American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-4, Issue-8, pp-205-211
www.ajer.org
Research Paper Open Access

Compression Pressure Effect on Mechanical & Combustion Properties of Sawdust Briquette using Styrofoam adhesive as binder.

Abdulrasheed A.[1], Aroke U. O.[2], Ibrahim M.[3]
Department of Chemical Engineering
Abubakar Tafawa Balewa University, P.M.B. 0248, Bauchi state, Nigeria.

Abstract*: In this paper, briquettes were produced from sawdust at different compression pressure using Styrofoam (Polystyrene foam) adhesive as binding material. The effects of changing the compression pressure used in moulding of briquettes on its combustion and mechanical properties were investigated. In evaluating Combustion properties, 0.940kg of water was boiled using oven-dried sample of briquette in the combustion chamber with air flow velocity supplied to the combustion chamber at 10.2m/s. Combustion properties investigated were afterglow time, burning rate, specific fuel consumption, power output, percentage heat utilized, flame propagation rate and percentage ash content. The mechanical properties investigated included density, compressive strength, impact resistance, water resistance and abrasion resistance. The blends of sieved sawdust and binder were prepared in the ratio of 4:1 and compacted at pressures ranging from 40 – 90 kN/m^2 at 10 kN/m^2 interval in a hydraulic press machine with a dwell time of 5minutes. The pressures of moulding were varied to evaluate the range that gives the best quality in terms of combustion and mechanical properties of the briquette produced. The potential use of Polystyrene foam adhesive as a binder in production of briquettes was found promising.*

Keywords *- Adhesive, Briquette, compression pressure, sawdust, Styrofoam.*

I. INTRODUCTION

Sawdust can be regarded among the most abundant waste in the agricultural industries in Nigeria. The waste generated from processing of wooden products is estimated to be 15% of the total 1.72 million/m^3 wood processed [1]. Sawdust also referred to as wood dust is waste obtained from cutting, sanding, grinding, drilling and pulverizing of wood with the aid of a saw or other tools and machineries. It is a collection of small particles of wood in different sizes and mass. Sawdust is a flammable material when ignited which makes it useable as a source of fuel [2]. Based on the increase in utilization of wood resources, there is an expectation that fuel wood demand would rise to about 2.13 x 10^4 metric tonnes. As a result of this imbalance, a shift to a more sustainable and alternative energy resource is seriously needed especially in developing countries like Nigeria [3]. Thus, the use of wood or sawmill waste known as sawdust as an alternative energy source is imperative.Briquetting of biomass is defined as the compression of loose materials obtained as agricultural waste to produce a composite which is compact by pressure application [4]. Biomass are wastes or residues from agricultural products such as leaves, shells, sticks, cob, husks and straws or from industries that use bio-materials such as sawmills, plywood and furniture industries.According to Demirbas, [5] briquettes can be defined as cylinders made of compressed wood fibres that are of about 30 cm in length and have a gross calorific value of 4200kcal/kg. About 2.2 kg of briquette produces the same amount of energy during combustion as 1 litre of furnace oil. For effective utilization, the briquettes are dried properly, de-dusted and pressed into compacted form.The technology of briquetting has not been fully explored in many developing countries due to constraints in the technical ability of its production and difficulty in adopting existing technology to use local resources and conditions. As such, overcoming such challenges encountered with this technology and selecting the appropriate waste material for briquette production is very important in determining whether the production can be in commercial quantity [6].
Combustion properties of the produced briquettes analysed in this work with their respective formulae, units and sources were presented in Table 1. The same was carried out for mechanical properties as shown in Table 2.

Table 1: Test of combustion properties of Briquettes carried out.

S/N	COMBUSTION PROPERTIES	FORMULAE	UNITS	REFERENCES
1.	Afterglow Time	-	s	Kim *et al.*, 2001 [7].
2.	Percentage Heat Utilized	$\frac{m_w C_p (T_f - T_i) + m_w L}{m_b \times H_b} \times 100$	%	Ibrahim et al., 2015 [8].
3.	Power Output	$\frac{m_b \times H_b}{t}$	kJ/s	Kim *et al.*, 2001 [7].
4.	Specific Fuel Consumption	$\frac{m_b}{m_w}$	kg briquette/kg water	Ibrahim et al., 2015 [8].
5.	Burning Rate	$\frac{m_b}{t}$	kg/s	Kim *et al.*, 2001 [7].
6.	% Ash Content	$\frac{m_a}{m_b} \times 100$	%	Kim *et al.*, 2001 [7].
7.	Flame Propagation Rate	$\frac{D_b}{t}$	m/s	Ibrahim et al., 2015 [8].

