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Determination of Combustion Efficiency and Compressive Stress of Cotton Stalk Charcoal and Agricultural Wastes

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Abstract - Investigation on the burning efficiency and compressive stress properties of cotton stalk charcoal and agricultural wastes was carried out on nine sets of briquettes from three different source of agricultural wastes. Cassava starch was used as binding agent, and calcium hydroxide Ca (OH)2 as desulphurizer. By the use of compressive machine model EL-31-34010 compressive strength of the briquettes was determined as 155.9, 113.5, 114.5, 46.7, 97.6, 89.1, 97.6, 89.1, and 113.5 KN/m^2 for Cotton stalk charcoals, millet chaffs, and rice husks of Biu, Nganzai, and Zabarmari in Borno state labelled as:A1, B1, C1, A2, B2, C2, and A3, B3, C3 briquettes respectively. A comparative water boiling tests of the briquettes against firewood was carried out. A1 boiled 5litre of water in 25 minutes, C1 in 30 minutes,, B1,C3 in 35 minutes, B2,A3 in 40 minutes, C2, B3 in 45 minutes, A2 in 50 minutes, while firewood boiled the same volume of water in 60 minutes. These results revealed that such briquettes were of appreciable strength that will not crumble during combustion, and indicates their superiority over firewood in terms of combustion, quality in handling and transportation.

Keywords - Millet Chaff, Rice Husk Cotton Stalk Charcoal, Briquette.

I. INTRODUCTION

Sequel to the increasing adverse environmental impacts related to the use of conventional fossil fuels, there is strong interest worldwide in the development of technologies that exploit renewable alternative energy sources; and also, new measures to limit greenhouse gas emissions are continuously sought [1], Biomass, a naturally abundant domestic energy source is seen as the most promising energy alternative to mitigate greenhouse gas emissions [4].

Fuel is defined as natural or artificial organic substance used as source of energy and raw material for industries [12]. Fuel briquettes produced under different conditions have been reported to have different handling characteristics. These characteristics are also found to be strongly affected by the raw material properties. If biomass or agro-waste briquettes are to be used efficiently and rationally as fuel [3]. All kinds of fuel as regards their state of aggregation are divided into solid, liquid and gaseous and as regards their origin into natural and artificial fuels [9]. In most developing countries like Nigeria recycling of waste products (agricultural waste product) into useful product is rarely practice. This has led to environmental problems such as pollution resulting into refuse heap on our streets, drainage system and water ways, which has resulted to flooding on rainy days due to the blockage of the waterways. This attitude has also resulted to the outbreak of epidemic in our societies today [12].

A briquette is a block of flammable matter used as fuel to start and maintain a fire. Briquettes are produced through a process known as briquetting. This process involves the densification of loose biomass residues, such as sawdust, straw, rice husk etc, into high density solid blocks that can be used as a fuel. Common types of briquettes are charcoal and biomass briquettes. Biomass briquettes (including pellets, which are very small briquettes) replace fossil fuels or wood for cooking and industrial processes. They are cleaner and easier to handle, and cut greenhouse gas emissions [3].

The advantage of being able to transform biomass into fuel, which traditionally has low density, low heating value and high moisture content, to highly efficient fuel briquettes is being researched in briquette development [5]. A variety of sources have been used and newer ones are being explored. Interests are tailored towards using locally available materials as raw materials for briquette production in various developing countries. For instance, in Uganda, [7] demonstrated the use of groundnut shell and bagasse briquettes for cooking purposes. [8] In Ethiopia made use of coffee husks and pulp, whereas, in Thailand, [11] produced briquettes from cold densified rice straw using sawdust as a binder. In Nigeria [10], produced a multi-component briquette comprising of coal, plastics and biomass. All these authors strived to show the role of briquettes in contributing to energy supply. This research is aimed at investigating the properties of biomass briquettes for varying proportions of agricultural wastes with the aim of determining the optimum combustion characteristics in related to their compressive strength.

