ARID ZONE JOURNAL OF ENGINEERING, TECHNOLOGY & ENVIRONMENT
AZOJETE March 2025. Vol.21(1):261-269
Published by the Faculty of Engineering, University of Maiduguri, Maiduguri, Nigeria.
Print ISSN: 1596-2490, Electronic ISSN: 2545-5818
www.azojete.com.ng

ORIGINAL RESEARCH ARTICLE

HARDNESS, DENSITY AND WATER ABSORPTION PROPERTIES OF DOUM PALM SHELL PARTICLES AND SUGARCANE BAGASSE REINFORCED POLYPROPYLENE HYBRID COMPOSITE

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ARTICLE INFORMATION

Received April 2024
Reviewed June 2024
Accepted June 2024

Keywords:
Characterization
Compression moulding
Reinforcement
Formulation
Material loading

ABSTRACT

Agricultural waste issues have been a subject of discussion mainly on its conversion to wealth because of some environmental problems associated with it. The use of natural fibers and agricultural wastes for the formulation of composites materials has therefore continue to receive great attention. This work is focused on the utilization of Doum Palm shell particles and Sugarcane Bagasse to reinforce polypropylene (PP) in the production of a hybrid composite. The influence of material loading on the hardness, density and water absorption properties of the composite was studied. The composites were set by compounding PP and Doum Palm shell particles using compression moulding technique. The particulate size of the filler materials considered was 150 µm. The different material loading to matrix mixture were 10:90,20:80, 30:70, 40:60 and 50:50 respectively, after which the composites were characterized. SEM analysis was also carried out in order to know the level of interaction between the matrix and materials loaded. Analyses of variance (ANOVA) were employed for optimization of the results. Hardness of neat PP was 65Hv but gradually decreased with material loading to a value of 42.3Hv at 50wt% loading of the PP. Water absorption showed a direct proportionality with exposure time and fiber loading up to 8.49% after 14days of soaking. Material loading ensured increased density proportionally to 0.468g/cm^3 at 50 wt%. The optimization result showed significant difference in most of the results obtained. It is concluded that Doum Palm shell and Sugarcane Bagasse hybrid composites have potential for industrial application.

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1.0 Introduction

The biodegradable and environmentally friendly properties of natural fiber/filler composites, together with their high strength and stiffness, make them a promising option for reinforcing materials in polymer matrix composites (Okeke *et al.*, 2020). The increased interest in composites have been prompted by growing demand for environmentally friendly resources, mounting prices for petroleum-based polymers, and imposing environmental limitations (Samuel *et al.*, 2019). Researchers have also made efforts to utilize thermoset polymers such as epoxy for composite formulation (Charles et al. 2024).

Polymer composites are made up of polymers as the matrix and one or more fillers or fibers added to fulfill certain requirements such as acceptable mechanical and physical qualities, enhanced thermal qualities, reduced weight and resistance to wear. Composites used in vehicle and aircraft applications, for example, must have strong thermal and mechanical qualities. Historically, glass or carbon-based synthetic fibers were utilized as composites' reinforcement and have the ability to create superior qualities. Nevertheless, with rising global environmental concerns, its delayed biodegradability is a drawback. As a result, researchers are discovering more workable methods to improve polymeric composites' biodegradability. Natural fibers and fillers have good potential as polymer reinforcements because of these required properties as reviewed by Aji et al. (2009). The key benefits of utilizing natural fibers are mainly because of their low cost, low weight, non-abrasiveness and non-hazardous properties. It has been determined that in comparison to the use of metals, composite materials have the potential to greatly lower the weight and cost of vehicles. Reducing vehicle

weight to conserve fuel is one of the primary goal for developing novel materials for automotive applications (Getu *et al.*, 2020).