KEY

- C_p = Specific heat capacity of water
- T_f = Final temperature of water
- T_i = Initial temperature of water
- L = Latent heat of vaporization of water.
- m_a= Mass of ash residue
- m_b = Mass of briquette used as fuel
- H_b = Calorific value of briquette
- m_w = Mass of water
- t = Time for flame propagation
- D_b = Graduated length of flame spread.

Table 2: Test of mechanical properties of Briquettes carried out.

	MECHANICAL PROPERTIES	FORMULAE	UNITS	REFERENCES
1.	Density	$\frac{\text{mass of briquette (kg)}}{\text{volume } (m^3)}$	kg/m^3	Obemberger and Thek, 2004 [9].
2.	Compressive Strength Test	$\frac{\text{Crushing load (kN)}}{\text{Area of sample } (m^2)}$	kN/m^2	Yadong and Henry, 2000 [10].
3.	Impact Resistance Test	$100 \times \frac{\text{Number of drops (N)}}{\text{Number of pieces (n)}}$	-	Richard, 1989 [11].
4.	Water Resistance Test	$100\% - \%\ water\ absorbed$	%	Obemberger and Thek, 2004 [9].
5.	Abrasion Resistance Test	$\frac{\text{Weight after tumbling}}{\text{Weight before tumbling}} \times 100$	%	Richard, 1989 [11].

II. MATERIALS AND METHODS

2.1 Sawdust Preparation

The sawdust material was sourced from sawmill in Muda Lawal market within Bauchi metropolitan area, Nigeria. The raw sawdust was sun-dried until stable moisture content range of 10 – 18% was obtained to give the briquette and was later subjected to size reduction through sieve analysis where a particle size of 1.18mm representing medium series was selected to produce uniform briquettes. Oversized materials were rejected and discarded.

2.2 Binder Preparation

Styrofoam was first collected from trash in bulk, pre-treated to be free of impurities and predetermined into smaller size particles by crushing. 400g of the crushed Styrofoam (about 20.43%) was then mixed with constituents such as gasoline, ethanol and dissolved gum Arabic of percent proportions; 42.90%, 8.07% and 28.09% respectively. The mixture was then stirred thoroughly forming polystyrene foam adhesive gradually. Consequently, about 0.51% proportion of silica gel was added to the content to enhance the emulsion characteristics of the adhesive, kept steady and undisturbed so as to further dehydrate the moisture in the adhesive [8].

2.3 Briquette Formation

The prepared binder constituting 30% by mass and sawdust were mixed in a vessel and thoroughly stirred to attain uniformity and enhance adhesion. The mixture was then fed into a mold (15cm height and 10cm diameter). The content in the mold was placed between round dies and positioned in the hydraulic powered press machine for compression into briquettes. The piston was actuated and a set pressure ranging between 40 - 90kN/m^2 was applied at a time to the material for 5minutes (dwell time). The briquette formed was then extruded and air-dried for 5 days and subsequently oven-dried for 24hrs at a constant temperature of 105^{0}C [8] [9] [10]. The detail procedure for the production process as stated by Ibrahim *et al.* is illustrated by Fig -1.

