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Influence of Plastic and Coconut Shell (Cocos *nucifera L.*) on the Physico-Mechanical Properties of the 8/6 Composite Rafter

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Abstract

In this paper, the authors aim to propose the use of waste plastics as a binder in a coconut shell reinforcement for the development of an 8/6 size composite rafter to replace the natural 8/6 size backbone in construction. Following a study into the choice of the best proportions, a total of 30 size 8/6 composite rafters with different proportions of 20%, 25%, 30%, 35%, 40% and 50% plastic content were developed. All the 8/6 composite rafters were subjected to mechanical (3-point bending strength and Monnin hardness) and physical (bulk density and water absorption) characterization analyses. The results show that flexural strength increases from 27.56 MPa to 33.30 MPa for proportions ranging from 20% to 35% plastic content. Above 35% plastic, the strength drops to 19.60 MPa for a 50% plastic content. Similarly, the Monnin hardness drops from 9 mm to 5 mm when the plastic content varies from 20 to 50%. As for the results of the physical characterisation, the values obtained for apparent density vary from 0.89 to 1 for proportions varying from 20% to 35% plastic content and drop to 0.94 for 50% plastic content. As for water absorption, values drop from 6.82% to 2.45% when the plastic content increases from 20% to 50%. These mechanical strengths stabilise at 35% plastic content. The development of an 8/6 chevron composite material based on plastic and coconut shell could therefore be a way of recovering waste and solving the problem of deforestation.

Keywords

Plastic Waste, Coconut Shell, Recovery, Mechanical and Physical Properties, 8/6 Composite Chevron

1. Introduction

Plastic is one of the most widely used materials in the world because it can take any shape. It is used for a wide variety of purposes, from single-use everyday products such as packaging and bottles, to products that last for years, such as furniture, clothing, building materials and parts of our cars [1]. Plastic has replaced many traditional materials such as glass, steel, wood and even concrete [2]. It is lighter, cheaper and offers excellent technical characteristics. However, the increase in the world's population, its concentration in cities and the development of industrial equipment have led to the generation of large quantities of plastic waste [3]. This plastic waste now occupies a very large volume at collection points and waste management facilities, including waste transfer centres, landfill sites and landfills. Disseminating them in nature is dangerous and unsightly because they are non-biodegradable and have a lifespan of up to 500 years [1] [4] [5]. These plastics have become ubiquitous in nature and in our lives. Every year, humans and other animal species ingest more and more nano-plastic (via food and drinking water), the full effects of which are still unknown [6]. Plastic pollution kills wildlife, damages natural ecosystems and contributes to climate change [7], clogs wastewater drains, causes visual pollution when it is blown away by the wind, scatters in nature and sometimes clings to trees, and its incineration in the street is a source of carbon dioxide (CO_2) emissions. Coconuts are also one of the foods eaten by humans. However, once the kernel has been extracted, the shells are thrown straight back into nature and become household waste [3]. The only common way of disposing of it is to landfill and incinerate it in the open air, causing smoke emissions and the release of carbon dioxide (CO_2), thereby causing public health problems and contributing to global warming [8]. With the aim of contributing to the recovery of plastic waste and coir shells and solving the problem of pollution associated with these wastes, a simple recovery route has been initiated through the development of a composite rafter of size 8/6 based on plastic and coir shells has been developed. The aim of this work is to determine the influence of the plastic content on the physical and mechanical properties of these 8/6 size csomposite rafters.

2. Materials and Methods

2.1. Raw Material

The raw materials used in this work consist of plastic waste (LDPE), coconut shell and come from the Autonomous District of Abidjan.

2.1.1. Plastic Waste

The plastic waste used is low-density polyethylene (LDPE), recovered from markets, rubbish tips and gutters in the Adjamé and Abobo districts of Abidjan. This plastic is used to package food, water, clothing and household appliances. Once stripped of their contents, they become waste that harms the environment. Plastic waste is sorted, washed thoroughly with water to remove grease, oil and sludge and dried at room temperature in the laboratory (**Figure 1(a)**). The plastic is ground (**Figure 1(b)**) using a fixed tooth mill and then melted down to be used as a binder in the mixture.

Figure 1. Plastic waste washed and crushed.