II. Materials And Method

A. Raw Materials

The raw materials used in this research include: Millet chaffs, Rice husks, Cotton stalk charcoals, and Cassava starch.

B. Apparatus

Triple beam balance, model: MB-2610, Compression machine model EL-31-34010, Locally fabricated briquetting machine, Laboratory thermometer, Stop watch, Mortar and pestle, Plastic basins, Aluminum kettle (2litres),Measuring cylinder(1000ml), Analytical balance sensitive to 0.1mg, Siever,), Aluminum pots, Locally fabricated stoves, Locally fabricated cylindrical mould.

C. Methods

Sample Preparation

The cotton stalks biomass were carbonized using the conventional earth kiln method as traditionally used for wood carbonization. The fully carbonized material was collected, air dried for 2 days, after which they were pulverized. Millet chaffs, and rice husks were sorted and as well pulverized into fine powder and sieved using 1mm siever. The briquettes were produced using cassava starch paste as a binder, nine sets of briquettes were produced at a formulating ratio of 4:2 (Agricultural wastes: cassava starch paste wt/wt). The various mixtures were loaded into cylindrical mould and compressed for some time, the compressed briquettes were later extruded and sun dried for a week plate 1.

Plate 1: Formed Briquettes.

III. Determination Of Compressive Strength

The compressive strength is the force required to crush or break a material [2]. In line with [5] method with slight modification the compressive strength of the briquette samples was determined using a triaxial cell compressive strength testing machine Model EL-31-34010 at the Structural Laboratory of Civic Engineering Department of Abubakar Tafawa Balewa University Bauchi, Bauchi State. Nigeria. This machine is 1000kN capacity capable of compressing non-metallic materials. It is powered by electricity, but hydraulically operated. The length and width of the briquette samples was measured and recorded. Each sample was centrally placed on the lower plate inside the machine, the plate was winded up by hand until a contact was made with the top plate, the strain dial gauge on the pillar was adjusted to zero, and the reading on the strain dials and the load in the starting position under zero compressive load was recorded. The machine is now powered on. Using stop clock the readings of the load dial were recorded at every 0.2mm and strain dial reading recorded, while others at interval of 0.4mm was taken. Loading and taking readings continue until it was certain that failure has occurred for more consecutive readings of the load dial to showed a decrease or a constant load. The machine will then be stopped and the motor is allowed to stop completely and was put into reverse until the load is taken off. The machine plate was lowered so as to enable the sample removed .The other way the machine will be switched from the mains and allowed to warm up for about 3minutes. The samples will then put on the movable bed, and the control lever applied upward to bring contact between the upper fixed bed and the movable lower bed on which the samples will be sitting on the lower base of the machine. The dial reading will be taken immediately; crack will be noticed in the briquette samples, an indication that the feedstock has been compressed. The value of the reading recorded from the machine was the strain dial force reading. The compressive strength of the samples will be calculated using the equation below. The unit will be given in KN/m^2.

$$\text{Compressive strength} = \sigma = \frac{RC_R\,(100-\varepsilon\%)}{100A_0}\times 1000\ KN/m^2$$

Where R is load dial reading, C_R is mean calibration load dial reading (2.11 Div.) constant, A_0 is cross sectional area = $\pi D^2/4$, D is diameter of briquette (mm), ε is the strain of sample =σ, ε% = DL/L_0, DL is change in length of sample at compression, and L_0 is initial length of sample before compressed [2].

