Thermal Properties of Charred Bamboo as A Source of Fuel

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ABSTRACT: This paper deals with the thermal properties of charred bamboo fuel made from rawbamboo with a moisture content of 19.8%. The charring was done in aretort charring unit (kiln) usingtwo different years of the raw bamboo growth (aged three years and four years) as samples to conduct the study. In the analysis nine readings were obtained to determine its average moisture content on adry basis for both ages of charred bamboo. The average moisture content for the three year old bamboo sample on wet basis and dry basis was approximately 25.6 and 19.6%respectively. The four year old charred bamboo sample's average moisture content on a wet basis and dry basis was approximately 26% and 19.1% respectively. The three year old charred bamboo sample's average moisture content on a wet basis and dry basis was approximately 6.3% and 6.7 % respectively. The four year old charred bamboo sample's average moisture content on a wet basis and dry basis was approximately 5.6% and 5.3% respectively. Three samples for both the three and four year old charred bamboo were used to determine the thermal properties with the bomb calorimeter and its average results wereobtained. The average heat capacity for the three year old and four year old charred bamboo was5048.26 J/K and 5246.32 J/K respectively. The average calorific value for the three yearand four year old charred bamboo was31331 J/g, 7483 Cal/g and 29267 J/g, 6990 Cal/g respectively.

Keywords: Charring, Bamboo, Calorific Value and Bomb Calorimeter

1 INTRODUCTION

Bamboo is a plant of the family Gramineae (grass family), grown chiefly inwarm or tropical regions of the world [1]. The most common bamboo is *Bambusa arundinacea.*Bamboo is classified in the division of Magnoliophyta, class Lilopsida, and order Cyperales, family Gramineae [4].Bamboo is the largest grassreaching up to 100 feet (30 m). The stalks are round (rarely square), jointed, sometimes thorny, and hollow or solid with evergreen or deciduous leaves. In many places bamboo is used as wood for construction work, furniture, utensils, fiber, paper and fuel [1].

More than 70 bamboo genera with 1,000 species exist throughout the world. The global bamboo forest area extends to 25 millionhectares. Bamboo timber can be harvested every year after 4-5 years, compared to 20 to 50 years for trees. With 10-30% annual increase in biomass versus 2- 5% for trees, bamboo can yield 20 times more timberthan trees in the same area. Bamboo can be selectively harvested annually, and regenerates without replanting. Bamboo generates 30% more oxygen than trees. It helps reduce carbon dioxide gases blamed for global warming. Some bamboo sequesters up to 12 tons of carbon dioxide per hectare, which makes it an efficient replenisher of fresh air [2].The term "charring" refers to athermochemical process of incomplete combustion of raw biomass (agricultural residue or plants) when subjected to high temperature by the action of heat [3]. During charring, removal of hydrogen and oxygen is undertaken from the raw biomass, so that the remaining char is composed primarily of carbon[3].

The thermal properties of wood vary considerably with temperature. Specific heat and carbonized layers for wood is temperature dependent. The factors thataffect the burning behavior of wood will determine the charring rate. These types of factors are considered to be the following: level of radiant heat exposure; formation of charring; moisture content; species of wood; and dimensions of the wood [3].

Biomass contains stored energy, which is a versatile fuel for energy and power generation in many countries [5]-[7]. Wood remains the largest biomass energy source today and several different kinds of biomass, such as wood, chips, corn, and some types of garbage, are used to produce electricity. The biomass is converted into liquid fuels called biofuels that can power cars, trucks and tractors [5]-[18].

In Ghana, biomass use forms 60% of the energy source equivalent to crude oil. This massive biomass usage as fuel has contributed to 30% of Ghana deforestation. The demand for charcoal as afirewood source of energy has gone up. This stems from the fact that Ghanaian citizens have and are attaining higher economic status. They are shifting from old ways of smoky three stone fire places to some form of modern charcoal stoves, which areless smoky [21].These groups of people are in the urban areas of Ghana where smoky cooking is somewhat frowned upon. There is an increase in charcoal usage while the use of firewood is decreasing [3].

2.MATERIALS AND METHODS

2.1 Collection of Bamboo Samples

The raw bamboo charcoal is made of bamboo culms, which is sliced into 5 cm pieces by a hand saw. The cut bamboo is put in a metal saggercovered with graphite flakes and is airtight sealed. The sealed sagger is put in a gas kiln fired to 650°C for 4 hours [19]. The sagger with charred bamboo samples in the kiln were taken out when the temperature was below 40°C. The moisture content of the raw bamboo were 15%-21%by air drying before loading into the kiln [4].

The thermal properties were conducted at the Cookstove Expertise Laboratory (C-Lab), TCC-KNUST with the Bomb Calorimeter. Samples of approximately 1.000 grams of each charred bamboo of aged three and four years were weighed and conducted three times for both heat capacity and specific calorific value respectively.

2.2 Preparation of Charred Bamboo

An average dimension of 8cm*6cm*2cm of thethree and four year uncharred bamboo was used to conduct the experiment respectively. The uncharred bamboo of thickness of 8cm were cut and placed in a metal sagger. The moisture content of the samples was 18% and 19.3% respectively. The metal sagger was filled with graphite, made airtight and placed in a laboratory gas furnace. The samples in the airtight metal sagger werefired to 600 degrees Celsius.

2.3 Determination of the Weight of the Samples and Moisture Content on a Dry Basis and on a Wet Basis Weight

For the test physical properties such as moisture content and sample weight were essential parameters to be considered before conducting the thermal properties with the bomb calorimeter [20].