2.1.2. Coconut Shells

The coconut shell (**Figure 2**) used comes from the village of Zimakro located in the locality of Vitré 1 precisely in the town of Grand Bassam (Autonomous District of Abidjan, Ivory Coast), it is obtained after extraction of the fibres and kernels. It is dried, crushed and ground into 6.5 mm diameter portions before being used. This vegetable waste is produced in Ivory Coast on an industrial or artisanal basis due to its accessibility and availability. Only the kernel of the coconut is used for domestic consumption or industrial processing, the shell being discarded. The shell is the hard part of the nut that is not biodegradable and can only be disposed of as waste by calcination [9]. In our study, we use them as reinforcement, with plastic as a binder, to make composite chevron. Some authors use coconut shells as activated carbon and others as aggregate in the cement matrix to make lightweight concrete.

Figure 2. Broken and crushed coconut shells.

2.2. Methodology

2.2.1. Elaboration of Rafters in Composites of Dimension 8/6

There Figure 3 below shows the different stages in the development of the herringbone composite woods that were used for the different tests.

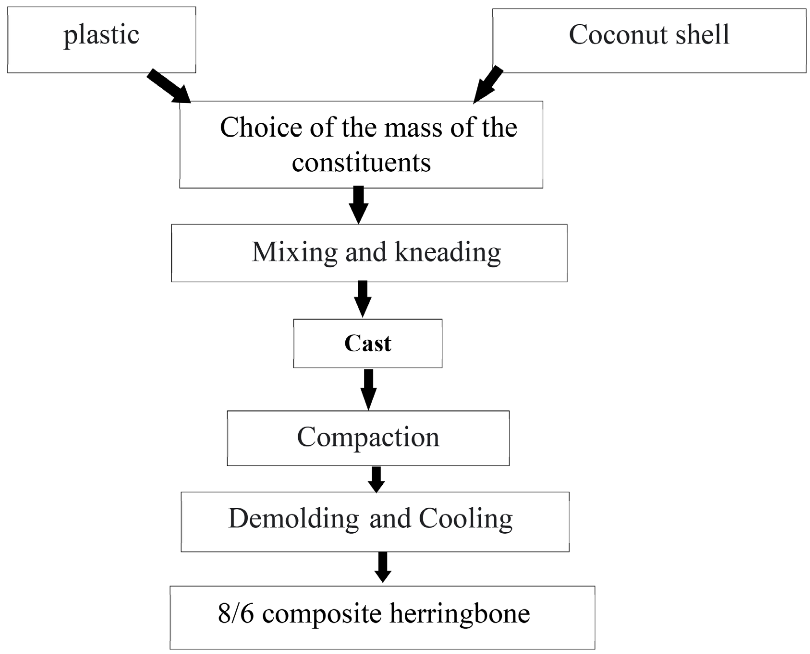

Figure 3. Stages of elaboration of the rafters in composites of dimension 8/6.

For each plastic ratio (20%, 25%, 30%, 35%, 40% and 50%) five (5) samples of 8/6 rectangular composite rafters were produced. Each raw material was weighed to obtain a plastic/shell ratio. The mass proportion of the ratios for processing was determined using the following general formula:

$$P\% = M_p / \left(M_p + M_c + M_l \right) \times 100 \tag{1}$$

With:

P (%): mass percentage of plastic, M_p: mass of plastic in grams (g);

M_c: mass of shell in grams (g);

M_l: mass of laterite (mineral filler) in grams (g).

After the raw materials have been dry-mixed, heated and kneaded in the extruder at a temperature of 170˚C, the homogenous paste obtained is poured into the metal mould through a drain hole in the extruder. On contact with the cold walls, the paste takes the shape of the mould and solidifies. This operation must be carried out as quickly as possible so that the dough does not solidify too much before compacting. The mould requires some preparation beforehand. First of all, the inner surface of the mould must be oiled to facilitate removal from the mould. This is done using a brush and a little palm kernel oil extracted from the kernels. After moulding, the homogeneous paste is pressed using a manual press to eliminate voids and pores that could store water in the material. Once the pressing operation is complete, the metal mould containing the composite chevron is soaked in cold water for two minutes to speed up cooling. After the two minutes, the lid and sleeves of the mould were removed to facilitate demoulding. After demoulding, the various tests are carried out.

2.2.2. Mechanical Characterization

1) Resistance to three-point bending

The resistance to three-point bending was carried out on rectangular specimens of dimension 345 × 80 × 40 mm^3. This test was carried out by an ELE International (**Figure 4**) brand hydraulic press with a maximum capacity of 2000 KN [2]. During the test, the specimens are placed on two supports and subjected to a load in the middle until rupture. The bending strength is given by Equation (1) below:

$$Rf = (3FL)/(2lh^2) \tag{2}$$

With,

Rf: the bending strength (Mpa);

F: the breaking load (N);

L: the distance between the supports (m);

l: the width of the specimen (m);

h: the thickness of the sample (m).