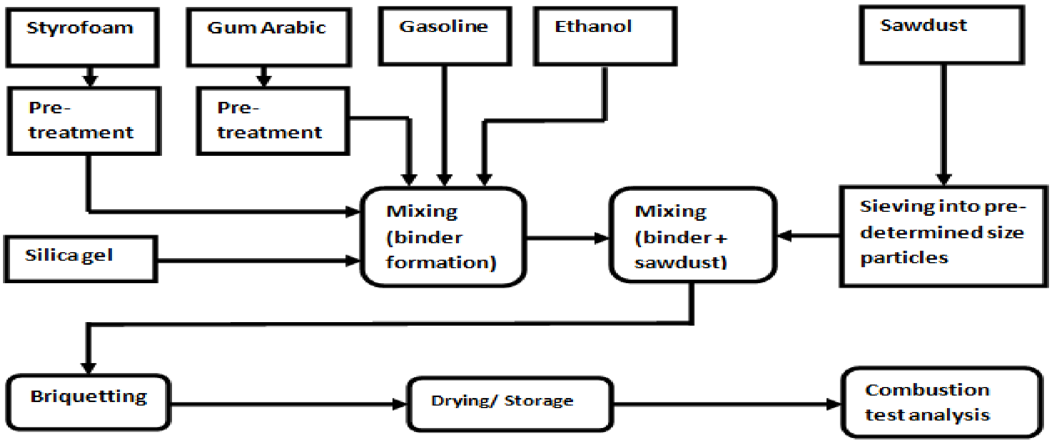

Fig -1: Block Diagram of processes involved in briquettes making from sawdust [8].

III. RESULTS AND DISCUSSION

3.1 Variations of combustion properties with molding pressure

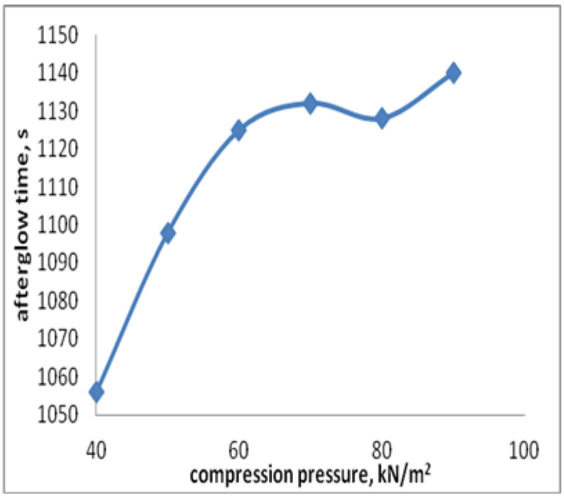

Fig -2: Sensitivity of afterglow time on compression pressure of briquette.

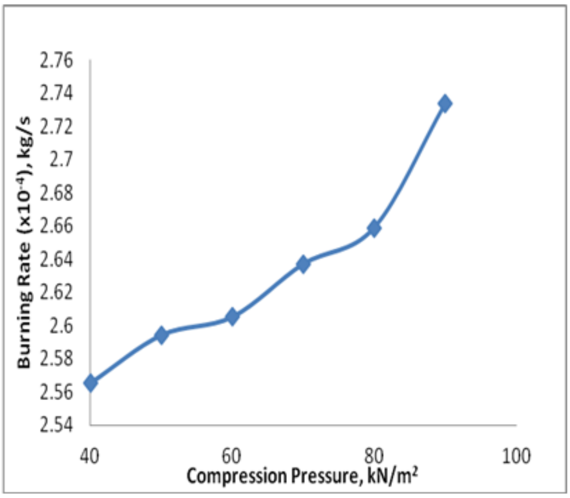

Fig -3: Sensitivity of burning rate on compression pressure of briquette.

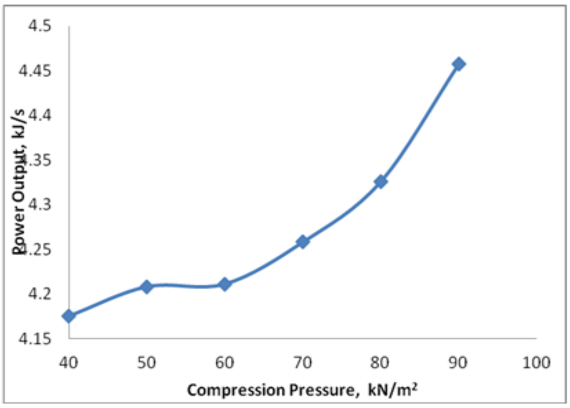

Fig -5: Sensitivity of power output on compression pressure of briquette.

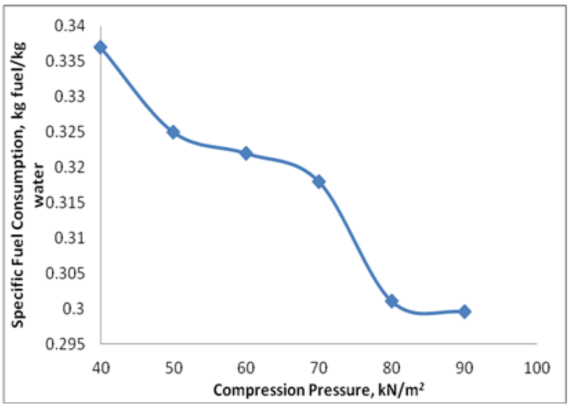

Fig -4: Sensitivity of specific fuel consumption on compression pressure of briquette.

