Characteristics Of Macadamia-Particle Plastic Boards Developed From Wastes

J. Kimathi, L.M. Ng'ang'a, D. Letting, F.M. Mwema

Abstract: The purpose of this study was to characterize mechanical and physical properties of experimental composite prepared from macadamia flour and waste HDPE plastics. Macadamia flour of different grades of less than 1mm and between 1mm and 2 mm were used. Four samples were fabricated with plastic to macadamia at mass ratios of 1:1 and 2:1. The composites were produced through a simple molding process. On characterizing the samples, it was observed that the finer grade of macadamia exhibited better tensile strength compared to sample with coarse particle sizes. The highest value of tensile strength was given by samples prepared at mass ratio of 1:1 and grain size of less than 1mm. The water absorption rate was lowest in samples with a mass ratio of 2:1 and grain sizes of less than 1mm. The samples showed good machinability properties.

Index Terms: Composites, HDPE, macadamia, particle boards, plastics, recycling, wastes.

1. INTRODUCTION

The increasing use of plastics in packaging of food and drinks has led to growth of landfills in major cities in Kenya. Being, a non-biodegradable waste, plastic poses a major environmental concern among the other municipal solid wastes (MSW) [1]. Macadamia shells are also a concern in the rural areas, though to a lesser extent, because they take longer to decay on disposal. Macadamia also pose health risks since when crushed they develop sharp edges, which can pierce through skin and cause physical injuries to humans and animals. Mostly in Kenya and other parts of Africa, plastics and macadamia nut shells either are burned or disposed resulting in extra pollution to the environment [2]. Good formability and availability of plastic wastes makes the development of plastic-based composites attractive in Kenya currently. Combination of biomass material such as wood fibers and macadamia shell particles with plastics produces a composite with attractive mechanical and environmental properties [3]. Such composites have found applications in automotive, packaging, fencing and construction industries. Application of these composites into these areas has been cultivated by the attractive properties, which include, durability, better stiffness, low-cost compared to the conventional timber [4]. Additionally, research has shown that these composites are resistant to biological deterioration, which makes them suitable for applications as chipboards and tiles. Other important properties for these composites include water absorption capacity, thickness swelling and fiber/particle-matrix interaction.Researchers have investigated different types of natural fibers and particles for applications in plastic-based composites including straw, flax, wood fiber, sisal, oats, papyrus, Raphia, rice husks, pennywort, kenaf, grass reeds, wheat, barley and Curaua [5]. Extensive previous works on natural fiber and particle-reinforced composites have emphasized on the use of wood and plastic to form wood plastic composites (WPCs) [3], [6], [7], [8]. There is conspicuously limited literature on use of other natural fibers and particles for plastic composites. Macadamia nutshell is hard and brittle and presents an exciting opportunity for development of plastic-based composites [6]. Furthermore, its structure is reasonably isotropic and uniform, contrary to tree fibers. As such, properties of macadamia shells are more desirable as compared to those of wood fiber/particles for production of composites [9]. There have been limited attempts to utilize macadamia nut shells in production of plastic composites due to its superior properties and abundance in areas such Australia, Brazil, Kenya and among others. Such attempts were by [10], [11], [9]. From these studies, plastic-macadamia composites have been reported to have good mechanical and physical properties for wide-range of applications. The general finding from the previous studies is that there is limited research into use of waste plastic and macadamia nut shells to produce composites. As such, this paper reports on the development and characterization of a macadamia nutshell-waste plastic composite.

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2 EXPERIMENTAL METHODS

2.1 Sample Preparation

The cleaning of the HDPE plastics involved washing them in hot water and detergents to remove paper labels, adhesives, oil, grease and other impurities. Then, the plastics were naturally dried in air and shredded into small pieces that could fit into the melting pan (Figure 1). The macadamia shells were collected from processing factories and farms and dried to reduce the moisture content. They were then crushed using macadamia nutshell crusher and then graded using sieves of <1 mm and 1 mm≤ sieve size ≥2 mm (Figure 1).The fabrication of the composites was undertaken by mixing in 100 g of macadamia shells with 100 g HDPE plastic and 100 g of macadamia shell with 200 g HDPE plastic to obtain two grades of composites (Table 1). Initially, the weighed plastic was melted in a pan and heated to a temperature of around 130 °C. The manufacturing of the samples involved a press-forming operation in which the molten plastic was poured into a pre-heated pan (Figure 1) and mixed with the required amount of crushed macadamia shells. The mixture was stirred until it sufficiently mixed into a homogenous mixture. The mixture was then transferred into a rectangular cross-section mold with stationary lower and moving top die (Figure 1) in which it was compressed under 265 N. Rectangular-shaped composite samples were obtained for various experimental characterizations [12]. There were no additives used in this study.

