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PRODUCTION OF BUILDING BOARDS FROM WASTE PLASTICS BLENDED WITH SILA SORGHUM STALKS USING MOLASSES AS COUPLING AGENT

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Abstract: **The Sila sorghum stalks are agri residues which are generated after harvesting the grain from Sila sorghum plant. Sila sorghum is a fast maturing sorghum variety grown mainly in the western Counties of Kenya. These wastes can be put into profitable use by using them as raw material (fillers) in the production of building boards. On the other hand, waste plastics are a menace to the environment due to irresponsible disposal and the fact that they do not degrade. In order to find a way of addressing the problem associated with disposal of plastics, this research proposed a method of producing building materials (boards) from Sila sorghum stalks and High Density Polyethylene (HDPE) using molasses as the coupling agent. The factors studied were particle size of Sila sorghum stalks filler. The size of Sila sorghum stalks was varied at 100, 125, 250 and 500 and 1000µm. HDPE and molasses were blended at a ratio of 1:0.25. The effect of these factors on density, compressive strength, water absorption and the thickness swelling of the boards was studied. The results of this study established that at particle size of 250µm for the Sila sorghum stalks filler, the density, compressive strength, water absorption and thickness swelling of the resulting building boards to be 1024kg/m3, 20.5MPa, 2.85% and 3.4% respectively.**

Keywords: **Board, Molasses, Plastics, Residues, Sorghum, Waste.**

1. INTRODUCTION

One of the dominating factors affecting the cost of housing in the world is the high cost of conventional building materials. One of the functions of any government is to provide or support the availability of affordable housing to its citizens. One way of achieving this is to support the availability of cheaper building materials. In waste management, reduction and recycling of waste are key activities which help in conserving natural raw materials used in the building and construction industry as well as reducing the demand for land to dispose the waste generated. Plastics form a significant portion of municipal waste in Kenya. Sila sorghum stalks, waste plastics and molasses are wastes from the sorghum farms, households and sugar industries respectively which can be used as raw materials to produce cheaper and environmentally sustainable building boards. The low cost of the raw materials lowers the overall cost of production consequently lowering the price of the finished product. When these products are used in any construction work, the overall building cost is reduced there by contributing to affordable housing. The quantity of plastics produced annually the world over is increasing at an alarming rate. The main challenge is how to dispose the large quantity of plastic that is leaving our homes and industries as waste plastic. Plastics cause environmental challenges of monumental proportions because they are non biodegradable. Plastics block sewage lines and storm water drains resulting in poor drainage which causes flooding of roads and residential areas during heavy rains. Plastic paper bags are consumed by animals causing poor animal health and even death. In some areas, plastics hold rain water which act as a conducive environment for the breeding of mosquitoes which lead to increase in malaria cases in these areas. With the ever decreasing size of landfills to handle the amount of plastic generated, other methods of handling waste plastic such as recycling must be advocated. Recycling of waste plastics will lead to a reduction in solid waste disposal problem in landfills, reduce the use of natural/primary raw materials in the building and construction industry as well as utilizing properties such as resistance to abrasion, water penetration resistance, resistance to chemical attack and low thermal conductivity found in plastics. Plastics are classified into two main categories; thermoplastics and thermosetting plastics. Thermoplastics soften on heating and can be re-moulded into different shapes when hot. This property makes them available for recycling. On the other hand thermosetting plastics harden on heating and cannot be re-moulded into a different shape. In this research study, thermoplastics will be used. The main types of thermoplastics include polyethylene and polypropylene. Polyethylenes (PE) are organic polymers of high molecular weight and density. They are made by the polymerization of ethane (ethylene). There are several varieties of PE including High density polyethylene (HDPE), Linear Low density polyethylene (LLDPE), Medium density polyethylene (MDPE), and Low density polyethylene (LDPE) [7]. These different kinds of PEs differ in their melting point, chain length, degree of crystallinity and rigidity. Plastics are considered non-biodegradable because their chemical bonds are too strong which enable them to resist biodegradation. HDPE are made by low pressure polymerization process carried out of solution. This results in a fully linear polymer with a high degree of crystallinity and density of 960 – 970 kg/m3 [7]. HDPE has a good impact resistance at low temperatures, excellent chemical resistance but is susceptible to stress cracking and has high mould shrinkage [7]. The high density and rigidity make them suitable in the manufacture of plastic bottles, buckets, bowls, toys, pipes and pipe fittings for water and refrigerator parts [7]. Sila sorghum is a new variety of sorghum that was introduced in Kenya within the western counties specifically Bungoma and Siaya Counties. The major features that distinguish it from the usual varieties of sorghum include drought resistance, fast growing and high yielding variety [1]. East Africa Breweries Limited (EABL) has been promoting the cultivation of Sila sorghum because Sila sorghum grain is a promising raw material for beer manufacture due to high sugar content. EABL intends to substitute barley with Sila sorghum grains [1]. This study intends to utilize the Sila sorghum stalks that are generated after the grain is sold to EABL to produce building boards. EABL stated in a press briefing that it will require 12 million kilograms of Sila sorghum grain for beer production in 2011 [5]. This will leave about 300,000 tonnes of Sila sorghum stalks from a material balance point of view. According to another report EABL has increased the use of Sila sorghum in beer manufacture. To this end, it has brought on board farmers from Tharaka Nithi County a region estimated to produce 7,000 tonnes of Sila sorghum per season [6]. It is projected that Sila sorghum grain will eventually substitute barley in beer making, thus ensuring sustainable supply of raw material that can be used to produce building boards. According to [4], the composition of Sila sorghum stalks found in Bungoma County is as shown in table 1.1.