2.3.1 Weighing of the Sample

The electronic balance used to determine the various weight sample was a précised CITIZEN SCALE of model CX 265 (max: 60/220g, min: 1mg, d=0.010/0.1mg, e=1mg, Serial No. 4154452/14 Temperature range: +18℃/ +30℃). The samples were weighed in three different crucibles for each thermal analysis test. The names for identification of weighed samples for recording and used for the test are:

HCW1 = Weight of Sample One for Heat Capacity Test 1
HCW2 = Weight of Sample Two for Heat Capacity Test 2
HCW3 = Weight of Sample Three for Heat Capacity Test 3

CVW1 = Weight of Sample One for Calorific Value Test 1
CVW2 = Weight of Sample Two for Calorific Value Test 2
CVW3= Weight of Sample Three for Calorific Value Test 3

2.3.2 Moisture Content

Moisture content was determined with the aid of the Delmhorst moisture meter (J-2000) on a dry basis for nine readings for each sample.The average moisture content was obtained by summing the total moisture content and dividing by the total number of moisture readings taken. The average moisture content on a wet basis was calculated with the formula:

$$MC_{wb} = \frac{MC_{db}}{1 + MC_{db}} \dots \dots \ (1)$$

Moisture Content on a Wet Basis = MC_{wb}
Moisture Content on a Dry Basis= MC_{db}

2.4 Determination of Thermal Properties of Samples -Calorific Values and Heat Capacity.

Heat capacity and calorificvalue were the essential parameters considered for both the three year charred bamboo and four year charred bamboo sampleswith the bomb calorimeter used to determine the thermal properties [20].The formulae belowincorporatingcooling calibration value, heat capacity, calorific value and gross calorific value is used to generate the outcome of the results [22];

Cooling calibration value, Cc= nVo + (Vn-Vo)/ (Tn-To) [(To-Tn)/2+ integral value in principal period –nTo]... (2)
Vo = bucket temperature- fall speed while firing, (K/min)
Vn = bucket temperature-fall speed at final point, (K/min)
To= bucket temperature while firing, (K)
Tn = bucket temperature at final point, (K)
Integral value in principal period = existing integral value + current temperature*(time lasting for current temperature-time lasting for previous temperature)

Heat Capacity E = (1.0015*Q*m+q1+q2)/ (Tn-To+Cc)…. (3)
Q = calorific value of benzioc acid, (j/g)
m = weight of benzoic acid, (g)
q1 = calorific value of firing wire, (J)
q2 = calorific value of additives, (J)
To= bucket temperature while firing, (K)
Tn = bucket temperature at final point, (K)
C = cooling calibration value

Calorific Value, Qb,ad(MJ/kg) = [E (Tn-To+Cc) - q1-q2]/m…..(4)

Gross calorific value Qgr,ad(MJ/kg) = Qb,ad- (94.1Sb,ad +aQb,ad)……(5)

Sulfur in oxygen bomb, Sb,ad = (CXV/m-aQb,ad/60) x1.6……(6)

C = Molecule concentration of sodium hydroxide solution, about (0.1mol/L)
V = volume of sodium hydroxide solution used by titration, (mL)
60 = formation heat equivalent to 1mmol of nitric acid, (J)
Qb,ad = Calorific Value of determination in oxygen bomb**,** (MJ/kg)
a= calibration coefficient of nitric acid:
when, Qb≤16.70MJ/kg, a=0.0010
when,16.70MJ/kg<Qb>25.10 MJ/kg, a=0.0012
when, Qb>25.10 MJ/kg, a=0.0016

Below is the procedure for the bomb calorimeter to determine the thermal properties [22].

- Measuring the weight of sample in a crucible on an electronic balance.
- Connecting an electrode across the terminals of the crucible holder to enable the flow of electrons resulting in combustion.
- Distilled water of 0.5mL is poured into the oxygen bomb cylinder to serve as a coolant during combustion thus high heat generation.
- The holder is placed into the cylinder and covered and3 MPa pressure of oxygen is supply into the system for about 10 seconds to close the circuit to aid the combustion.

- The oxygen bomb is placed into a bomb calorimeter and covered to initiate the process.
- After about 4 to 5 minutes the process would be ready for either heat capacity or calorific value determination.
- The results are automatically determined from a software programme connected to the bomb calorimeter to analyze the sample's thermal properties,beingheat capacity and calorific value.

3.0RESULTS AND DISCUSSION

During the analysis of the physical properties weights of 1.0283g, 1.0286g, 1.0289g and 1.0257g, 1.0254g, 1.0255 g was used for the heat capacity of the threeyear old charred bamboo and fouryearold charred bamboo respectively.

3.1 Moisture Content (MC)

The table below indicates the moisture readings on a dry basis (bd) and wet basis (wb);

3.1.1 Moisture Content (MC) Reading for Three Year Old Charred Bamboo

Table 1: MC of the 3 year Charred Bambooon db

6.7%	**6.8%**	**6.8%**
7.3%	6.1%	7.1%
6.4%	6.8%	6.1%

Source: Obed Nenyi Otoo and Michael Commeh

Table 2: Total and Average Moisture Content

Total MC(db)	60.1%
Average MC(db)	6.7%
MC(wb)	6.3%

Source: Obed Nenyi Otoo and Michael Commeh

Table 1 indicates the nine readings of the moisture content (MC) on a dry basis (db) obtained from theDelmhorst moisture meter (J-2000); while Table 2 indicates the total moisture content on a dry basis (db), average moisture content on a dry basis and moisture content on a wet basis of 3 year oldcharred bamboo (60.1%, 6.7% and 6.3% respectively).

3.1.2 Moisture Content (MC) Reading of the Four Year Old Charred Bamboo

Table 3:MC of the 4 year Charred Bamboo on db

7.0%	**6.1%**	**6.4%**
6.2%	5.9%	6.1%
6.1%	6.4%	6.5%

Source: Obed Nenyi Otoo and Michael Commeh

Table 4:Total and Average Moisture Content

Total MC(db)	50.3%
Average MC(db)	5.6%
MC(wb)	5.3%

Source: Obed Nenyi Otoo and Michael Commeh

Table 3 indicates the nine readings of the moisture content on a dry basis (db) obtained from the Delmhorst moisture meter (J-2000); andTable 4 indicates the total moisture content on a dry basis (db), average moisture content on a dry basis and moisture content on a wet basis of 4 year old charred bamboo (50.3%, 5.6% and 5.3% respectively).