IV. Water Boiling Test

The method adopted by [12] was followed with slight modification. The water boiling test is a test, which has been used to test the combustion characteristic of briquette. It measures the time it takes a given quantity of fuel to heat and boil a given quantity of water. In this case 5kg quantity each of both briquettes and firewood were measured. 5kg each of millet chaffs labelled (A1, B1, and C1) was stacked in a fabricated stove differently one at a time, while the firewood was stacked in a different stove. Two aluminum pots containing 5 litres of water each were mounted on the stoves (one for formed briquette, and one for firewood). The stoves were ignited and as soon as the flames were stabilized for 5 minutes, a stopwatch was activated. The initial temperatures of the water were noted (31^0C) and thereafter readings were obtained at 5 minutes interval using a laboratory thermometer. The experiment was terminated after attaining boiling point of 100^0C. The pots were then remove and similar quantity of the second samples of rice husks (A3, B3, and C3) was then stacked in the stove as was done in the first experiment while firewood was stacked in the second stove and the procedure was repeated for cotton stalks charcoal (A1, B1, and C1) respectively, plate 2 indicate the water boiling test expirement.

V. Results And Discussion

The results of the strain dial reading and compressive strength for all the formed briquettes is presented on below tables 1 and 2.

Plate 2: Water Boiling tastes Experiment's

Table 1: Load Dial Readings

S/N	ΔL (mm)	A1 R(N)	B1 R(N)	C1 R(N)	A2 R(N)	B2 R(N)	C2 R(N)	A3 R(N)	B3 R(N)	C3 R(N)
1.	0	0	0	0	0	0	0	0	0	0
2.	2	4	6	5	20	27	22	27	22	6
3.	4	8	10	9	27	36	31	36	31	10
4.	6	12	14	13	31	47	36	47	36	14
5.	8	16	20	21	35	54	42	54	42	20
6.	10	23	34	35	41	68	48	68	68	34
7.	12	38	50	51	44	82	54	92	54	50
8.	14	57	66	67	44	90	58	90	58	66
9.	16	77	28	79	43	66	62	66	62	78
10.	18	87	88	89	41	52	64	52	64	88
11.	20	94	95	96	40	41	67	41	67	95
12.	22	109	100	101	39		71		71	100
13.	24	112	104	105	34		74		74	104
14.	26	130	106	107	31		79		79	106
15.	28	147	107	108	29		84		84	107
16.	30	142	102	103	27		82		**82**	102

17.	32	135	95	96	25	80	80	95
18.	34	122	82	83	23	77	77	82
19.	36	114	74	75	21	**73**	73	74
20.	38	102	62	63	19	68	68	62

Table 2: Determination of Compressive Strengths

S/N	%ε	A1 σ (KN/m²)	B1 σ (KN/m²)	C1 σ (KN/m²)	A2 σ (KN/m²)	B2 σ (KN/m²)	C2 σ (KN/m²)	A3 σ (KN/m²)	B3 σ (KN/m²)	C3 σ (KN/m²)
1.	0	0	0	0	0	0	0	0	0	0
2.	1.2	4.2	6.4	5.3	21.2	28.6	23.3	28.6	23.3	6.4
3.	2.4	10.2	10.6	9.5	28.6	38.2	32.9	38.2	32.9	10.6
4.	4.7	12.7	14.9	13.8	32.9	49.9	38.2	49.9	38.2	14.9
5.	5.9	16.9	21.2	22.3	37.1	57.3	44.6	57.3	44.6	21.2
6.	7.1	24.4	36.1	37.1	43.5	72.1	50.9	72.1	50.9	36.1
7.	8.2	40.3	53.0	54.1	46.7	86.9	57.3	86.9	57.3	53.0
8.	9.4	60.5	70.0	78.1	46.7	97.6	61.5	97.6	61.5	70.0
9.	10.6	81.7	82.8	83.8	45.6	95.5	66.6	95.5	66.6	82.8
10.	11.8	92.3	93.4	94.4	43.5	70.0	67.9	70.0	67.9	93.4
11.	12.9	99.7	100.8	101.8	42.4	52.2	71.1	52.2	71.1	100.8
12.	14.1	115.6	106.1	107.2	41.4	43.5	75.3	43.5	75.3	106.1
13.	15.3	118.8	110.3	111.4	35.9	-	78.5	-	78.5	110.3
14.	16.5	137.9	112.5	113.5	32.9	-	83.8	-	83.8	112.5
15.	17.6	155.9	113.5	114.6	30.8	-	89.1	-	89.1	113.5
16.	18.8	150.1	108.2	108.8	28.6	-	86.9	-	86.9	108.2
17.	20.0	143.2	100.7	101.8	26.5	-	84.9	-	84.9	100.7
18.	21.2	129.4	86.9	88.1	24.4	-	81.7	-	81.7	86.9
19.	22.4	120.9	78.5	79.6	22.3	-	77.4	-	77.4	78.5