Table 1: Chemical composition of Sila sorghum stalks [4]

Component	Percentage
Cellulose	27.04
Hemicellulose	27
Lignin	31.28
Ash	4.70
Moisture	9.45
Extractives	0.53
TOTAL	**100**

Molasses is a byproduct of the sugar production process. It consists of a mixture of complex compounds which vary in composition depending on the plant source, location the plant is grown, season, age, weather conditions and the efficiency

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of the sugar production process. In this research study, molasses will be used as the coupling agent due to its binding properties which reduces the amount of water in the resulting building board. This will enhance properties such as compressive strength of the building board [2]. Molasses is also cheap and available in large quantities thereby making it a sustainable binder. In addition, molasses improves the interaction between HDPE and Sila sorghum stalks which leads to a stronger building board. Reference [10] reported that some coupling agents can cause the development of primary bonds (covalent bonds) between plastics and cellulosic fillers with profound effect on chemical and mechanical properties of the resulting composites. The main objective of this research study was to investigate the potential of waste HDPE and Sila sorghum stalks (cellulosic fiber material) as raw materials for the production of building boards using molasses as the coupling agent and to establish the optimum particle size of Sila sorghum stalks in the production of building boards with high compressive strength. Waste HDPE will act as the matrix, Sila sorghum stalks as the reinforcing material while molasses will act as the coupling agent. According to [9], the matrix has low strength and holds the reinforcing material (filler) together while the filler material is the main load carrying component since it provides the strength and stiffness required to resist bending and breaking when stress is applied. An interface bonding occurs between matrix and filler which is crucial during the transfer of stress from matrix to filler [9]. This interface bonding can be enhanced by use of coupling agents such as molasses and coconut oil. The coupling agent forms a bond between matrix and filler due to enhanced compatibility between matrix and coupling agent and between filler and coupling agent. According to [12], incorporating reinforcing fillers in polymeric materials such as plastics has a significant influence on the mechanical properties, water absorption and thermal properties of the resulting composite. The properties of the composite will depend on the type, size, shape, and amount of filler in addition to whether or not a coupling agent is used [12].

2. MATERIALS AND METHODS

The materials used included Sila sorghum stalks, waste plastics (HDPE) and molasses. Equipment used included laboratory scale hammer mill, sieves, oven, mixing containers, mould, pressing metal block, vernier caliper, electronic weighing scale and compressive strength testing machine.