Figure 4. ELE brand three point bending device.

2) Monnin hardness resistance

The Monnin hardness resistance was obtained using a Control brand hydraulic press (**Figure 5**), on part of the 172 × 80 × 50 mm^3 rectangular test piece from the three point bending. We have support is fixed to steel point of diameter 11 mm. This test makes it possible to determine the depth of the penetration of the steel point after 30 seconds of application on the face of the sample using a hydrostatic mass press (1960 Newton). The specimen is placed and centered between two platens of the press. Then, the imprint (depth) made on the specimen is measured using a caliper. Then, the indentation length is recorded at the level of the five specimens used. It is then the average indentation length that will be used for the hardness calculation. The penetration deflection (*t*), in millimeters (mm), of each specimen is calculated using formula (2) and the Monnin hardness (*N*), a unitless number, is equal to the inverse of the penetration deflection (*t*) which is calculated using the following formula (3).

$$t = 15 - \frac{1}{2}\sqrt{900 - a^2} \tag{3}$$

$$N = \frac{1}{t} \tag{4}$$

where:

t: penetration arrow; *N*: Monnin's hardness;

a: is the average indentation length, expressed in millimeters (mm).

Figure 5. Monnin hardness measuring device.

2.2.3. Physical Characterization

1) Apparent density

Density is one of the most important physical properties for wood materials, in the sense that it determines the weight of the species. This test consists of determining the mass of the sample using a 0.01 g resolution balance and the volume (length, width and thickness) using an electronic caliper with a precision of 0.01 mm [10]. From these parameters, the sample volumes were calculated. Density is calculated using the following formula.

$$D = M/V \tag{5}$$

With:

D: apparent density; *M*: mass of the specimen (g);

V: volume of the specimen (cm^3).

2) Water absorption

Water absorption is a weighing method used to determine the water behavior of samples. The dry mass (ms) of the samples are obtained after passing through an oven at 105˚C. Then, after stoving, the samples are immersed in a water tank for 24 hours. After the 24 hours, the samples are removed and wiped with a cloth so as to rid them of their surface water, then the new mass (Mwet) is determined. The water absorption by immersion (**Figure 6**) is determined by the following formula 6:

$$Abs = (Mhumide - Msèche)/(Msèche) \times 100 \quad (6)$$

With:

Abs: Absorption by water immersion in %;

Mwet, the wet mass after immersion in g;

Mdry, the dry mass before immersion in g.

Figure 6. Water absorption herringbone specimens.

3. Results and Discussion

3.1. Mechanical Characterization

3.1.1. Influence of Plastic Content on Three-Point Bending Strength

Figure 7 shows the evolution curve of the bending strength of different proportions depending on the plastic content.

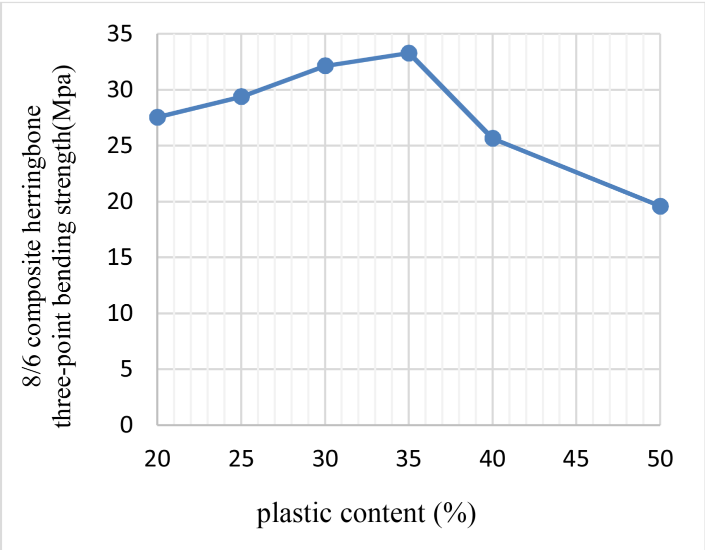

Figure 7. Variation of flexural strengths as a function of plastic content.