Particulate reinforcement of polymers is vital for enhancing their physical and mechanical characteristics; attributes include hardness, impact strength, resistance to abrasive wear, etc., making them more suitable for use in applications in engineering. Particles incorporated into the polymer matrix can regulate a polymer's mechanical properties. Fillers have an impact on many other aspects of composite materials, including solidity, density, and cost reduction. The mechanical behaviour of composites made of polymers is significantly impacted by the effects of particle/filler loading, fiber length and fiber orientation (Obasi *et al.*, 2021; Aji et al. 2011). Doum Palm (*Hyphaenethebaica*) are desert palm trees that are mostly found in the Nile Valley. It bears edible, egg-shaped fruit. In Nigeria's north, it produces exceptionally well as "Goruba" in Hausa and it is widely recognized. Reportedly, it is among the world's most advantageous plants. The Doum Palm's leaves can be eaten, and their stem can be used to build structures. The leaves are also used to make mats, ropes, baskets, and hats(Hossam *et.al.*,2018). Bagasse is the excess of 30% that remains after the crushing of the sweet cane stalk in sugar or alcohol mills. Bagasse is obtained from several parts of the cane stalk, such as the outer rind and the crushed inner pith (Dan-asabe *et al.*,2018). Polypropylene (PP) is a polymer synthesized catalytically from propylene and has the lowest density among commodity plastics. PP has a high resistance to chemicals and may be changed using a number of techniques, such as extrusion and injection molding. It is also utilized for several parts of an automobile, i.e. dashboards, batteries casing, air conditioning ducts, doors, and quarter panels (Adediran *et al.*, 2022).

2. Materials and Methods

2.1 Materials

Materials utilized for this experiment were:

i. Sugarcane Bagasse and Doum Palm shell particles sourced from Baga Road and Gamboru (Custom) market in Maiduguri - Nigeria.

ii. Polypropylene with Density 0.905g/cm^3, melt flow index of 12g/10min and melting temperature of 135-171^{0}C was purchased in Hafason Chemicals and Scientific Equipment Ltd, 53, Sokoto Road, Samaru Zaria, Kaduna State - Nigeria.

iii. Distilled water.

iv. Sodium Hydro-Oxide (NaOH) for treatment of the bagasse fiber.

v. pH Paper for testing the alkalinity and basicity of the fiber

2.2 Equipment

The equipment used in this work were:

- Two Roll Mill, North Bergen, U.S.A(Model: 5183) for compounding the composite
- Microhardness Tester, Vicker Hardness Tester (Model no MV 1-PC)
- Digital Weighing Balance, Mettler Instruments Ltd (Model no: AE200)
- Standard set of sieves (150μm size required)

2.3 Methods

2.3.1 Extraction, Treatment and Preparation of Fiber

The Bagasse fibers were collected from Baga Road market in Maiduguri, weighed to 500.50grams.It was cut to the length of 3mm and chemically treated by submerging it in alkaline solution with 10% NaOH solution for 3 hours (Putra & Anggono, 2020). It was filtered, washed with distilled water severally until the colour of

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the filtrate became clear and the pH of the filtrate to approximately 7.0.The cleaned bagasse was dried under the sun for 48hrsas reported by (Abedom *et al.*, 2021). The dried fibers were pulverized into particulate using laboratory milling machine (MekinsAgro Products Ltd Model No 150) as depicted in figure 1(a-c) and then sieved separately using ASTM sieve size 150μm because smaller particle size tend to undergo better compaction and therefore provides the composite with reduced porosity which gives effective stress transfer between matrix and particles (Samuel *et al.*, 2018).



(a) Sugar cane (b) Bagasse (c) pulverized Bagasse

Figure 1(a-c): Pulverized Bagasse from Sugarcane

2.3.2 Doum Palm Shell Particle Extraction and Preparation

Weighed 500:50rms of Doum Palm shell was collected from Gamboru (Custom) market Maiduguri. The edible part of the fruit and the seed were removed. The shell was weighed and dried under the sun for 24 hours until the residual moisture was ensured to have greatly reduced when it showed a constant weight after each measurement. The dried Doum Palm shell was shredded to smaller pieces and milled into particulate form using laboratory milling machine (Mekins Agro Products Ltd Model No 150) as shown in figure 2(a-c).The powdered Doum palm shell were sieved separately using ASTM sieve size 150μm, which was the required size (Adebisi *et al.*, 2021).