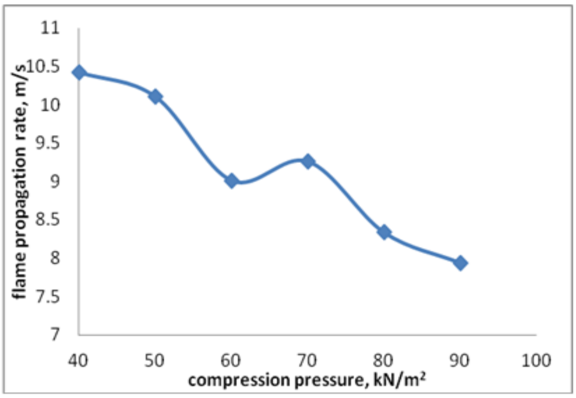

Fig -7: Sensitivity of flame propagation rate on compression pressure of briquette.

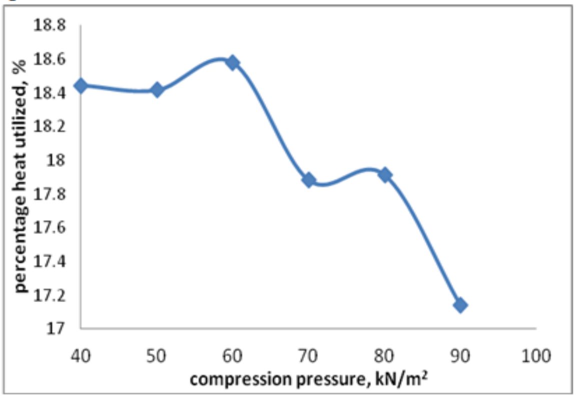

Fig -6: Sensitivity of percentage heat utilized on compression pressure of briquette.

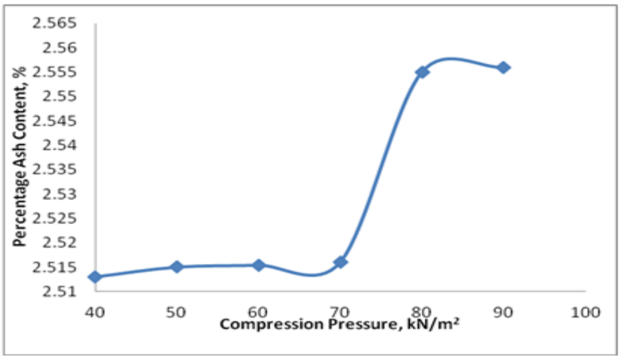

Fig -8: Sensitivity of percentage ash content on compression pressure of briquette.

The results obtained from water boiling tests showed that the afterglow time required for each set of briquettes to boil an equal volume of water increases with increase in the briquettes' compression pressure as shown in Fig -2 . The briquette with the lowest compaction pressure recorded lowest ignition time. The ignition time of the studied briquettes varied between 1,055 – 1,140s which showed a significant difference in variation at all level of compaction. This could be attributed to high porosity exhibited between particles which enable easy percolation of oxygen and out flow of combustion briquettes due to low compaction force. The observed values on ignition time showed that briquette bonded by Styrofoam adhesive took a longer time for it to burn out (1055 – 1140s) completely for each compaction as compared to the corresponding burn-out time (703 – 749s) of briquette bonded by cassava starch gel under 55 – 75 kN/m^2 compaction pressures as reported by (Onuegbu *et al.*, 2010) [8].