3.2 Heat Capacity for the Charred Bamboo

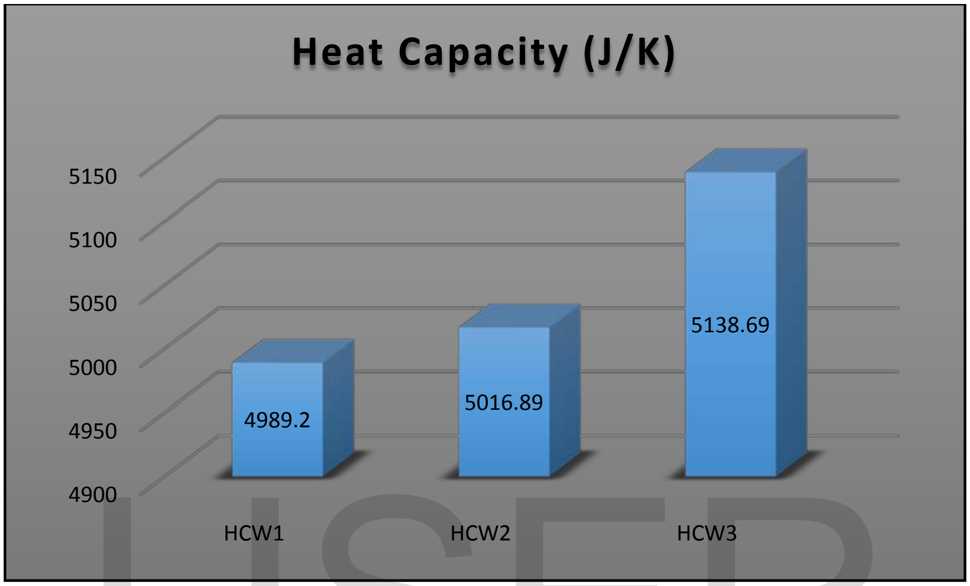
Table 5:Three Year Old Charred Bamboo Heat Capacity Parameters

Test No	Sample Weight	Heat Capacity, EE (J/K)	Vo (K/min)	Vn (K/min)	To (℃)	Tn (℃)	Duration ofthe Test (minutes)	Temperature Rise (K)	Cc (K)
HCW1	1.028	4989.20	-0.0758	-0.0405	33.6515	39.3258	3.66	5.6743	-0.2055
HCW2	1.028	5016.89	-0.0819	-0.0466	33.3732	39.0414	3.66	5.6682	-0.2280
HCW3	1.028	5138.69	-0.0795	-0.0451	33.7653	39.2980	3.63	5.5237	-0.2199
Mean Value	**1.028**	**5048.26**					**3.65**	**5.6221**	

Source: Obed Nenyi Otoo and Michael Commeh

Table 5 indicates the values for theweight of the sample; heat capacity;bucket temperature- fall speed while firing; bucket temperature-fall speed at final point;bucket temperature while firing; bucket temperatures and duration taken for the sample to combust; and the temperature rise during the test for the three samples. The mean value for the heat capacity was 5048.26 J/K with its test duration and temperature rise of 3.65 and 5.6221 respectively.

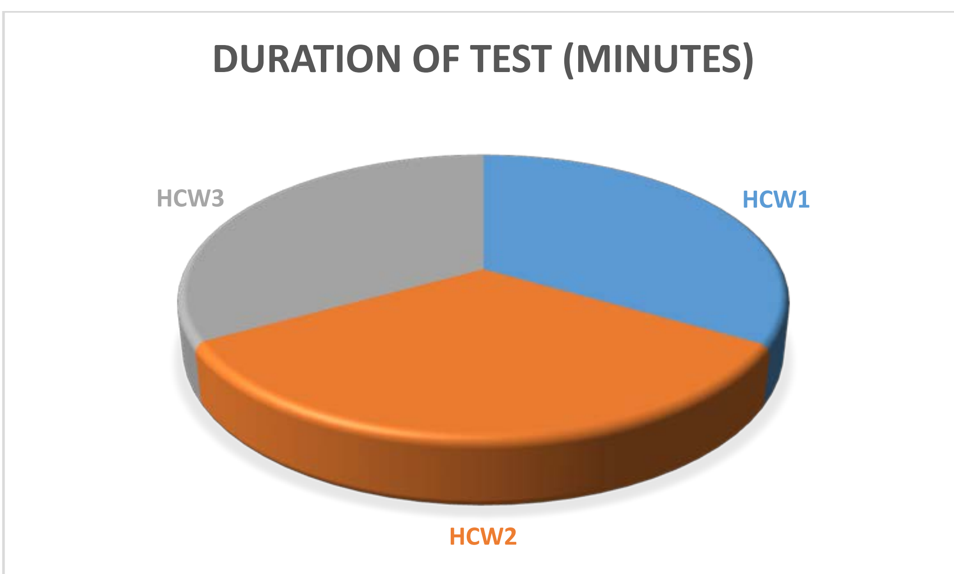
Figure 1: Heat Capacity Generated after Combustion of the Samples



Source:Michael Commeh and Obed Nenyi Otoo

Figure 1 shows the graphical representation of the three samples used to determine theheat capacity for the threeyear old charred bambootest.From the graph, the heat capacity of sample HCW1, HCW2 and HCW3 is 4989.20, 5016.89 and 5138.69 respectively. The average heat capacity for the three tests conducted is 5048.26 for the three year old charred bamboo sample.

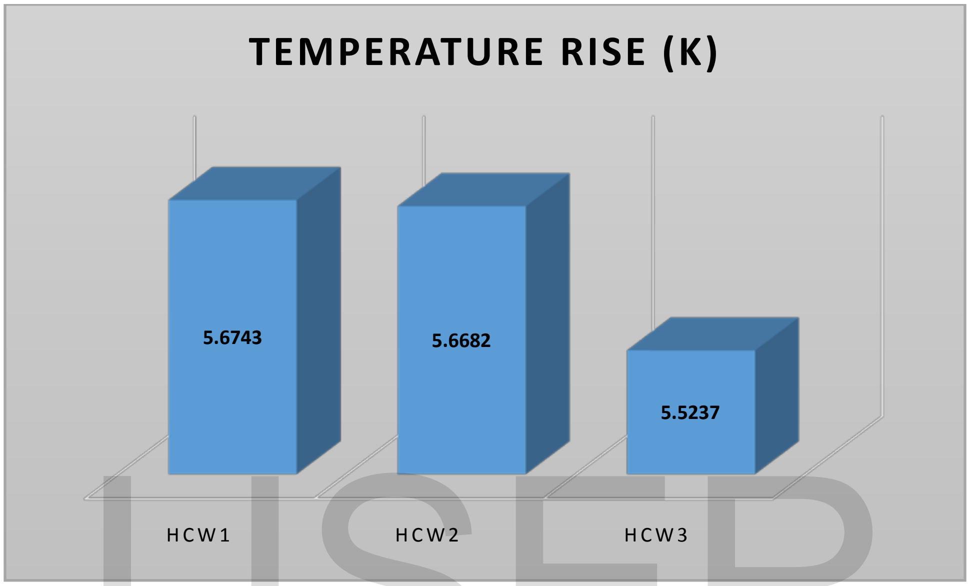
Figure 2: Duration for the Samples to be CombusteddduringTesting



Source: Michael Commeh and Obed Nenyi Otoo

Figure 2 indicates the duration taken for the sample of the three year charred bamboo to undergo combustion in the bomb calorimeter. It shows that samples HCW1 and HCWI undertook the same combustion time of 3.66minutes and sample HCW3 indicates a combustion time of 3.63 minutes.