The flexural strength of 8/6 composite rafters increases as the plastic content increases. The strength increases from 27.56 MPa to 33.30 MPa when the plastic content is varied from 20% to 35%. It then falls from 33.30 MPa to 19.60 MPa when the plastic content is increased from 35% to 50%. The increase in flexural strength is due to improved adhesion between the binder and the shells. As the plastic content (binder) increases, the result is a mixture containing a sufficient quantity of plastic to fill the voids and coat the coconut shell grains. However, above 35% plastic, the strength of the material drops because there is too much plastic in the mix, making it less resistant because plastic has low strength. The same observations were made by [11]. He showed that when the plastic content reaches a threshold of 30%, the flexural strength drops. The same observations were made on samples of river sand and gravel pavers stabilised with plastic waste by [12] [13].

3.1.2. Influence of Plastic Content on Monnin Hardness of 8/6 Composite Herringbone

Figure 8 shows the variation of Monnin hardness (tip depression) as a function of plastic content. The sinkage rate decreases as the plastic content increases.

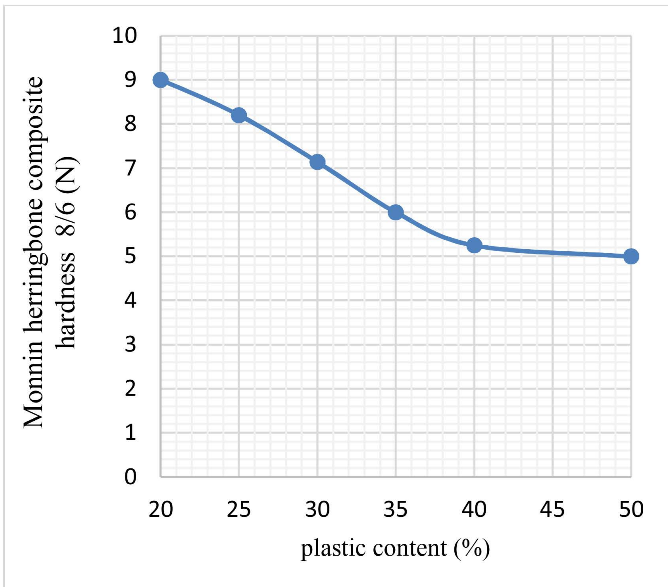

Figure 8. Evolution of resistance to Monnin hardness as a function of plastic content.

The sinking of size 8/6 composite rafters drops from 9 mm to 5 mm for plastic contents ranging from 20% to 50%. This reduction in sinkage is due to the consolidation of the coconut shell grains by the gradual addition of plastic. Under the action of the steel point, the uncoated and unconsolidated grains separate. This separation of the uncoated grains will result in the point sinking into the composites to a considerable depth. The gradual addition of plastic to the material creates cohesion between the shell grains, making the material more rigid to the penetration of a point. Consequently, increasing the amount of plastic considerably reduces the depth of penetration. This sinking of the depth with the plastic content was also observed by [10] [11] [12] [13], working on a mixture (of plastic waste as a binder containing sand in order to manufacture a paving stone and a tile) different from that of our work. They explain this sinking by the gradual addition of the plastic content, by the decrease in the depth of the material.

3.2. Physical Characterization

3.2.1. Influence of Plastic Content on Bulk Density

The quality or characterization of a material is assessed by knowing its density. Figure 9 shows the variation in apparent density as a function of plastic content. The density increases from (0.89 to 1) from 20% to 35% plastic content before decreasing (1 to 0.94) from 35% to 50% plastic content.

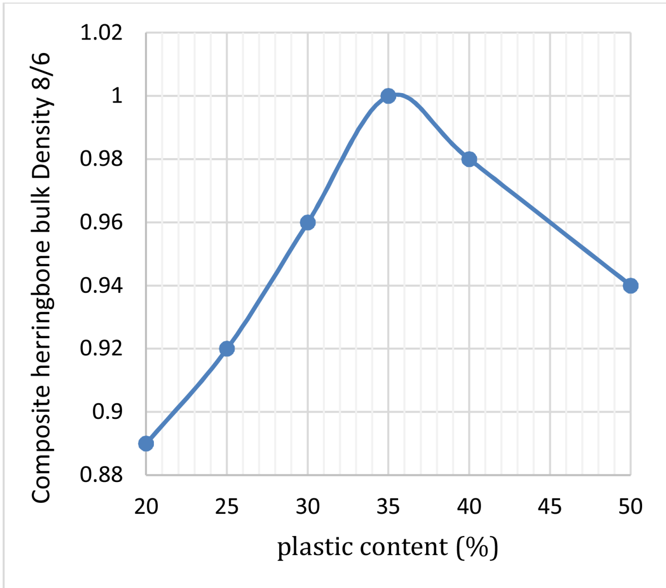

Figure 9. Apparent herringbone density as a function of plastic content.