2.1 Collection and preparation of raw materials

Sila sorghum stalks were obtained from Bungoma County and delivered to the Chemical and Process Engineering Laboratories at Moi University. The stalks were washed using distilled water and dried in the sun for 2 days. The dried Sila sorghum stalks were milled using a laboratory scale hammer mill. After milling, screening was done through screens of size 100, 125, 250, 500 and 1000µm. The screened stalks were dried in an oven at a temperature of 105^0C to reduce its moisture content to below 10%. Molasses was bought from an agrovet shop. Waste plastics (HDPE) samples were collected from a dump site situated within Moi University. The plastics were washed to remove any adhering dirt, dried followed by shredding into 2 cm sized plastic samples.

2.2 Preparation of boards

The shredded HDPE samples were placed in a mixer and molasses was added at a ratio of 1:0.25 (HDPE: molasses). Milled Sila sorghum stalks (size varied at 100, 125, 250, 500 and 1000µm) was added to the plastic/molasses mixture at 5% weight. The HDPE/molasses/ Sila sorghum stalks mixture was mixed mechanically for 15 minutes at 55 rpm using a mixer. The contents of the mixer were transferred into a steel container which was placed on an electric heater which was heated and stirred during heating until a consistent mixture was obtained. This was done at a temperature of 190^oC for 10 minutes. The total weight of each sample was 2000g for each experimental run. The molten plastic/molasses/Sila sorghum stalks mixture at 190^oC was poured into a rectangular mild steel mould of 30cm by 20cm by 3cm dimensions whose inside was covered with a film made of Teflon in order to ensure that the forming board does not adhere on the surface of the mould. During moulding the mixture was pressed manually using a metallic block to allow faster and effective settling of the plastic/molasses/Sila sorghum stalks mixture. While still in the mild steel mould during the board forming process, the final shape of the board was realised using a flat metal bar which leveled the upper surface of the forming building board which resulted in the scrapping of excess plastic/molasses/Sila sorghum stalks mixture. The final building board was allowed to cool for 1 hour at room temperature after which the density, compressive strength, water absorption and thickness swelling of the resulting board was established using the procedures described below.

2.3 Density analysis

The weight of the board was measured using an electronic weighing scale while the volume of the board was calculated using equations 1. The density was calculated using equation 2.

$$\text{Volume} = \text{Length} \times \text{Width} \times \text{Thickness} \qquad (1)$$

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \qquad (2)$$

2.4 Compressive Strength Analysis

The Compressive strength of the boards was determined using a 50 kN semi-automatic controlled universal testing machine.

2.5 Water absorption test

This test was carried out using the building board that was established to have the highest compressive strength. A piece of the building board of dimensions 3x3x3 cm was cut from the building board and immersed in water(about 4cm below the water) at room temperature for 24 hours. The test piece was removed from the water, wiped off any adhering water and the weight measured using an electronic weighing scale. The change in weight which is an indication of the amount of water absorbed was calculated using equation 3.

$$\text{Water Absorption (\%)} = \frac{W_2 - W_1}{W_1} \times 100 \qquad (3)$$

Where:

W_1 = initial thickness of test piece

W_2 = final thickness of test piece

2.6 Thickness Swelling

This test was done together with the water absorption test described above. During this test the thickness of the test piece was measured using a vernier caliper before and after immersion in water. The change in thickness was calculated using equation 4.

$$\text{Thickness Swelling (\%)} = \frac{t_2 - t_1}{t_1} \times 100 \qquad (4)$$

Where:

t_1 = initial thickness of test piece

t_2 = final thickness of test piece

3. RESULTS AND DISCUSSIONS

3.1 Effect of particle size of Sila sorghum stalks on the density of building board

The results of the effect of the size of Sila sorghum stalks on density of the building boards are shown in table 1.