Figure 3: Temperature Rise Variations of Samplesduring the Test



Source: Michael Commeh and Obed Nenyi Otoo

Figure 3 indicates the temperature rise within the bomb calorimeter during the test. Sample HCW1 shows a higher rise in temperature comparatively followed by HCW2 and HCW3. This indicates the temperature variation for each three sample for the 3 year charred bamboo test on heat capacity.

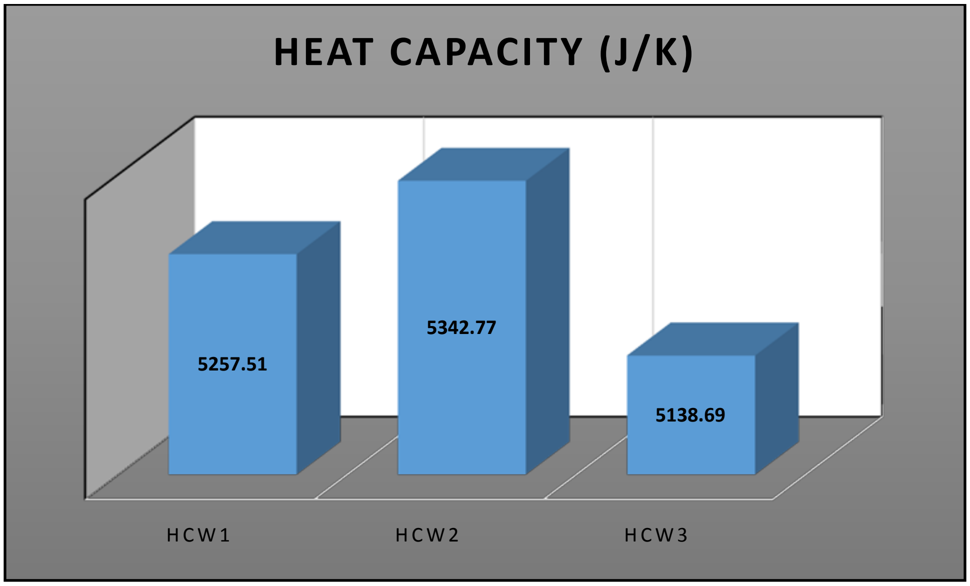
Table 6: FourYear Old Charred Bamboo Heat Capacity Parameters from the Bomb Calorimeter

Test No	Sample Weight	Heat Capacity, EE (J/K)	Vo (K/min)	Vn (K/min)	To (°C)	Tn (°C)	Duration ofthe Test (minutes)	Temperature Rise (K)	Cc (K)
HCW1	1.025	5257.51	-0.0776	-0.0441	33.7264	39.1123	3.55	5.3859	-0.2093
HCW2	1.025	5342.77	-0.0832	-0.0500	33.443	38.7730	3.66	5.3287	-0.2362
HCW3	1.025	5138.69	-0.0795	-0.0451	33.7653	39.2980	3.63	5.5237	-0.2199
Mean Value	**1.025**	**5246.32**					**3.61**	**5.4127**	

Source: Michael Commeh and Obed Nenyi Otoo

Table 6 indicates the values of the weights of the sample; heat capacity;bucket temperature- fall speed while firing; bucket temperature-fall speed at final point;bucket temperature while firing; bucket temperatures and duration taken for the sample to combust; and the temperature rise during the testsofthe three samples. The mean value for the heat capacity is 5246.32 J/K with its mean test duration and temperature rise of 3.61 and 5.4127 respectively.

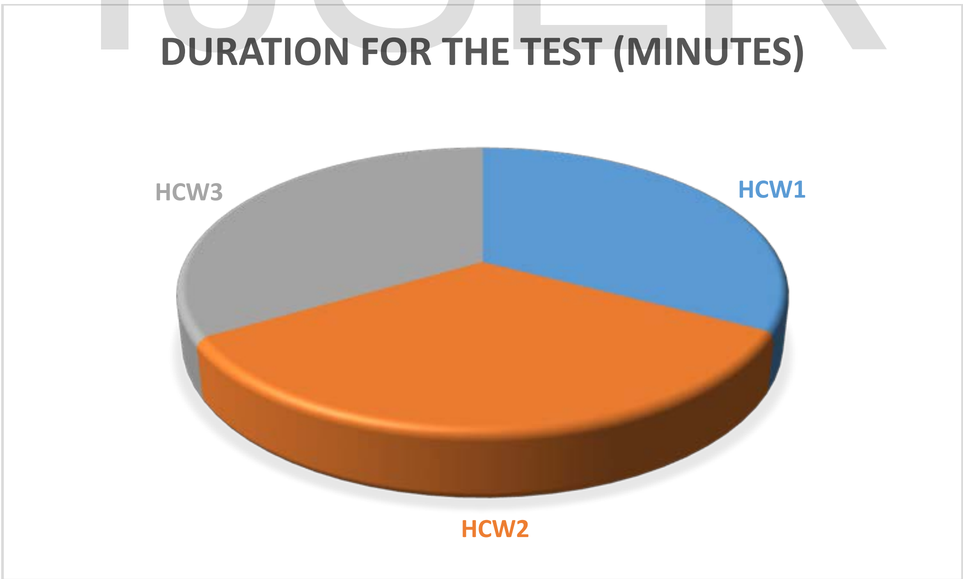
Figure 4: Heat Capacity Generated after Combustion of Samples



Source:Michael Commeh and Obed Nenyi Otoo

Figure 4 shows the graphical representation of the three samples used to determine the heat capacity for the fouryear old charred bamboo tested. From the graph,the heat capacity of samples HCW1, HCW2 and HCW3 was 5257.51, 5342.77 and 5138.69 respectively. The average heat capacity for the three tests conducted is 5246.32 for the four year old charred bamboo samples.