(a) Doum Palm fruit (b) Doum Palm shell c) Doum Palm Particles

Figure 2(a-c): Doum Palm shell particles preparation from Doum Palm fruits

2.3.3 Composite preparation

The Sugarcane Bagasse and Doum Palm shell particles and polypropylene were blended together in a two-roll mill. First, polypropylene was melted to allow for adequate flow of the molten polymer before pouring the Sugarcane Bagasse and the Doum Palm shell particles as reinforcing materials. The composites samples were produced by a melt mixing process involving the introduction of the PP pellet while the rolls of the two rolls mill machine were in counter clockwise motion and soften for a period of 5 minutes at a temperature of 180 °C and rotational speed 45rpm. The Bagasse were utilized with Doum Palm shell at a ratio of 50:50 percent by weight ranging from 10-50% of the total weight while PP were varied in the composite till a suitable mixture was obtained. The composite obtained from the mixing process was placed into a metal mould of dimensions 140 mm x 120 mm x 3.2 mm and was placed on the hydraulic hot press (Compression Moulding Machine) at a temperature of 160°C and pressure of 2.5 MPa for 5 mins. It was allowed to cool at room temperature, removed from the mould and labelled accordingly. Five specimens for each sample were tested for hardness,

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density and water absorption and the composites were named DPS/SCB (Doum Palm shell/ Sugarcane Bagasse) for easy identification. Figure 3 describes the flow chart of the production process while table 1 shows the formulation processes.