Fig -3 depicts the variation of burning rate with the compression pressure of the briquette. Briquettes with lower compaction burned faster than the ones with higher compaction. The study elucidated that increase in densification pressure increases the burning rate of the briquettes (ranging from $2.56 \times 10^{-4} – 2.73 \times 10^{-4}$kg/s). In comparative of this result analyzed with those reported by (Onuegbu *et al.*, 2011) [11] ranging between ($1.59 \times 10^{-4} – 1.64 \times 10^{-4}$kg/s) showed a significant variation in the mass of briquette burnt per time.
The specific fuel consumption of briquette was found to decrease progressively with increase in compaction pressure which ranges from 0.3375 to 0.2988 kg fuel/kg water as depicted in Fig -4. This is from the fact that the mass of sawdust per volume would increase on increasing the compaction/compression pressure of moulding while the availability of air containing Oxygen for combustion is reduced and excessive consumption of fuel resulting to wastage of heat minimized. The efficiency of the analyzed data compete favourably with that of briquette bonded by starch as stated by Onuegbu et al. (2011) which experienced lower fuel consumption rate at higher compression pressure of 65 – 85 kN/m^2.
Fig -5 is a representation of the variation of power output with respect to changes in compression pressure. This is a measure of the energy released on burning the briquette. It increases progressively from sample of low compression pressure to high ranging from 4.176 to 4.461 kJ/s. These values were observed to be slightly greater than that of briquettes bonded by common starch.
Percentage heat utilized from briquette fuel was found to decrease with increase in pressure of compression. This is a measure of the thermal efficiency of the fuel. The result displayed in Fig -6 shows that briquettes produced from high compression pressure have low heat utilization which is due to longer time it requires to burn completely. In so doing, more heat is lost to the surroundings thereby reducing the amount of heat utilized in the heating process. Best utilization of heat were noticed at compression pressures of 40, 50, 60 kN/m^2 with corresponding values of 18.46, 18.42 and 18.58% respectively. These fuel efficiencies were less than that of briquettes bonded by starch obtained from Adeniji et al. (2007) [12] which is between the ranges of 28.17 – 29.05%.
From Fig-7, flame propagation rate which is the rate at which briquette burn over a graduated length decreases with increase in compression pressure. This trend is due to decrease in porosity and low oxygen percolation in the fuel biomass. There is a close range of values when compared with briquettes produced with cassava starch as adhesive and is in conformity with minimum requirement of DIN 51731[13] and that of Ajayi & Lawal (1995) [14].
Percentage ash content on burning sawdust briquette increases as the compression pressure increases as can be seen in Fig -8. The ash content was found to increase very slowly from compaction range of 40 - 70 kN/m^2 while it increases rapidly from 70 - 80 kN/m^2. It can be deduced from this trend that increment in compression of briquette results into increment in mass of sawdust per volume resulting to subsequent increment in ash formation. Briquettes produced at compression pressure of 40 &50 kN/m^2 produces the lower ash content which were 2.513& 2.515% respectively.

3.2 Variations of mechanical properties with molding pressure

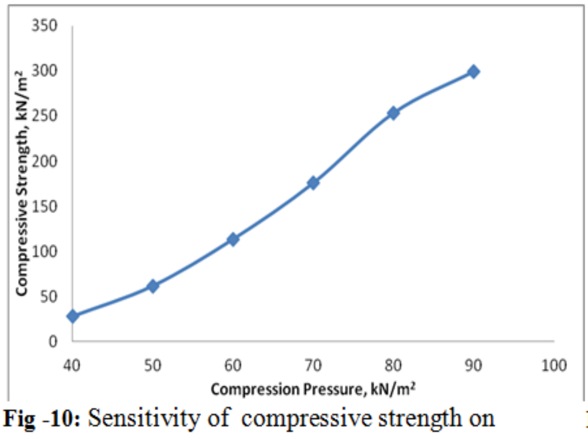

Fig -10: Sensitivity of compressive strength on compression pressure of briquette.

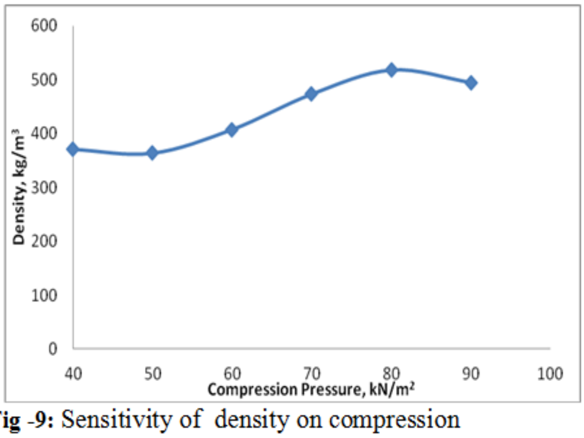

Fig -9: Sensitivity of density on compression pressure of briquette.