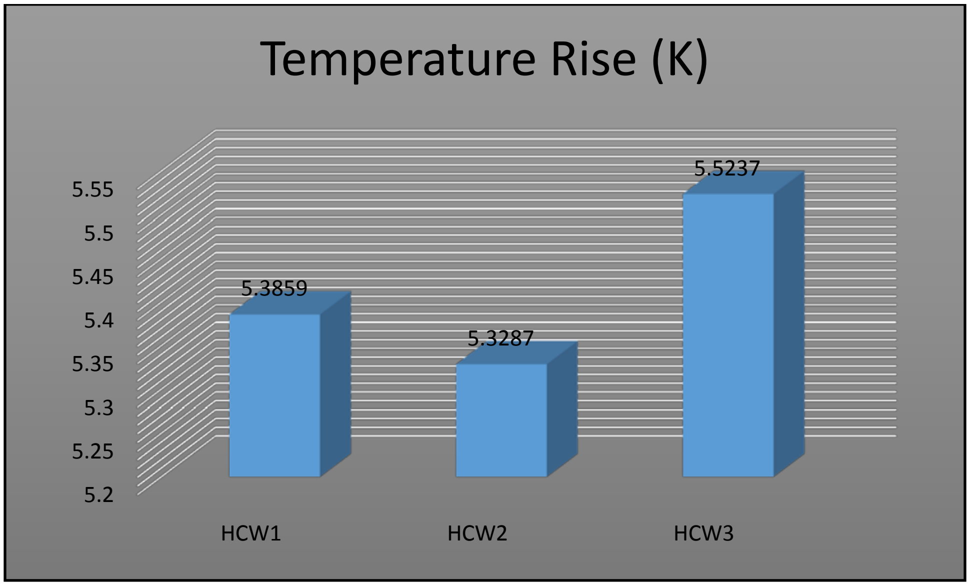
Figure 5: Duration requiredfor the Samples to be Combusted duringTesting



Source: Michael Commeh and Obed Nenyi Otoo

Figure 5 indicates the duration taken for the sample of four year old charred bamboo to undergo combustion in the bomb calorimeter. It shows that the duration required for combustion for each test conducted forsamples HCW1, HCW2 and HCW3 was3.55, 3.66 and 3.63 respectively. It depicts that HCW2 requiredthe longest duration for combustion.

Figure 6: Temperature Rise Variations of Samplesduring the Test



Source: Michael Commeh and Obed Nenyi Otoo

Figure 6 indicates the temperature rise within the bomb calorimeter during the test. Sample HCW1 shows a higher rise in temperature comparatively followed by HCW2 and HCW3. This indicates the temperature variation generated for each of the three tests conducted onthe four year old charred bamboo sample hence indicating the heat capacity readings for each test on the sample.

Calorific Value (Qb,ad) for the Charred Bamboo

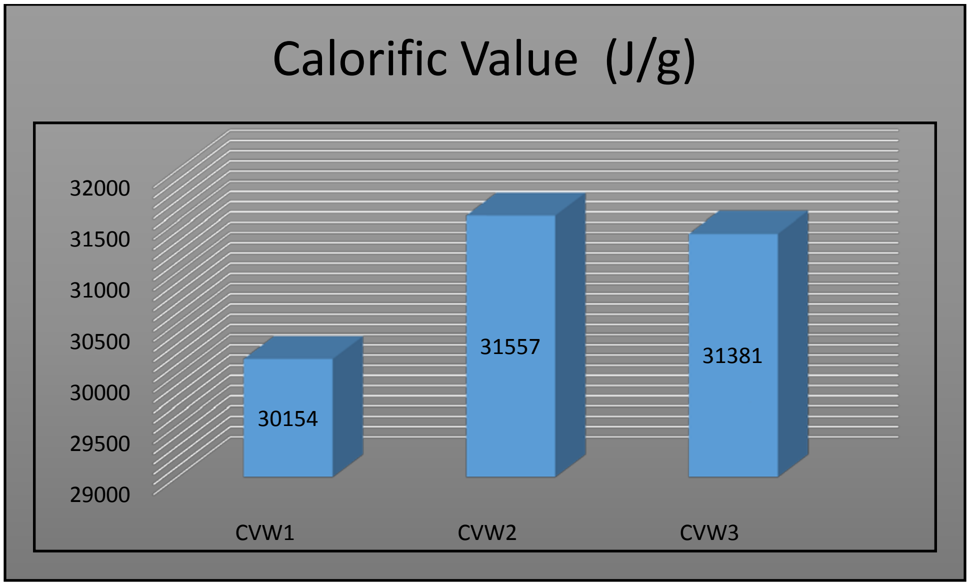
Table 7: Calorific Values for Three Year Old Charred Bamboo Samples

Test No	Sample Weight	Qb,ad (J/g)	Qb,ad (Cal/g)	Qb,ad (MJ/kg)	To (°C)	Tn (°C)	Duration ofthe Test (minutes)	Temperature Rise (K)	Cc (K)
CVW1	1.057	31054	7417	31.05	33.625	39.420	3.49	5.7950	-0.2078
CVW2	1.057	31557	7537	31.56	32.947	38.7934	3.75	5.8461	-0.2298
CVW3	1.057	31381	7495	31.38	32.991	38.716	3.83	5.7247	-0.1957
Mean Value	**1.057**	**31331**	**7483**	**31.33**			**3.69**	**5.7886**	

Source: Michael Commeh and Obed Nenyi Otoo

Table 7 indicates the values of the weight of the sample; calorific value;bucket temperature- fall speed while firing; bucket temperature-fall speed at the final point;bucket temperature while firing; bucket temperatures and duration taken for the sample to combust; and the temperature rise during the testsofthe three samples. The mean value for the calorific value is 31331 J/g, 7483 Cal/g and 31.33 MJ/kg with its mean test duration and temperature rise of 3.69 and 5.7886 respectively.