The increase in density could be explained by the increase in plastic in the material, and the compaction of the material, resulting in a material that contains fewer voids. The voids between the shell grains are gradually filled by the addition of plastic. This reduction in voids, which is reflected in the homogeneous distribution of the plastic in the mix, leads to an increase in the density of the specimens until a threshold is reached. Beyond this threshold (35% plastic), the material contains too much plastic, and will tend towards the density of the plastic (0.92), which is low. The same observation was made on samples of lagoon sand pavers and tiles stabilised with plastic waste [5]-[13].

3.2.2. Influence of Plastic Content on Water Absorption

Figure 10 shows the variation in water absorption as a function of plastic content. Water absorption drops from 6.82% to 2.45% from 20% to 50% plastic content.

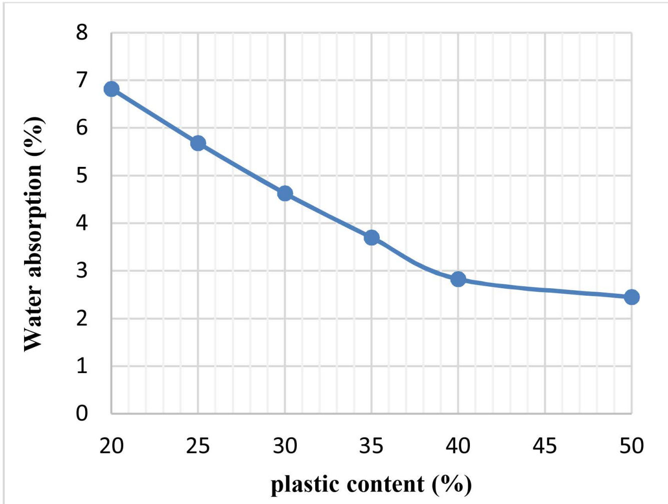

Figure 10. Variation of water absorption as a function of plastic content.

The decrease in water absorption is linked to the increase in plastic content. This result confirms that of density, since a material with more voids absorbs more water. On the other hand, the increasing addition of plastic, which is hydrophobic, will prevent water from entering the material. In fact, the molten plastic that acts as a binder in the material will fill the voids and pores that may exist between the constituents, binding and coating them. These results confirm those obtained in the work of [5]-[10] [12] who showed that the increasing plastic content prevents water from entering the material. According to the work of Mariam [14] and Ledru [15], the contribution of plastic waste, which is impermeable and acts as a binder, considerably reduces the rate of water absorption. By comparing these results with the NBN EN 1338 standards for good quality materials in construction, the water absorption rate must be less than 6% (≤6%), whereas the water absorption obtained on samples of composite rafters of size 8/6 varies from 6.82% to 2.45%, we can say that from 25% in plastic content, these composite rafters have good qualities in terms of water absorption.

4. Conclusion

This work falls within the framework of recycling and recovery of plastic waste of the density base type and vegetable waste of the coconut shell type, which is nowadays a concern for everyone after the use of containers. The aim was, on the one hand, to propose a method for recycling and recovering waste plastics by using them as a binder and plant waste as a reinforcement and, on the other hand, to produce 8/6 composite rafters that could replace 8/6 natural rafters in interior and exterior joinery. The 8/6 composite rafters developed were subjected to satisfactory mechanical and physical tests. In addition, the various results of this study show a flexural strength that increases progressively from 27.56 MPa to 33.30 MPa when the plastic content varies from 20% to 35%. It gradually decreases until it reaches 19.60 MPa when the plastic content exceeds 35%; the hardness decreases from 9 mm to 5 mm in depth, qualifying the rafter as a hard composite. Like flexural strength, density increases from (0.89 to 1) at 20% to 35% plastic content, before falling (1 to 0.94) at 35% to 50%. This qualifies them as heavy composite rafters. The water absorption rate drops from 6.82% to 2.45% when the plastic content rises from 20% to 50%. These results are satisfactory, since a construction material is good when the water absorption rate is less than 6% (≤6%). We can conclude from this study that the optimum plastic content for obtaining the best characteristics of 8/6 composite rafters is 35%, with a plastic/shell ratio (35%/65%).

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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