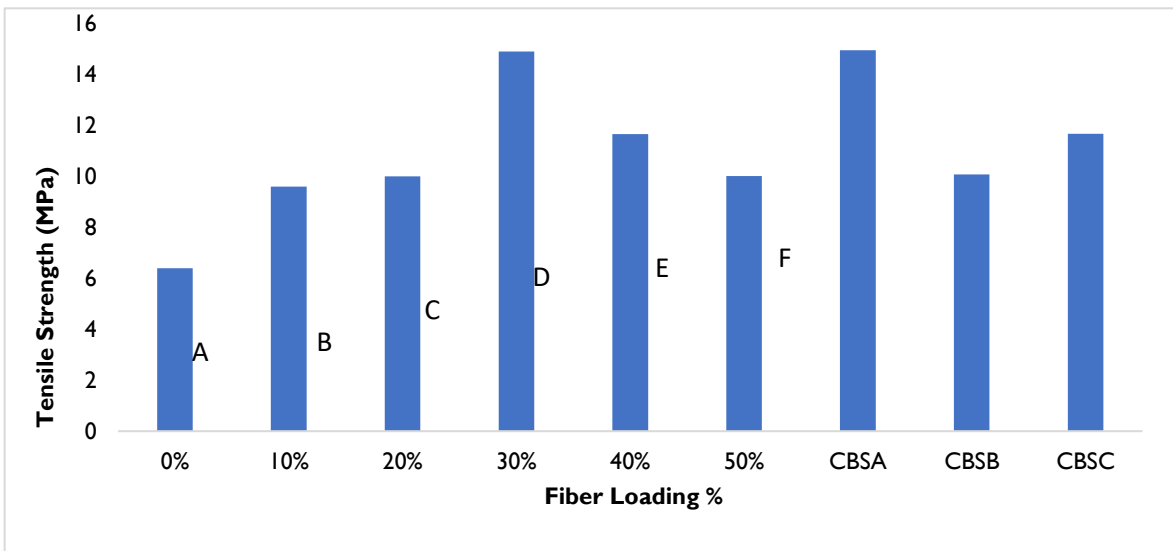
### **2.2.3 Impact Test**

Izod impact test methods were conducted according to the ASTM 256-04 standard. The sample with specified dimensions and notches were prepared and tested for impact (Felix et al, 2017).

## **3. Results and Discussions**

### **3.1 Tensile Strength**

Figure 1 shows the graph of tensile strength against % fiber loading. It can be seen from the graph that the highest tensile strength was obtained to be 14.96 MPa for sample D and lowest with 6.4MPa with sample A. The tensile strength of samples D, E, F and C compares reasonable with the values obtained by conventional/Standard car bumpers CBSA, 14.96 MPa, CBSB 10.08 MPa, CBSC 11.67 MPa. Samples A and B have values 6.4 MPa, 9.6 MPa, less than the conventional/standard bumpers. These sample materials can also be used in many other Engineering applications that requires lesser Tensile strength.

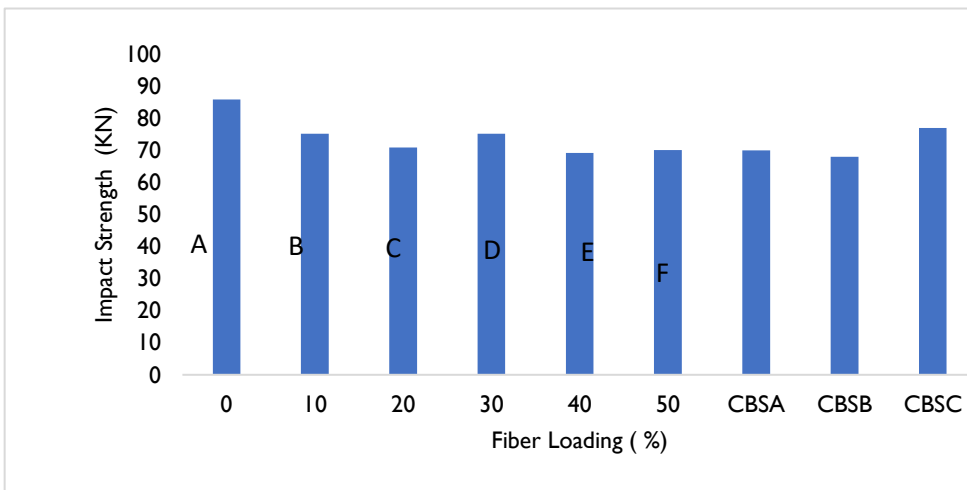


**Figure 1:** Plot of Tensile Strength against Fiber Loading

Note: CBSA=Bumper sample of Toyota corolla LE, CBSB=Bumper sample of Mercedes Benz C class, CBSC=Bumper sample of Honda 86

### 3.2 Impact Test

Figure 2 shows the graph of impact strength against % fiber loading. It can be seen from the graph that the highest impact test was obtained with sample A 85.9kN with sample A and lowest value of 69.2 kN with sample E. Samples B, C, D and F gave values of 75.25 kN, 70.9 kN, 75.23 kN and 71 kN respectively which are slightly higher than the values obtained by the conventional/standard bumpers CBSA (70 kN), CBSB (68 kN) and CBSC (77 kN). According to the comparism made above, it can be said that the fabricated samples have good impact result for car bumpers.