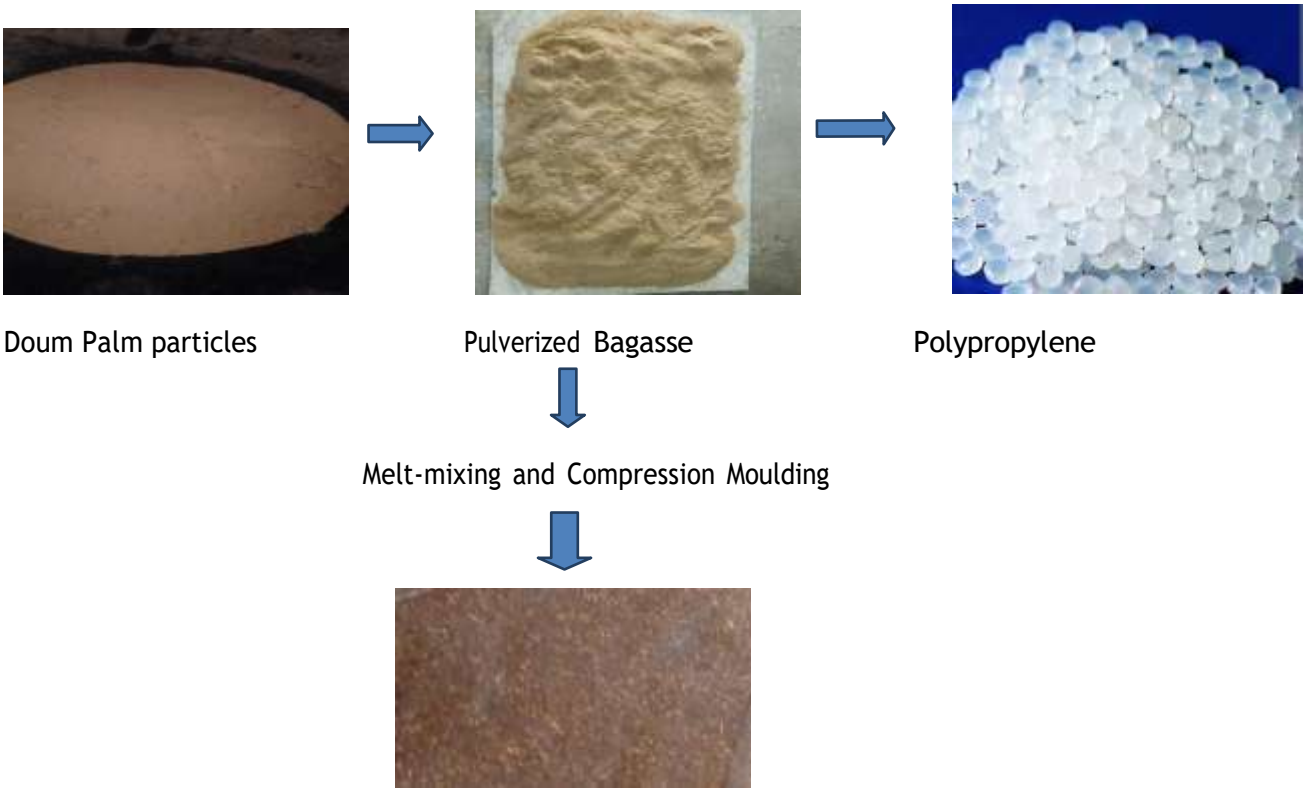


Figure 3: Flow chart for the Production of Hybrid Composite

Table 1: Formulation Table

Sample	**Bagasse (SCB) and Doum Palm Shell (DPS) (50:50% weight)**	**Polypropylene (% weight)**
Control	0	100(500.50 grms)
DPS/SCB A	10	90
DPS/SCB B	20	80
DPS/SCB C	30	70
DPS/SCB D	40	60
DPS/SCB E	50	50

2.4 Characterization of the Composites

Upon production of the hybrid composites, their properties were characterized.

2.4.1 Determination of Hardness Properties

Hardness is the resistance of a solid to local deformation. The hardness test characterizes the Indentation hardness of materials by measuring the depth of penetration of the indenter point. A hard indenter was placed onto the surface of a material and then pressed into the material. Indentation test for composite samples were carried out in accordance with ASTM D2240 on a Micro Vicker Hardness Tester as depicted in figure 4. Five samples were used to determine the hardness and was recorded directly by the machine through a computer monitor attached to the hardness tester.

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Figure 4: Micro Vicker Hardness Tester

2.4.2 Investigation of its Water Absorption behaviour

This test was carried out in accordance with ASTM D-570 with sample size of 70mm × 25mm × 3.2mm. The weights of the samples were taken on a digital weighing machine and soaked in water as depicted in figure 5. After every 24 hours for 14 days, the samples were removed, dried with a tissue paper gently and weighed again. The expression in equation 1 by Kumar *et al*. (2019) was used to determine the water absorption of the samples.

$$Waterabsorption = \frac{M_2 - M_1}{M_1} \quad (1)$$

where M_1 is the mass of the sample (g) before water immersion and M_2 is the mass of sample after every 24 hours water immersion.



Figure 5: Sample specimen of Water Absorption

2.4.3 Determination of Density

The samples were weighed on a digital weighing machine and the volumes were determined by liquid displacement method. The samples were placed in water and the volume of water displaced was same as the volume of the samples. This test was carried out in accordance with ASTM D-792. The expression of density was calculated using equation 2 (Agbo *et al*., 2020).

Density, $P = \frac{M}{V}$ (2)

where M is the mass, of the sample (g), V is the volume of the sample (cm^3) and P is density.

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2.4.4 Micro-Structural Analysis

The internal morphology of the composites produced were studied by microscopic analysis using Pro: X: Phenom world (Model no. 800-07334). The microscopic features of the sample were viewed and a particular area of the microscopic feature was magnified under electron microscopy at 300X magnifications and 15Kv until clear electron features of the samples were viewed and recorded accordingly.

3. Results and Discussion

3.1 Hardness of the Composite

Figure 6 shows the influence of the fiber and particles loading on the hardness property of PP reinforced with Sugarcane Bagasse and Doum-Palm shell particles. It shows a gradual drop in hardness of the composite with material loading. A drop of 35% of the composite hardness was observed from the initial 65Hv value for neat PP at 50wt% loading of PP. Increased in material loading softened the composite (Ismail *et al.*, 2018).The addition of Doum Palm shell particles and Sugarcane Bagasse decrease the matrix surface resistance to the indentation (Ali *et al.*, 2020).