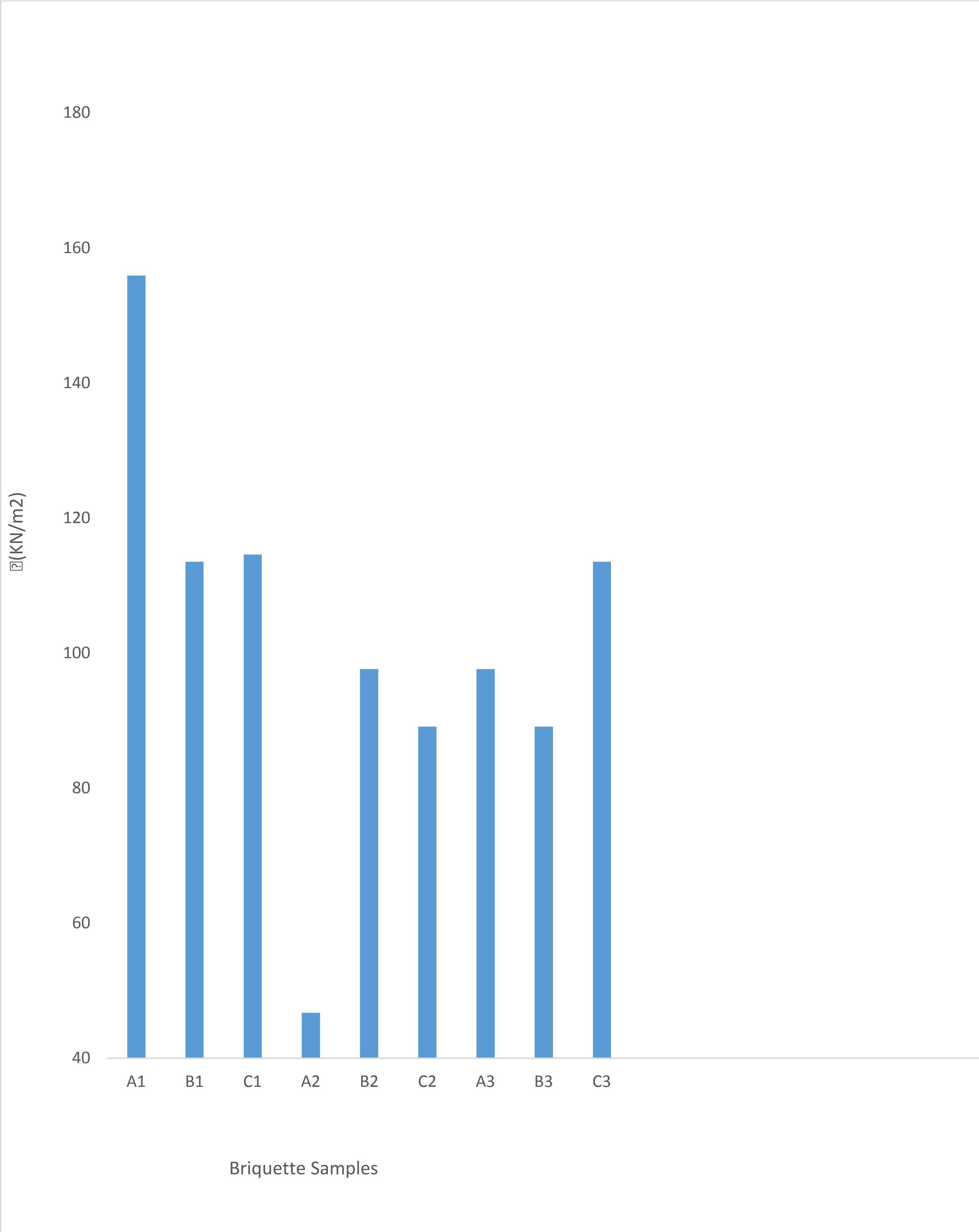

Figure 1: Bar chart showing compressive strength of sample briquettes

A. *Compressive Strength test*

Samples A1, B1 , C3 and C1 from Table 2 are observed to have the highest compressive strength of 155.9, 113.5, and 114.6 KN/m^2 respectively. This may be due to the uniform formulation and integration of particles of varying sizes as shown in figure 1. Samples A2, C2, B3, B2 and A3 have lower compressive strength of 46.7, 89.1, and 97.6 KN/m^2. Sample A1 has a higher compressive strength due to its elastic nature influenced by the presence of more gelatinous cassava starch. Sample A2 is brittle black and has the lowest compressive strength due to its particle size being larger at formulation all these are presented in figure 1. Compressive strength is one of the most important characteristics of a briquette that determines the stability and durability of the briquette [6].

B. *Water Boiling Test*

The result obtained from the water boiling test for all the nine produced briquettes are show on tables 3 to 5