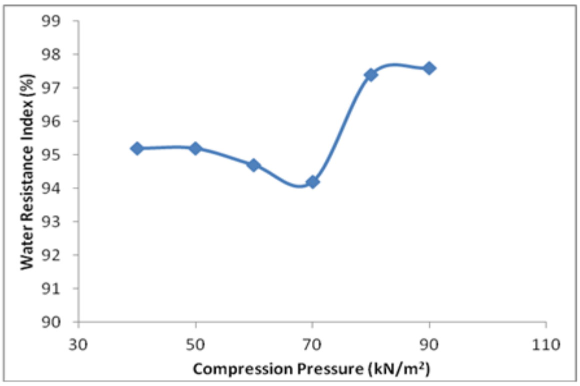

Fig -12: Sensitivity of water resistance on compression pressure of briquette.

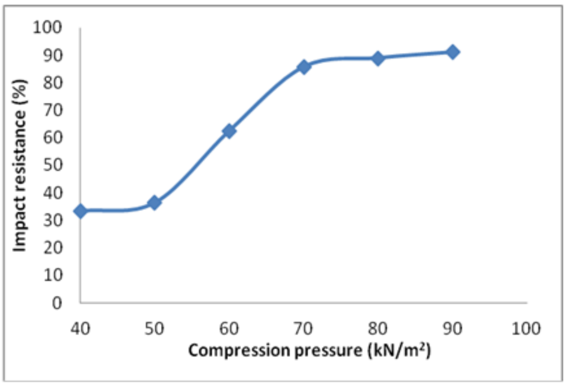

Fig -11: Sensitivity of impact resistance on compression pressure of briquette.

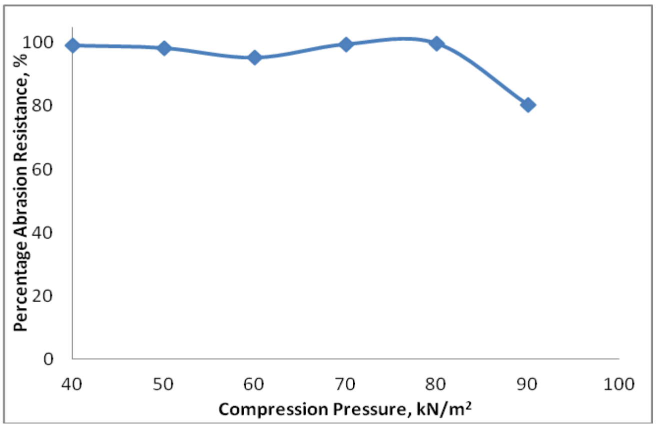

Fig -13: Sensitivity of Abrasion Resistance on compression pressure of briquette.

The density of briquettes was found to increase or the compaction was increased as depicted in F 9. As the compaction is increased, the particles that make the up material are forced closer to one another which minimize the void space between them. In so doing, the density of the briquettes is expected to increase on increased compaction for the fact that the briquettes particles which comprises of sawdust and Styrofoam are denser than the air pockets in void spaces. At slightly above 70 kN/m^2, the density of briquettes was no longer sensitive to compaction meaning further compaction results to no change in density.

Fig -10 shows the trend of compressive strength on increasing compaction of briquettes. It is an important parameter which indicates the ability of the briquettes to withstand loading capable reducing its sizes. It is critical in handling and transportation of the fuel. Increase in compaction result to increase in its compressive strength.

Fig -11 is a plot to show the effect of compaction on the ability of the briquettes to resist shock or high force applied to it in a short duration. It is a measure of the toughness of the briquettes. The impact resistance was found to increase as the compaction increases but more significantly at 50 – 70 kN/m^2. From 70 – 90 kN/m^2 compactions, the impact resistance was no longer sensitive to increase in compaction. The impact resistance of briquettes should be moderate because the biomass fuel is not frequently exposed to short time high force impact and also not to inhibit important combustion properties of the fuel.

From Fig -13, it was observed that the compression pressure has little effect on the abrasion resistance which is a measure of the briquette's ability to resist wearing of its surface when being in contact with the surface of another material. Compression pressure from 40 – 80 kN/m^2 produced briquettes at approximately 100% abrasion resistance. The only exception being at 90 kN/m^2 with percentage abrasion resistance of 80%. It can be deduced from this trend that the surface wear resistance of briquettes does not depend significantly on the compression pressure they are moulded.