2.2 Characterizations

Mechanical properties

Tensile test and hardness tests were performed using Universal Tensile Machine-UTE 20 (ASTM D638) and digital Rockwell testing machine (ASTM D785) respectively. The tests were conducted at room temperature (23 °C). A load of 10 Kg and a dwell time of 15 seconds were used during the hardness measurements.

Water Absorption Test

The water absorption test was carried according to ASTM D570. The samples with known weight were soaked in distilled water for 24, 48 and 72 hours after which they were removed, wiped and weighed. This was undertaken for five samples to ensure statistical accuracy. The water absorption was computed according to the equation below.

$$\%\ \text{Water absorption} = \frac{\text{Final weight} - \text{Initial weight}}{\text{initial weight}} \times 100$$

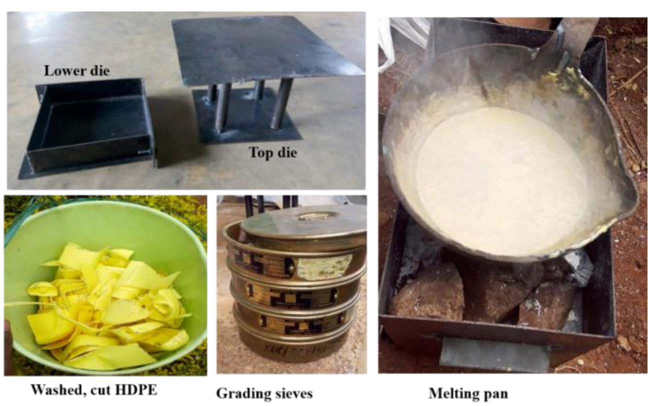

***Figure 1**. Materials and equipment used in the preparation of the composites*

TABLE 1

EXPERIMENTAL MATRIX

sample	Mass of plastic (g)	Mass of macadamia (g)	Grade
1	100	100	Less than 1 mm
2	100	100	Between 1 mm and 2 mm
3	200	100	Less than 1 mm
4	200	100	Between 1 mm and 2 mm

3 RESULTS AND DISCUSSIONS

Tensile test properties Figure 2 shows the tensile strength and modulus of composites of the four samples. As shown, the tensile strength was higher for samples prepared from the ration of 1:1, which indicates that increase in plastic content decreases the tensile strength of the composite. Generally, the fabricated samples were brittle, which is expected because of the macadamia particles into the plastic matrix [1]. As shown, sample 1 produced the highest value of tensile strength of 10.5 MPa while sample 4 produced the lowest value of tensile strength of 6.4 MPa. The finer the flour, the higher the tensile strength of the composite for the same plastic-to-macadamia mass ratios. Tensile strength of such composites is mainly influenced by the filler fraction and the interfacial adhesion between particles and the plastic matrix [13-16]. The finer particles, the better interfacial adhesion and hence the higher the mechanical strength of the composites. To further improve the tensile properties of these materials, a coupling agent can be used to enhance the reinforcing effect of the macadamia flour. In terms of distribution, finer particles tend to form a homogenous dispersion within the matrix, and this further explains increase in strength for finer reinforcements [2].