Table 3: Water Boiling Test of Cotton Stalk Charcoals against Firewood

		A1	B1	C1	firewood
S/N	Time (s)	Temp (^OC)	Temp (^OC)	Temp (^OC)	Temp (^OC)
1.	0	31	31	31	31
2.	5	60	50	55	45
3.	10	0	58	65	50
4.	15	80	66	75	55
5.	20	90	4	85	60
6.	25	100	82	95	65
7.	30	-	90	100	70
8.	35	-	100	-	75
9.	40	-	-	-	80
10.	45	-	-	-	85
11.	50	-	-	-	90
12.	55	-		-	95
13.	60	-	-	-	100

Table 4: Water Boiling Test of Millet Chaffs against Firewood

		A2	B2	C2	Firewood
S/N	Time (s)	Temp (^OC)	Temp (^OC)	Temp (^OC)	Temp (^OC)
1.	0	31	31	31	31
2.	5	46	48	47	45
3.	10	52	56	54	50
4.	15	58	72	61	55
5.	20	64	78	68	60
6.	25	70	84	75	65
7.	30	76	90	82	70
8.	35	82	96	89	75
9.	40	88	100	96	80
10.	45	94	-	100	85
11.	50	100	-	-	90
12.	55	-	-	-	95
13.	60	-	-	-	100

Table 5: Water Boiling Test of Rice Husk Vs Firewood

S/N	Time (s)	A3 Temp (^{O}C)	B3 Temp (^{O}C)	C3 Temp (^{O}C)	Firewood Temp (^{O}C)
1.	0	31	31	31	31
2.	5	48	47	49	45
3.	10	56	54	58	50
4.	15	72	61	67	55
5.	20	78	68	76	60
6.	25	84	75	85	65
7.	30	90	82	94	70
8.	35	96	89	100	75
9.	40	100	96	-	80
10.	45	-	100	-	85
11.	50	-	-	-	90
12.	55	-	-	-	95
13.	60	-	-	-	100