Table I: Effect of particle size of Sila sorghum stalks on density of building boards

Particle size (μm)	Density, kg/m^3
100	925
125	995
250	1024
500	980
1000	885

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The results in table 1 were plotted as shown by figure 1

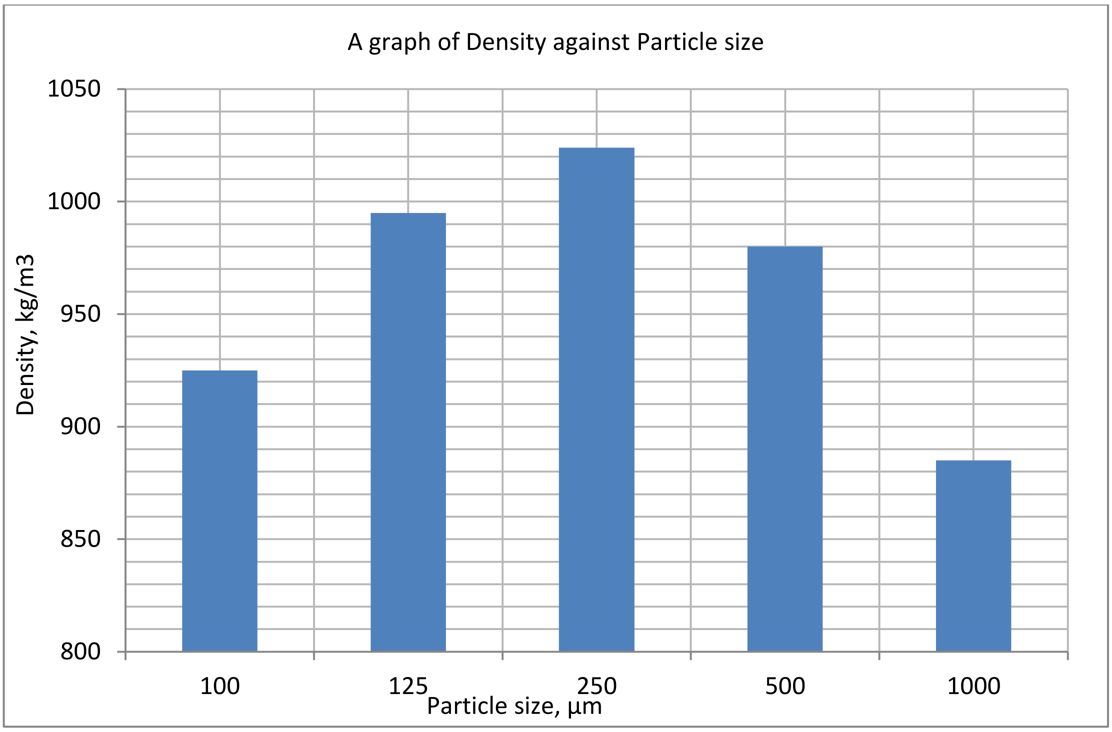

Fig. 1: Effect of particle size of Sila sorghum stalks on density of building boards

Figure 1 shows the variation in density between 1024kg/m^3 and 885kg/m^3 as the size of Sila sorghum stalks is varied between 100 to 1000µm. Small particles have a tendency to fit into almost all available free space within the bulk of the composite. This leads to a low porosity which results in high bulk density. On the other hand, large particles tend to allow larger pore spaces in between them that are filled with air. This results into a less dense building board with a lower bulk density. However there is an optimum size which allows for closer packing of the blended materials leading to low void space and high density. In this study the size of Sila sorghum stalk particles that resulted in high density (1024kg/m^3) was 250µm. A low density is an indication of high porosity caused by high void/empty space within the structure of the building board [9].

3.2 Effect of particle size of Sila sorghum stalks on the compressive strength of the building board

The results of the effect of the size of Sila sorghum stalks on compressive strength of the building boards are shown in table 3.2.