Fig -12 shows the sensitivity of briquette fuel water resistance to variations of compression pressure in which higher resistance to water was obtained at higher compression pressure. The stability of briquette's resistance to water on changing the compression pressure was observed at 80 - 90 kN/m^2.

The strength of a briquette is a function of the pressure at which it was moulded as observed from Fig -9, 10 & 11 with the exception of the abrasion resistance which shows very low sensitivity as the compression pressure increases (Fig -13).

IV. CONCLUSIONS

The possibilities and potential use of Styrofoam as a binding material in sawdust briquetting was explored and found promising. The combustion and mechanical properties of the briquette was found to be dependent on the compression pressure with which it was moulded. Briquette quality is relative to its manner of application, transport and handling which determines the optimal compression pressure that best gives the required or desired properties of it. Optimization of the process should be carried out to ascertain the optimal conditions that give desired properties of the briquette. Cost analysis is relevant to evaluate the profitability of the process.

REFERENCES

[1] Badejo, S.O. 1990. "*Sawmill wood residue in Nigeria and their utilization*". Invited Paper. Proceedings of National on workshop on Forestry Management Strategies for self sufficiency in wood production, Ibadan 12th - 15th June, 1990.

[2]. Stout, B.A. and Best, G. 2001. "*Effective energy use and climate change: needs of rural areas in developing countries*". Agricultural Engineering International: the CIGR E-Journal of Scientific Research and Development. Vol. III, 19pp.

[3]. Yahaya, D. B. and Ibrahim, T. G. 2012. "*Development of Rice Husk Briquettes for use as fuel*". Research Journal in Engineering and Applied Sciences. *1(2) 130-133*.

[4]. Demirbas, A. and Sahin, A. 2001. "*Evaluation of Biomass Residue; Briquetting Waste Papers and Wheat Straw Mixtures*", *Journal on Fuel Processing Technology, (55) 175-183*.

[5]. Grover, P. D. and Mishra, S. K. 1996. "Biomass *Briquetting, Technology and Practices, Regional Wood Energy Development Programme in Asia*". Field document No. 46. FAO: Bangkok, Thailand.

[6]. Green, Harvey (2006) *Wood: Craft, Culture, History* Penguin Books, New York, page 403, ISBN 978-1-1012-0185-5.

[7]. Ibrahim M., Aroke U.O., Abdulrasheed A. (2015). "*Investigation of Mechanical & Combustible properties of Briquettes produced from Rice Husk using Polystyrene Foam Adhesive as a binder"*. International Journal of Science, Engneering and Technology. *3(2) 449-454*.

[8]. Onuegbu, T. U., Okafor, I. Ilochi, N. O. Ogbu, I. M. Obumselu, O. F. and Ekpunobi, U. E. 2010. "*Enhancing the efficiency of coal briquette in rural Nigeria using Pennisetum purpurem"*. Advances in Natural and Applied Sciences, *4: 299-304*.

[9] Emerhi, E. A. 2011. "*Physical and combustion properties of briquettes produced from sawdust of three hardwood species and different organic binders*" Advances in Applied Science Research, 2 (6):236-246.

[10] Ugwu, K. E. and Agbo, K. E. 2011. "*Briquetting of Palm Kernel Shell*" Journal of Applied Sciences and Environmental Management. *15 (3) 447 – 450*.

[11]. Onuegbu, T. U., Ekpunobi, U. E. Ogbu, I. M. Ekeoma, M. O. and Obumselu, F. O. 2011. "*Comparative studies of ignition time and water boiling test of coal and biomass briquettes blend*". International Journal of Research and Review in Applied Sciences, *7: 153-159*.

[12]. Adeniji, T. A., Sanni, L.O., Barimalaa, I.S., Hart, A.D. 2007. "*Nutritional and anti-nutritional composition of flour made from plantain and banana hybrid pulp and peel mixture*". Nigerian Food Journal, *25(2) 1-7*.

[13]. Standard DIN 51731. "Solid fuels testing, natural wood pressed pieces, demands and testing".

[14]. Ajayi, O. A. and Lawal G. T. 1995. "*Some Quality Indicators of Sawdust/Palm Oil Sludge Briquettes*": Journal of Agric Engineering and Technology, *3, 55-65*.