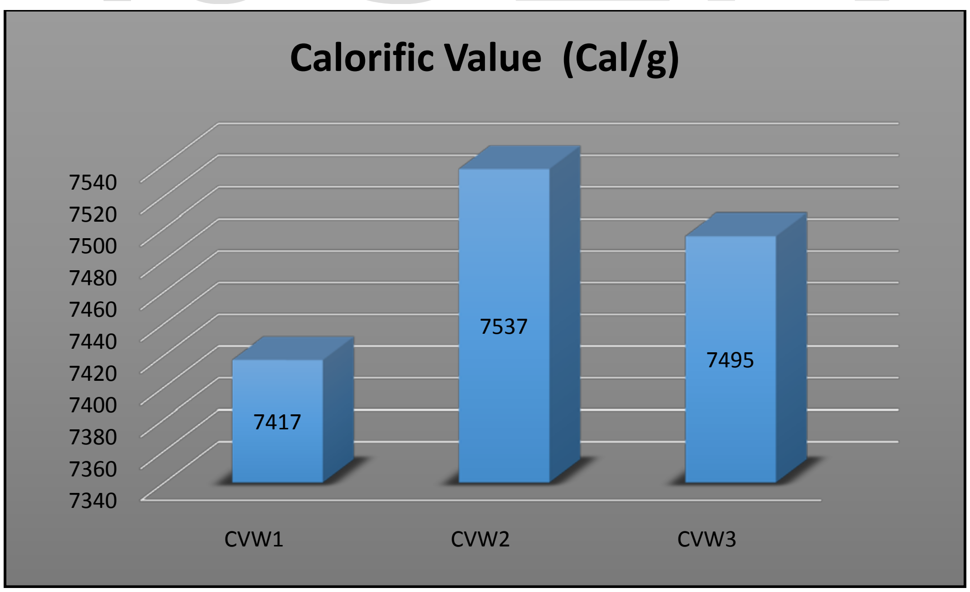
Figure 7: Calorific Values Generated after Combustion of the Samples in Joules per Grams



Source: Michael Commeh and Obed Nenyi Otoo

Figure 7shows the graphical representation of the three samples used to determine the calorific value, (J/g) for the threeyear old charred bamboo tests.From the graph,the calorific values of samplesCVW1, CVW2 and CVW3 corresponds to 30154J/g, 31557J/g and 31381J/g respectively. The average calorific value in J/g for the three tests conducted is 31331J/g for the three year old charred bamboo samples.

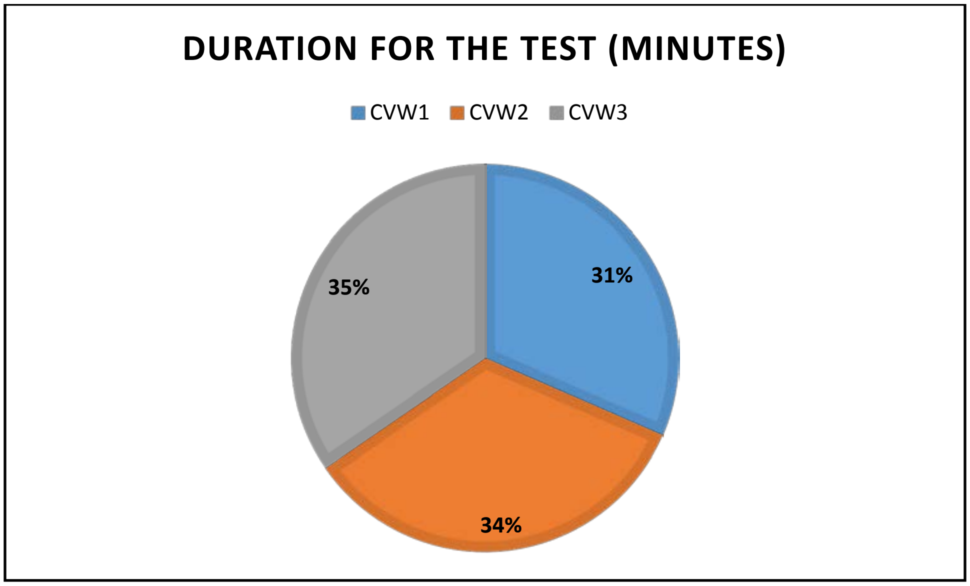
Figure 8: Calorific Values Generated after the Combustion of the Samples in Calories per Grams



Source: Michael Commeh and Obed Nenyi Otoo

Figure 8shows the graphical representation of the three samples used to determine the calorific value in calories per grams (Cal/g) for the 3 year old charred bamboo. The calorific values for samples CVW1, CVW2 and CVW3 are 7417Cal/g, 7537 Cal/g and 7495 Cal/g respectively. Themean value for the tests is 7483 Cal/g

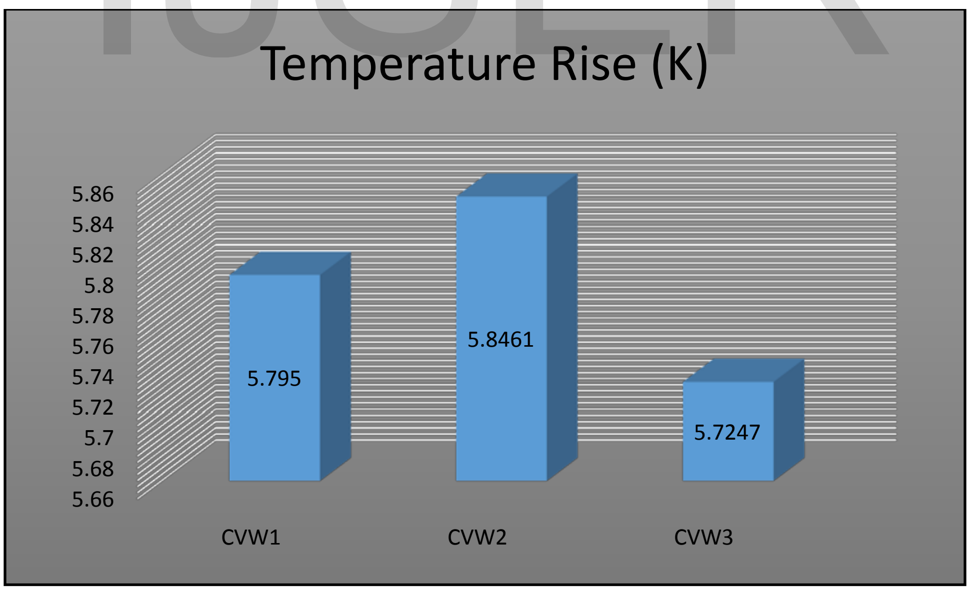
Figure 9: Time Taken for the Samples to be Combusted during Testing



Source:Michael Commeh and Obed Nenyi Otoo

Figure 9indicates the duration taken for the sample of threeyear old charred bamboo to undergo combustion in the bomb calorimeter in the determination of the calorific value. It shows that the duration for combustion for each test conducted with sample testsCVW1, CVW2 and CVW3 in percentage. It depicts that CVW5 had the longest duration for combustion.