Table 3.2: Effect of particle size of Sila sorghum stalks on compressive strength of building boards

Particle size (µm)	Compressive Strength, MPa
100	18.1
125	18.3
250	20.5
500	19.7
1000	17.9

The results in table 3.2 were plotted as shown in figure 2

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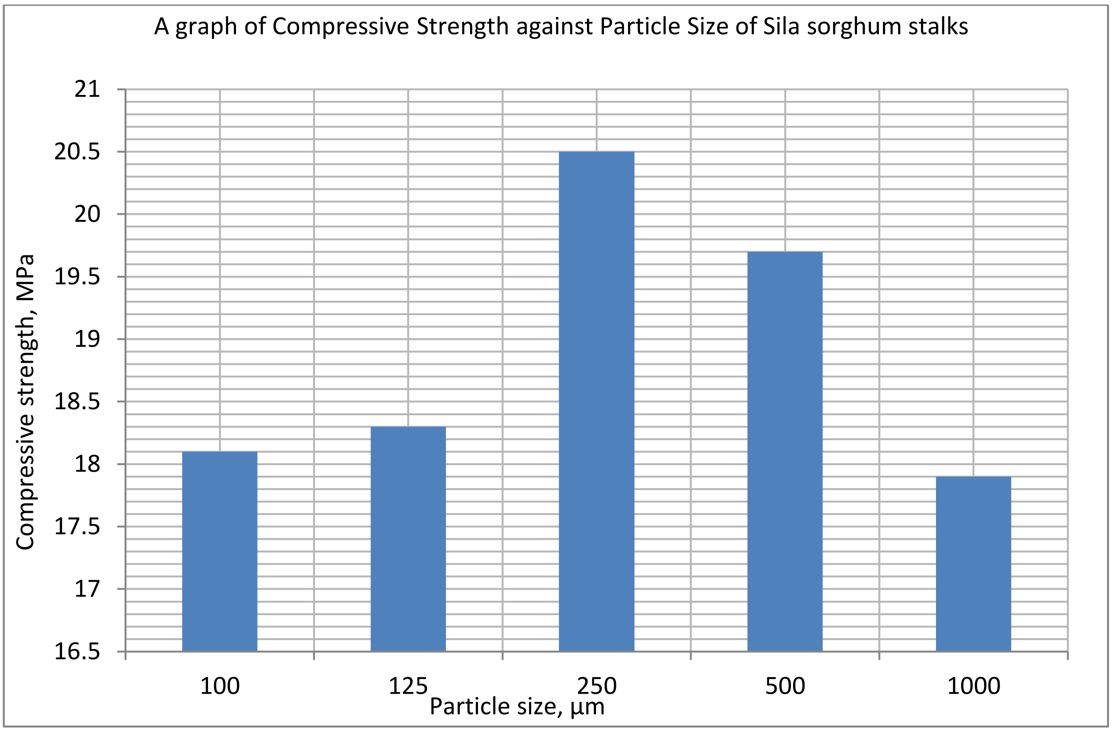

Fig. 2: Effect of particle size of Sila sorghum stalks on the compressive strength of building boards

Figure 2 shows the effect of particle size on compressive strength of the building boards. The maximum compressive strength is achieved at a particle size of 250µm. The small particle diameter offers a large surface area of contact between the HDPE and Sila sorghum stalks. This leads to stronger interaction between these two materials which results in stronger building boards. On the other hand, bigger particles lead to the formation of flaws within the building board which result in large spaces (void space) which are filled with air. This contributes to low compressive strength since less energy is required to disintegrate a building board consisting of large sized particles due to easy of crack propagation. Large sized particles reduce the degree of interaction between the HDPE and Sila sorghum stalks thus reducing the compressive strength. In addition, the presence of molasses (coupling agent) improved the interfacial interaction between the HDPE and Sila sorghum stalks molecules which resulted to higher compressive strength. Finally the amount of lignin found in Sila sorghum stalks is substantial (table 1). This contributed to additional binding of the matrix and filler further contributing to high compressive strength of the boards.