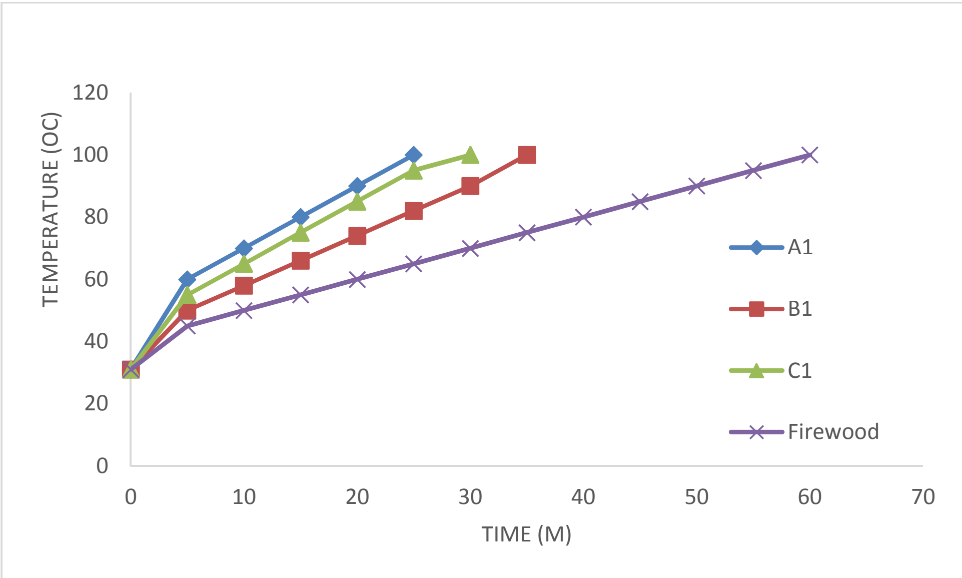

Figure 2: Burning Efficiency of Cotton Stalk Charcoals against. Firewood

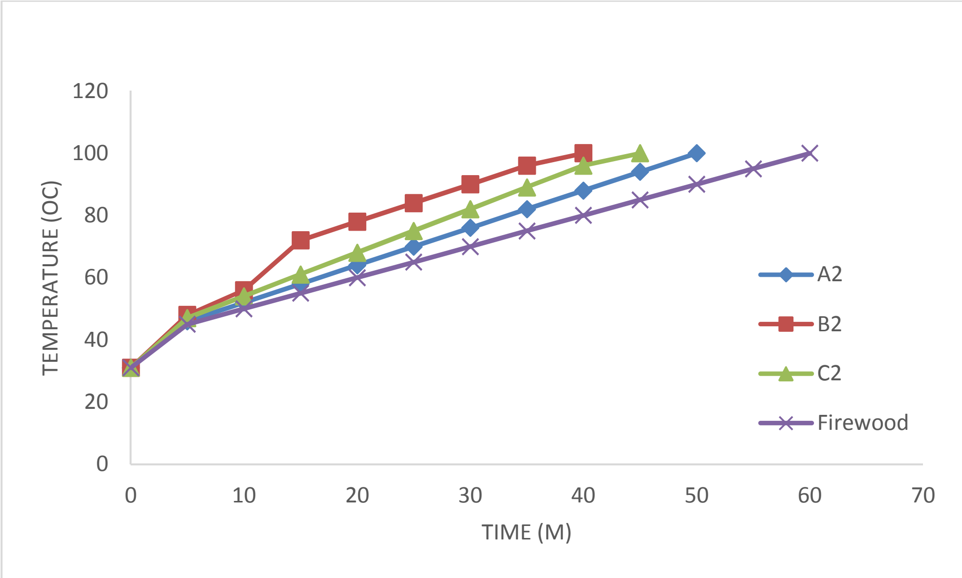

Figure 3: Burning Efficiency of Millet Chaffs against Firewood

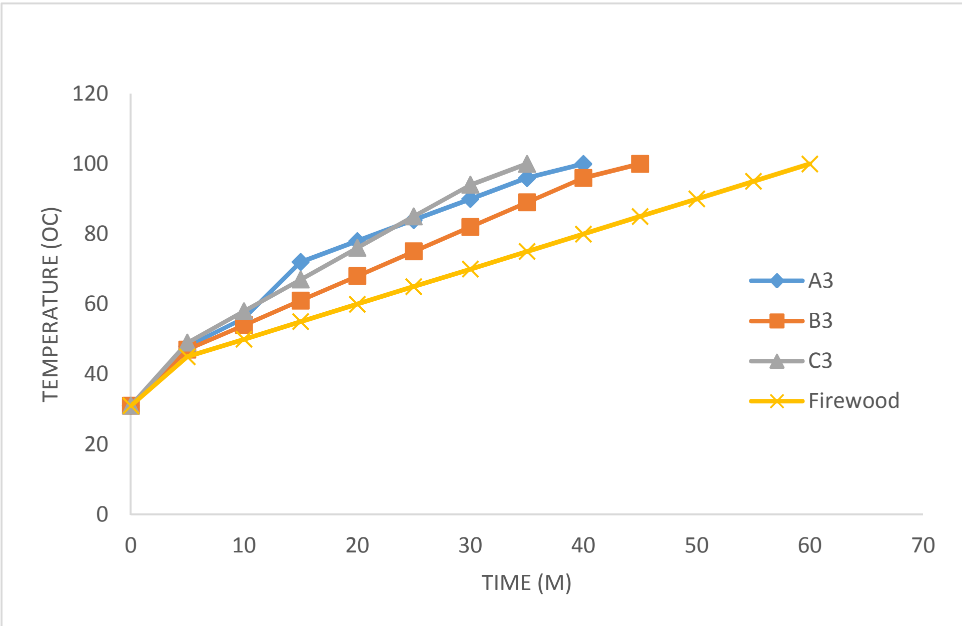

Figure 4: Burning Efficiency of Rice Husks against Firewood

Table 1 shows the variation of temperature with time for both cotton stalk charcoal briquettes and firewood. It is seen from this table that the cotton stalks charcoal briquettes (A1, B1, and C1) attained a temperature of 100 ^{0}C in 25, 40, and 30 minutes while fire wood attained 100^{0}C at 60 minute. In 0 minutes the samples and firewood all start a temperatures of 31 minutes. This indicates that A1 shows a better combustion characteristics followed by C1, then B1 compared to firewood. This clear difference can be observed from the graph of temperature versus time for all the cotton stalk charcoal briquettes (A1, B1, and C1) and firewood as shown in figure 1.

Similarly, table 2 shows the variation of temperature with time for all the millet chaffs - cassava starch briquette and fire wood both from initial temperature of 31^{0}C, it is seen from this table the millet chaffs starch briquette (A2,B2, and C2) attained a temperature of 100^{0}C in 50,40, and 45 minutes while fire wood attained a temperature of 100^{0}C at a time of 60 minutes This difference can also be observed from the graph of temperature versus time for all the millet chaffs – starch briquettes and firewood as shown in figure 2. Also, table 3 shows the variation of temperature with time for all the Rice husks - cassava starch briquette (A3,B3, and C3) and fire wood both from initial temperature of 31^0C, it is seen from this table that the rice husk starch briquette (A3,B3, and C3) attained a temperature of 100^0C in 40, 45 and 35 minutes respectively while fire wood attained same temperature of 100^0C at a time of 60 minutes This difference can also be observed from the graph of temperature versus time for all the rice husk – starch briquettes and firewood as shown in figure 3.

VI. CONCLUSION

The optimum combustion characteristics of briquettes showed thermal efficiency similar to that of other biomass already used as fuel for energy generation. The high compressive strength 155.9 KN/m^2 provide a good combustibility of the briquettes. The maximum energy released was observed at 100°C for the briquettes. The time compression exerted little influence on the physical properties of the briquettes. The compaction of the wastes increases their energy density and reduces the problems associated with their disposal in the environment. Biomass wastes briquettes demonstrate potential for use as biomass fuel for energy generation.

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