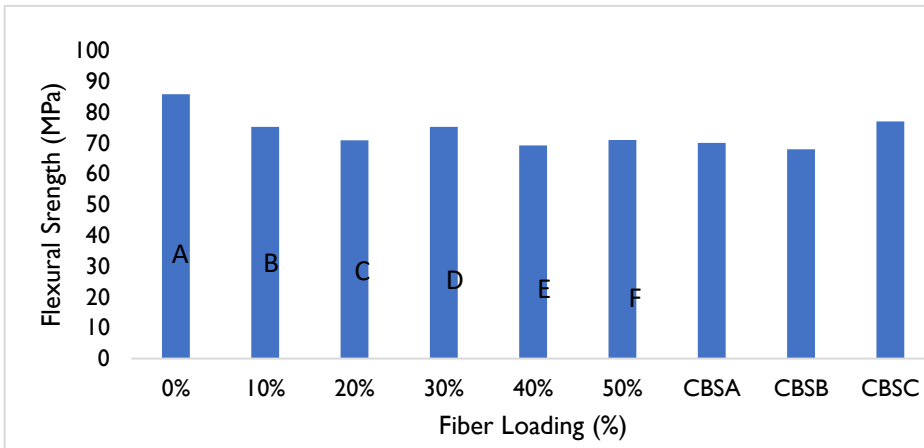
**Figure 2:** Impact Strength against % Fiber Loading

Where CBSA=Bumper sample of Toyota corolla LE, CBSB=Bumper sample of Mercedes Benz C class, CBSC=Bumper sample of Honda 86

### 3.3 Flexural Strength

Figure 3 shows the graph of Flexural strength against % weight of fiber loading. The highest flexural strength was recorded to be 85.9 MPa for sample A and the lowest of 69.2 MPa for sample E. Almost all the samples gave good values of flexural strength in terms of the % composition mix ration and compares reasonable with

the conventional/standard car bumpers. The flexural strength of the other samples were found to be 75.25MPa, 70.9MPa, 75.23MPa, and 71MPa for samples B, C, D F respectively which compares well with CBSA, CBSB, and CBSC with values 70 MPa, 68 MPa and 77 MPa respectively.

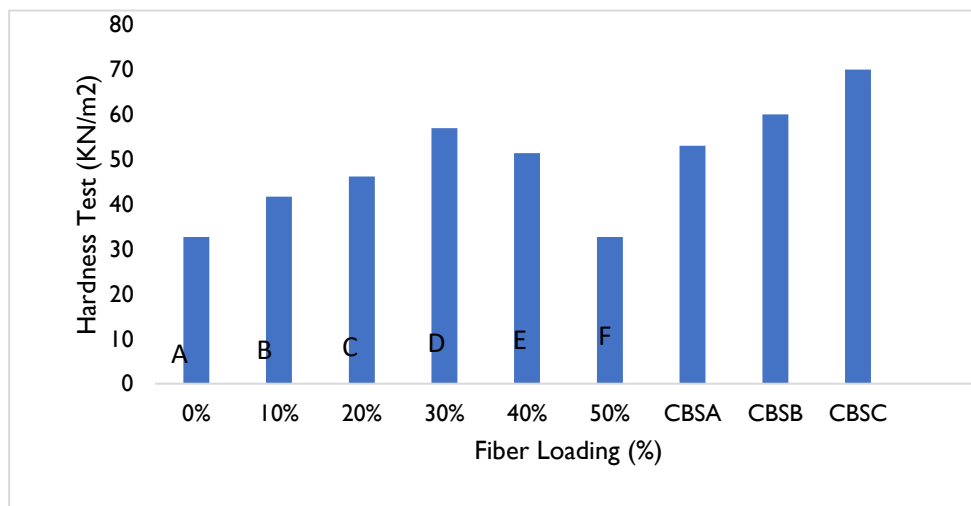


**Figure 3:** Flexural Strength against % Fiber Loading

Where CBSA=Bumper sample of Toyota corolla LE, CBSB=Bumper sample of Mercedes Benz C class, CBSC=Bumper sample of Honda 86

### 3.4 Hardness

Figure 4 shows the graph of hardness against % fiber loading. It can be seen from the graph that samples D gave the highest hardness of 56.92 kN/m<sup>2</sup> and the lowest hardness was obtained with samples F with the value of 32.7kN/m<sup>2</sup>. Samples A, B, C and E gave the values of 32.7 kN/m<sup>2</sup>, 41.7 kN/m<sup>2</sup>, 46.2 kN/m<sup>2</sup> and 51.4 kN/m<sup>2</sup> respectively. Comparing the results with the conventional bumpers, it can be seen that only samples D and E compares reasonable with conventional car bumpers CBS A (53 kN/m<sup>2</sup>), CBSB (60 kN/m<sup>2</sup>) and CBSC (70 kN/m<sup>2</sup>). The values of other samples which are less than the CBSA, CBSB, and CBSC can also be used in other Engineering applications that requires less hardness.