Figure 10: Temperature Rise Variations of the Samplesduring the Test



Source: Michael Commeh and Obed Nenyi Otoo

Figure 10 indicates the temperature rise within the bomb calorimeter during the test. Sample CVW1 shows a higher rise in temperature comparatively followed by CVW2 and CVW3. This indicates the temperature variation generated for each of the three tests conducted with threeyear old charred bamboo sample in the determination of the calorific value.

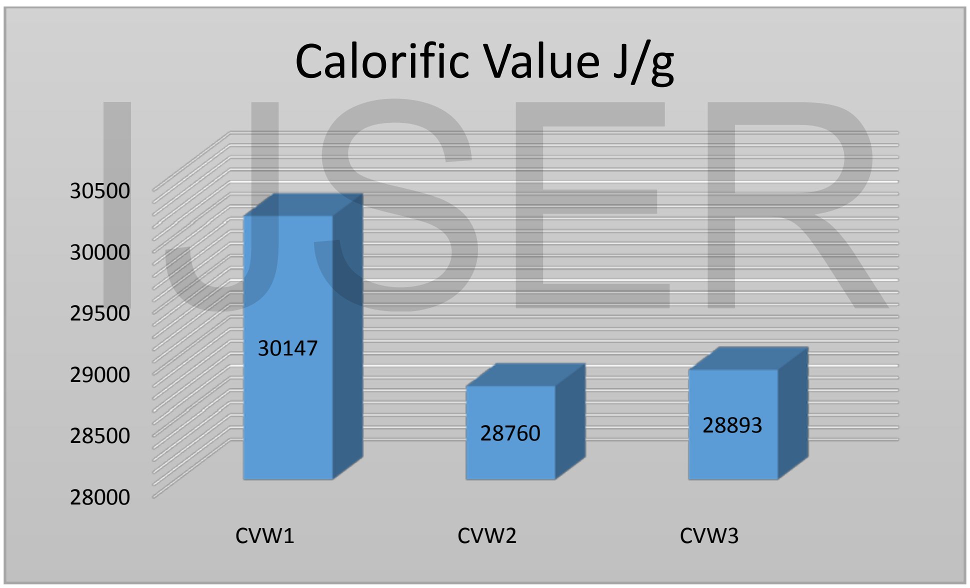
Table 8: Calorific Values for Four Year OldCharred Bamboo Samples

Test No	Sample Weight	Qb,ad (J/g)	Qb,ad (Cal/g)	Qb,ad (MJ/kg)	To (°C)	Tn (°C)	Duration ofthe Test (minutes)	Temperature Rise (K)	Cc (K)
CVW1	1.025	30147	7200	30.15	33.1043	38.5304	3.55	5.4261	-0.2244
CVW2	1.025	28760	6869	28.76	33.0445	38.2413	3.66	5.1968	-0.2318
CVW3	1.025	28893	6901	28.89	32.0836	37.3046	3.72	5.2210	-0.2345
Mean Value	**1.025**	**29267**	**6990**	**29.27**			**3.64**	**5.2813**	

Source: Michael Commeh and Obed Nenyi Otoo

Table 8 indicates the values of the weight of the sample; calorific value, bucket temperature- fall speed while firing; bucket temperature-fall speed at final point;bucket temperature while firing; bucket temperatures duration taken for the sample to combust; and the temperature rise during the test for the three samples. The mean value for the calorific value is 29267 J/g, 6990 Cal/g and 29.27 MJ/kg with its mean test duration and temperature rise of 3.64 and 5.2813 respectively.

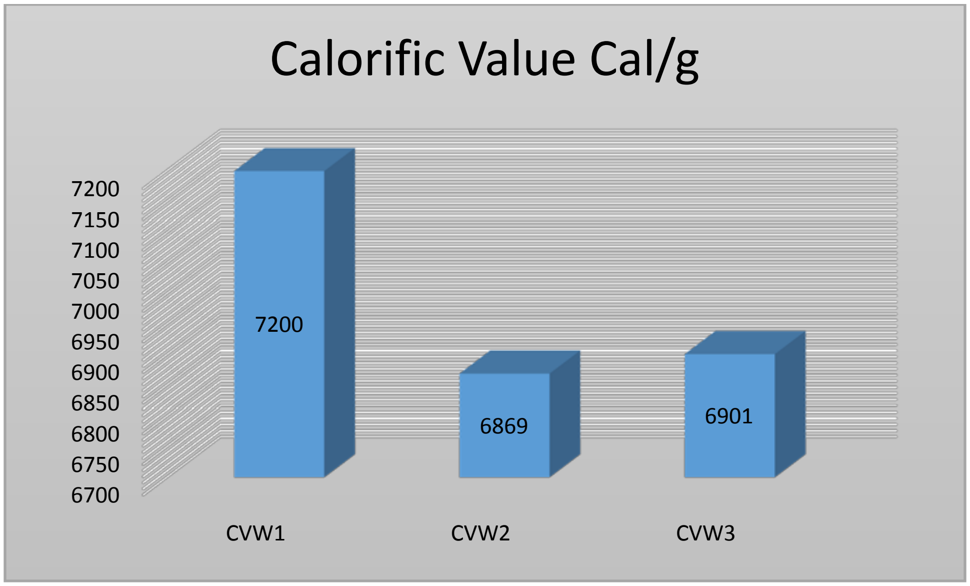
Figure 11: Calorific Values Generated after the Combustion of the Samples in Joules per Grams



Source: Michael Commeh and Obed Nenyi Otoo

Figure 11shows the graphical representation of the three samples used to determine the calorific value, (J/g) for the threeyear old charred bamboo test. From the graph,the calorific valueof samples CVW1, CVW2 and CVW3 corresponds to 30147J/g, 28760J/g and 28893J/g respectively. The average calorific value in J/g for the three tests conducted is 29267J/g for the three year old charred bamboo sample.