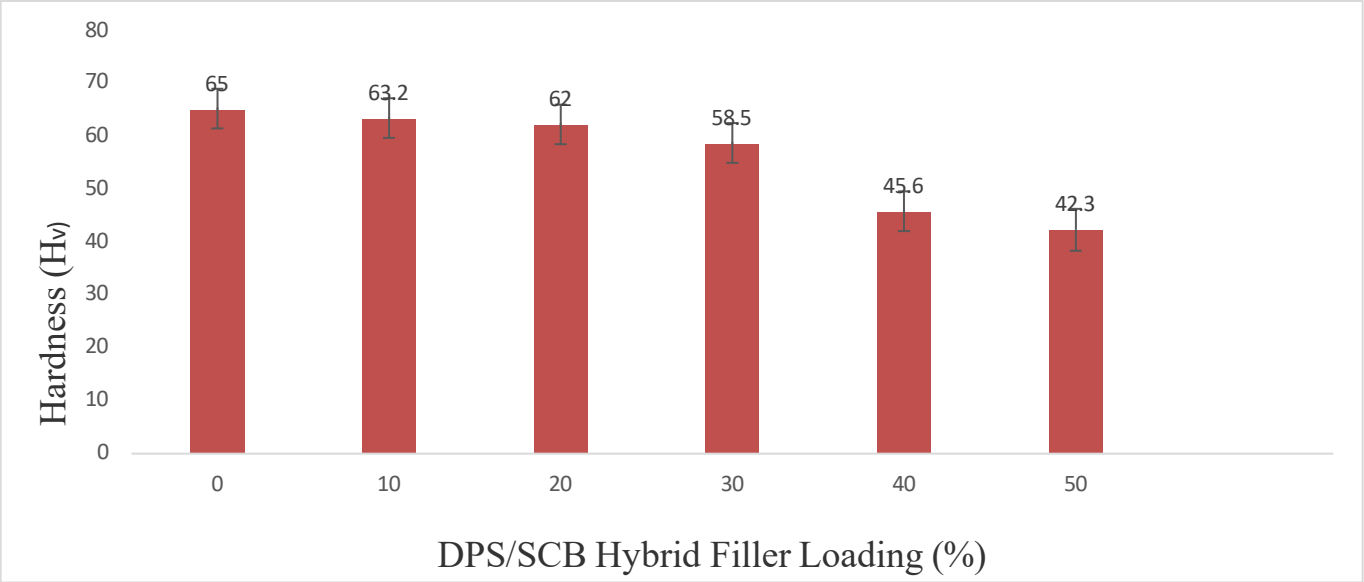


Figure 6: Effect of material loading on Hardness of DPS/SCB/ PP hybrid Composite

Plate 1 shows the scanning electron microscopy test result of hardness at 50wt% fiber loading. It indicates image of inadequate mixing of composites. Cracks of matrix surface was observed leading to poor interfacial bonding.