**Figure 4:** Hardness Test against % Fiber Loading

## 4. Conclusion

From the experiments and analysis carried out on the Goat hoof fibers and the different composition mixtures in the experiment using epoxy resin, it was discovered that Goat hoof satisfied almost all of the mechanical

properties needed in the production of Car bumpers for Toyota Corolla LE, Mercedes Benz class and Honda 86.

## References

- Benke, R. R. 2017. Numerical Time-Domain Modelling of Hoof Ground interaction during the stance phase. *Equine Veterinary Journal*, 50 (4): 519-524.
- Chatys R. 2013. Investigation of Effect of Distribution of the Static Strength on the Fatigue Failure of a layed Composite by using the Markov Chains Theory, *Mechanics of Composite Materials*, 45(6): 529-639.
- Chatys, R., Kleinhofs., Panich., Miskow. 2018. Composite Laminates for Automotive Bumpers and Light Weight Support Structures. 24<sup>th</sup> Internal Conference on Engineering Mechanics. May 14-17: 145-148 Svatka, Czech Republic.
- Dina, I. A., Gimba C. E., Hamza A., Ekwumemgbo 2023. Comparative Study of the effect of Poly lactic Acid, Starch, Charcoal on Physico – Mechanical Properties of Virgin and Waste low Density Polyethylene Composites. *Journal of Chemical Society of Nigeria*, 48(3): 585 – 599.
- Douglas, J., Mittal, C. Thompson, J. Jofriet, J. 1996. The Modulus of Elasticity. *Equine Hoof Wall: Implications for the Mechanical Function of the Hoof. Equine Veterinary Journal*, 199: 1829-1836.
- Felix, A. Yahaya B. S., Apeh E. S. and Akinyeye J. O. 2017. Application of Glass Fibre Reinforced Composite in the Production of Light Car Bumper (A case study of Mechanical Properties). *International Journal of Engineering Research and Technology*, 6(7): 575-579.
- Ibitoye, Y. A. 2024. Mechanical Properties of Goat Hoof Fiber Reinforced Polystyrene Composite for Car Bumper (Unpublished Thesis) Department of Mechanical Engineering Nigerian Army University Biu.
- Jing, Z., Dan, B. Marghitu., John S and Wenzhong, W. 2020. Impact of Horse Hoof Wall with different Solid Surfaces. *Journal of Applied Sciences*, 10(8743): 1-12.
- Julian, 2016. The use of Natural Fiber Composites for Bumper Materials. *European Journal of Mechanical Engineering Research*, 3(3): 18-26.
- Kasapi, M. A. and Gosline, J. M. 1996. Strain Rate Dependent Mechanical Properties of the Equine Hoof Wall. *Journal of Experimental Biology*, 199: 1133-1146.
- Kroschwitz, J. I. 2005. *High Performance Polymer Composites*, John Wiley and sons New York.
- Mallick, P. K. 2007. *Fiber-Reinforced Composites Materials, Manufacturing and Design* (3<sup>rd</sup> edition). CRC press.
- Morello, L. 2011. *The Automotive Body*, Springer Dordrechi Heidelberg Components Design. Volume I London – New York.
- Olorunnishola, A. A. G. and Adubi, E. G. 2018. A Comparative Analysis of a Blend of Natural Jute and Glass Fibers with Synthetic Glass Fibers Composites as Car Bumper. *Journal of Mechanical and Civil Engineering*, 15 (3): 67-77.
- Roy, R., Kween J. and Chol J. H. 2014. Meso-Scale Finite Element Modeling of Nomex Honey Comb cover. *Advance Composite Materials*, 23(1): 17-29.
- Sule, S. O., Sotolu., A. O., Ojetayo., T. A and Owodeinde., F. G. 2020. Evaluation and Potential Generation of Goat Hoof and Horn Waste as Protein Feedstuffs. *African Journal of Science and Nature*, 11: 75-82.
- Sulove, T. 2019. Investigation into Mechanical Properties to use recycled Polypropylene/Tale Composites for Car Bumper Application. *Technical Journal*, 1(1):54 – 64.

Takosoglu, J. E. 2016. Control System of Delta Manipulator with Pneumatic Artificial Muscles. *Journal of Engineering Mechanics*, 5(6): 546-549.

Thompson, J. J., Peterson, M. L. 2008. Biomechanical and Mechanical Investigations of the Hoof Track Interface in Racing Horses. *Veterinary clinic of North America. Equine practice*, 24(1): 53-77.

Vipul, J., Mohit., and Rajiv C. 2020. International Symposium on Fusion of Science and Technology. IOP Conference Series: Material Science and Engineering, 804.