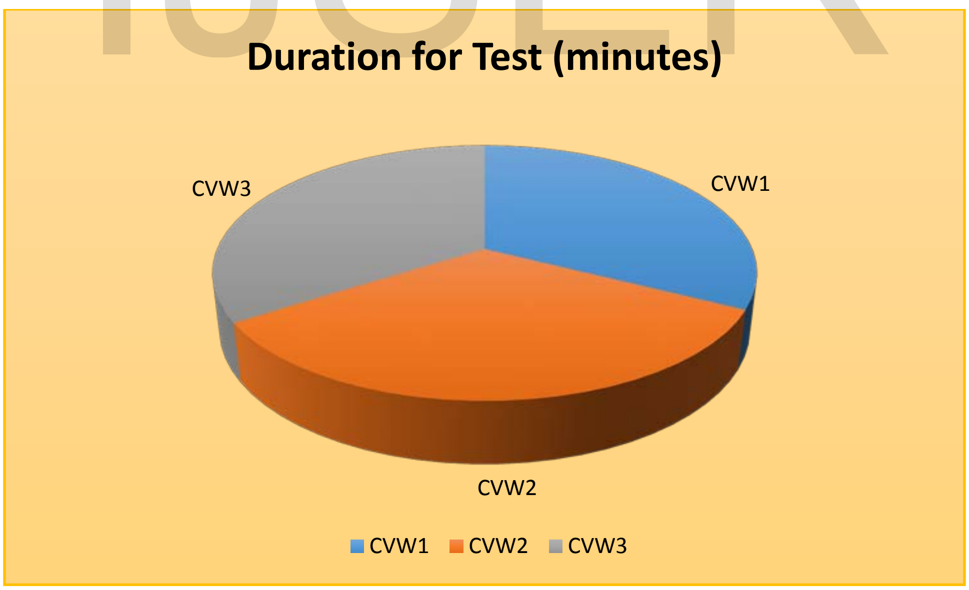
Figure 12: Calorific Values Generated after Combustion of the Samples in Calories per Grams



Source: Michael Commeh and Obed Nenyi Otoo

Figure 12 shows the graphical representation of the three samples used to determine the calorific value in calories per grams (Cal/g) for the four year old charred bamboo used to conduct the test. The calorific values for CVW1, CVW2 and CVW3 are 7200Cal/g, 6869 Cal/g and 6901 Cal/g respectively. Themean value for the test is 6990 Cal/g.

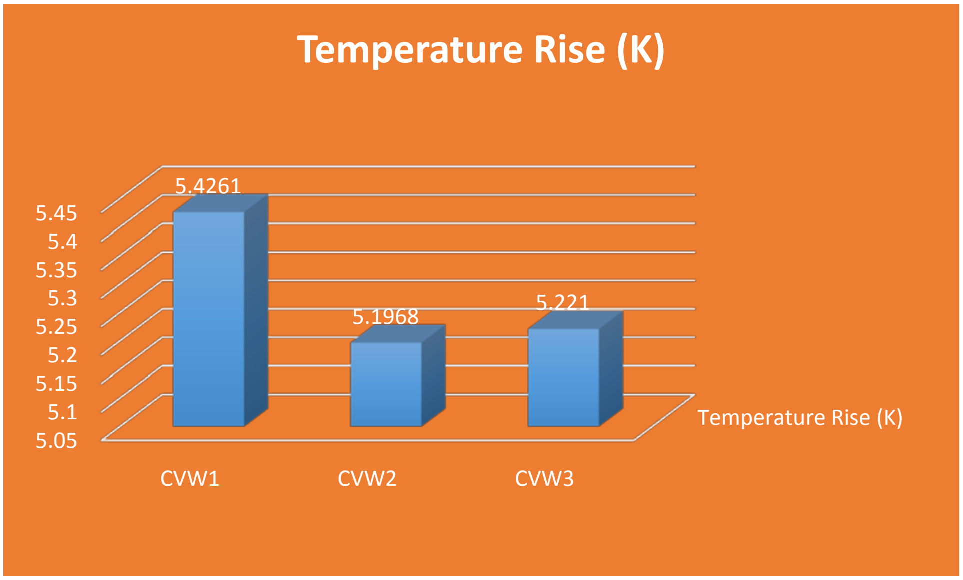
Figure 13: Time Taken for the Sample to be Combusted during Testing



Source: Michael Commeh and Obed Nenyi Otoo

Figure 13 indicates the duration taken for the sample of four year old charred bamboo to undergo combustion in the bomb calorimeter. It shows that the duration for combustion for each test conducted with sample test CVW1, CVW2 and CVW3 are 3.55, 3.66 and 3.63 respectively. It depicts that CVW2 had the longest duration for combustion.

Figure 14: Temperature Rise Variations of the Samplesduring the Test



Source: Michael Commeh and Obed Nenyi Otoo

Figure 14 indicates the temperature rise within the bomb calorimeter during the test. Sample CVW1 shows a higher rise in temperature comparatively followed by CVW2 and CVW3. This indicates the temperature variation generated for each three test conducted with four year charred bamboo sample in the determination of the calorific value. The mean value is 5.281.

4.0 CONCLUSION

The average heat capacity for the three year old charred bamboo sample and average heat capacity for the four year old charred bamboo sample are 5246.32 J/K and 5048.26J/K respectively.The average calorific value for the three year old charred bamboo sample is 31331 J/g and 7483 Cal/g.The average calorific value for the four year old charred bamboo sample is 2926 J/g and 6990 Cal/g. The average moisture content on a dry basis and a wet basis for the three year old charred bamboo sample is 6.7 %$\approx 7\%$ and 6.3 % $\approx 6\%$ respectively;andthe average moisture content of the four year old charred bamboo on a dry basis and a wet basis is 5.6%$\approx 6\%$ and 5.3% $\approx 5\%$ respectively.

ACKNOWLEDGMENT

We are very grateful to Technology Consultancy Centre (TCC) for agreeing to the usage of their first class laboratory, Cookstove Testing and Expertise Laboratory (C-Lab).

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