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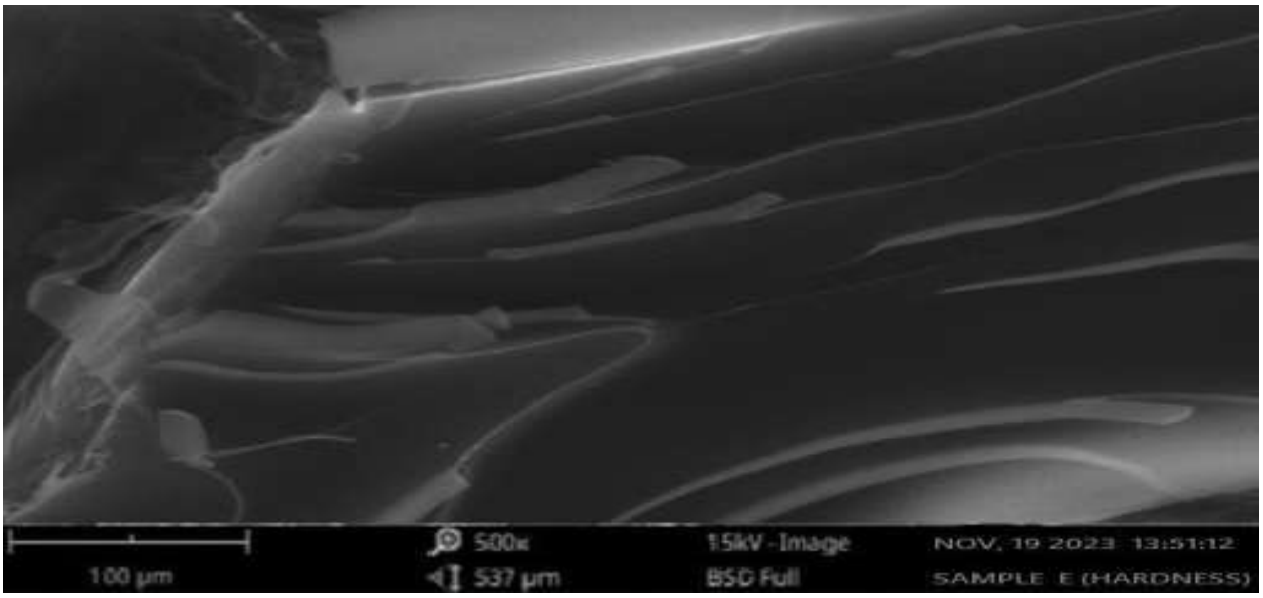


Plate 1: SEM micrograph of 50wt% for Hardness

3.2 Water Absorption Behaviour of the Composite

Figure 7 shows the result of water absorption behaviour of PP reinforced Sugarcane and Doum Palm shell particles composite. The water absorption increased from 1.61% for neat PP to maximum of 8.49% at 50wt%. The water absorption property of the composites increases with exposure time and fiber-particle loading of the matrix for all the formulation. It can be seen that the composites with higher filler loading showed tendency for more water absorption. This is because Sugarcane Bagasse and Doum Palm shell particles contains polar hydroxyl group which result in water absorption of the composite The hydrophilic nature of particles and the greater interfacial area between the particles and the matrix resulted in an increase in water uptake as the particles content increases in the matrix (Jacob *et al.*, 2018).The water absorption was high at 8.49% at 14 days exposure.

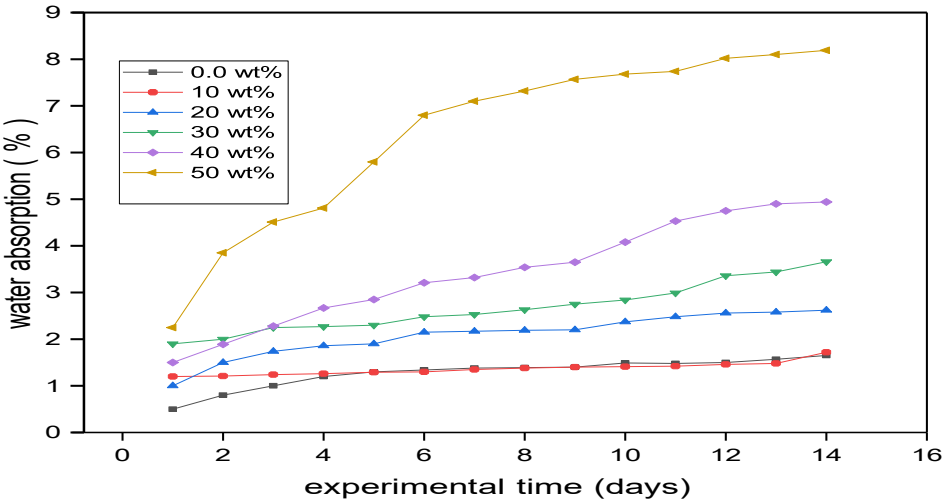


Figure 7: Percentage water absorption of DPS/SCB composites

3.3 Density Test

Figure 8 shows the density test of the composite which showed increase with increase in material loading of PP. The fiber and particles loading made the composite denser than the neat PP. The density increases from 0.115g/cm^3 for neat PP to maximum 0.468g/cm^3 at 50wt%, it is about 75 % increase when compared with the neat PP. The densities of the material loading were higher than that of PP which increased the overall density of the formulated hybrid composite. This is not an advantage when weight is a critical factor in material