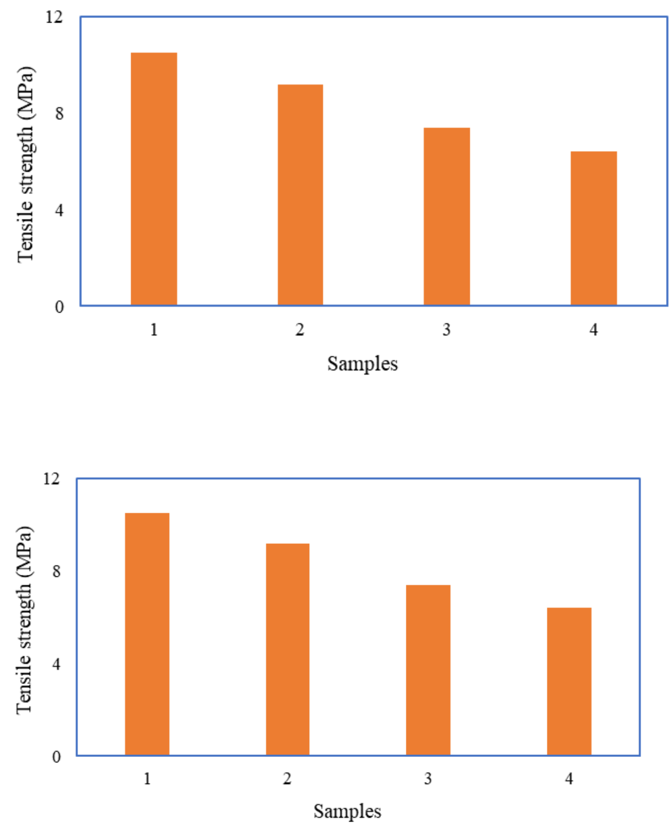

***Figure 2.** Tensile strength of the fabricated samples*

Rockwell Hardness test

This hardness test was conducted using ASTM D785 standards. The sample were cut to a thickness of 6.4 mm. Table 2 shows the hardness measurements on all the four samples. Sample 1 (with grain size less than 1 mm and ratio of 1:1) revealed the highest hardness with sample 4 (with grain size 1-2 mm and ratio 1:2) having the lowest Rockwell hardness.

TABLE 2
ROCKWELL HARDNESS VALUES OF THE FABRICATED SAMPLES

Sample	Ratio (macadamia-to-plastic)	Grain size	Measurements	Average hardness
1	1:1	Less than 1 mm	61.9	
			68.5	
			236	
			241.5	151.975
2	1:1	1-2 mm	60.2	
			63.2	
			120.2	
			130.6	93.55
3	1:2	Less than 1 mm	86.5	
			139.8	
			109.7	
			133.5	117.34
4	1:2	1-2 mm	64.5	
			53.8	
			60.3	
			77.7	64.075

Water absorption
Water Sensitivity is an important factor on the applications of WPCs for particle boards and for outdoor applications. Figure 3 shows the results for the water absorption test for 24, 48 and 72-hour soaking time. The absorption percentages of water absorption vary with the ratio plastic content, size of the particles and duration of the sample in water [17-19]. The weight gain during the first 24 hours were higher, this is because of the hydrophilic nature of the Macadamia flour, however the rate of weight gain tends to decrease with increase in duration this is due to the fact that the macadamia flour is already soaked and the slight change is due to the water reaching the more deeper parts of the composites. The moisture is absorbed by the lignocellulose fibers in the composite. Samples with less plastic content reported the highest water absorption rates, this is because they had more water residence sites. Similar results on WPC had been reported by Alireza [3].

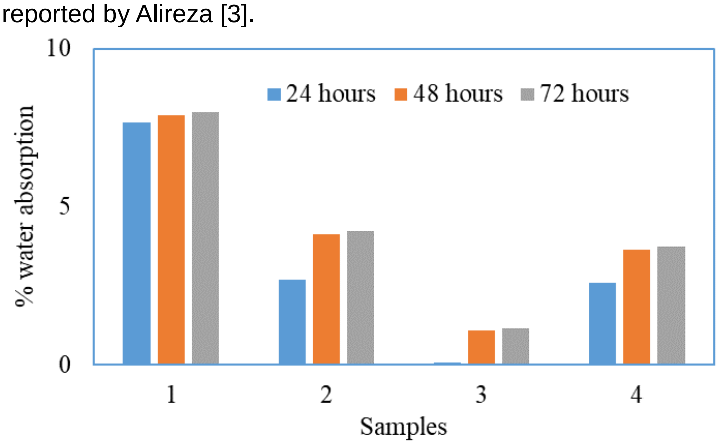

Figure 3. *Percentage (%) water absorption for plastic-macadamia composites*

4 CONCLUSIONS

This study examined the properties of a macadamia flour plastic composite. The mechanical and physical properties were reported in the study. The ratio of plastic-to-macadamia and size of macadamia particles significantly influence the quality of the composite. It can be suggested that coupling agents can be used to enhance the tensile properties of the composite. Furthermore, the water absorption can be improved by incorporating nanoparticles (metallic or ceramic) to penetrate the open space within the composite. The macadamia-plastic composites are promising materials for furniture (particle boards) and construction industries.

5 ACKNOWLEDGEMENTS

We acknowledge Dedan Kimathi University of Technology, Nyeri, for supporting this work through the final year project budget.

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