3.3 Water absorption test

The result of this test showed a 2.85% change in weight after immersing the test piece in water which indicates that the building boards are highly water resistant. This is a good property for the building boards because when used as ceiling boards, they will not deteriorate when they came into contact with rain water in situations where the roofing material is leaking. Leakage of rain water through faulty roofing material is a common problem in most buildings. This normally affects the durability and appearance of ceiling boards manufactured using wood chips or saw dust and a binder (particle boards). The minimal (2.85%) change in weight which is an indication of water absorption by the test piece can be attributed to the presence of voids within the structure of the test piece and the tendency of Sila sorghum stalks present in the test piece to absorb water (hydrophilic). In addition, the minimal percentage water absorption is an indication of low number of voids which are small in size. According to [10], water is absorbed by the Sila sorghum stalks found in the board and the amount of water absorbed increases as the amount of Sila sorghum stalk content in the board increases [3]. Sila sorghum stalks provide water residence sites within the board [10] due to its hydrophilic nature. Reference [10] concluded that the water absorption in a HDPE composite reinforced with lignocellulosic filler depends on the quantity of cellulosic filler in the composite, permeability and orientation of the filler, number of voids present and the surface area of the composite exposed to water. Water absorption is also affected by the particle size of filler since it has an effect on the porosity of the boards.

3.4 Thickness Swelling

The trend of thickness swelling follows that of water absorption. These two properties are related in that the more water is absorbed, the higher is the thickness swelling. According to [9] when the amount of molasses (coupling agent) increases, the interaction between the HDPE and Sila sorghum stalks is stronger which leads to a reduction in the amount of water absorbed due to less void spaces which normally accommodate water. In this study, the thickness swelling was established to be 3.4%. This was lower than 7.4% to 36.3% reported in [10]. This can be attributed to the difference in the properties and amount of filler used in the study in addition to the ability of the coupling agent (molasses) to resist water penetration by maintaining its binding property.

4. CONCLUSION & RECOMMENDATION

4.1 Conclusion

The need for alternative building materials has generated interest in composites. The manufacture of composites requires reinforcing materials. Cellulosic materials are increasingly being used as reinforcing materials in many composites because they are cheap, easily available, renewable and sustainable. Sila sorghum stalks are promising fillers for use in composites because they are cheap and are available in abundance in Kenya. On the other hand, HDPE has good chemical and abrasion resistance, excellent processing properties such as low melting point and ability to allow repeated processing through recycling. Molasses is a complex mixture of many compounds. Some of these compounds have polar ends and others have non polar ends. This characteristic allows molasses to blend well with the Sila sorghum stalks which are polar and the waste HDPE which are non-polar. Composite materials need stronger bonds which in turn improves their mechanical properties. Coupling agents provides the required chemical interface between the HDPE and Sila sorghum stalks. Finally, molasses prevents the formation of lumps when HDPE/Sila sorghum stalk mixture is being heated. This leads to the formation of a uniform mixture of HDPE/Sila sorghum stalks/molasses resulting in a stronger building board after curing. This research study investigated the potential of waste HDPE and Sila sorghum stalks as raw materials for the production of building boards using molasses as the coupling agent. The following conclusions were drawn for the study.

1. Sila sorghum stalks improved the density of HDPE when used as filler.
2. The building boards manufactured using waste HDPE and Sila sorghum stalks are able to resist water penetration and do not undergo significant changes in thickness when subjected to moisture.
3. The building boards manufactured using waste HDPE and Sila sorghum stalks are of sufficient compressive strength.

4.2 Recommendation

The following studies have been proposed in order to fully understand the performance of the waste HDPE and Sila sorghum stalks building boards.

1. A study on the biodegradability of the boards. This will help to inform decisions on appropriate disposal methods.
2. Investigating the morphology of the building boards produced using a scanning electron microscope in order to study the dispersion of HDPE and Sila sorghum stalks.
3. Establishing the thermal conductivity of the building boards produced from waste HDPE and Sila sorghum stalks using molasses as the coupling agent.
4. Optimization of the amount of Sila sorghum stalks filler and molasses coupling agent that can be incorporated in the boards for optimum mechanical and chemical properties.

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