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selection for the production industry. Except for some automobile components, example, the conventional headliner which varies from 0.3g/cm³ to 0.5g/cm³(Ibraheem *et al.*, 2015). It has shown that the Density result was found to be in standard range of Honda Accord Headliner 0.5 g/cm³ (Savic and Hector, 2011).

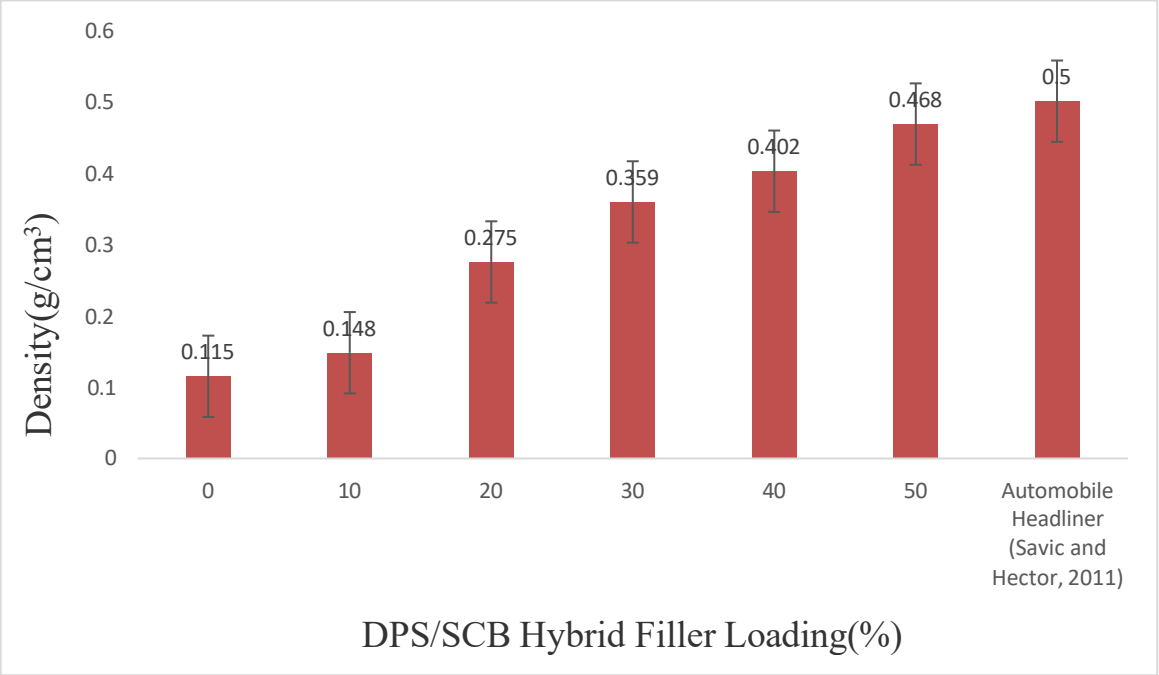


Figure 8: Density of DPS/SCB composites

4. Conclusion

Doum Palm shell particle and Sugarcane Bagasse reinforced PP was successfully produced using melt-mixing and compression moulding method. The study showed that hardness of composites decreased gradually with increase in material loading of PP. The density and water absorption behaviour showed increase with increase in material loading. The density of the particles used influenced the overall density of the hybrid composite produced. When these physical properties are a critical factor in industrial production of certain products, such materials must be selected with carefulness.

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