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Correlation Analysis of Particle Sizes and Compression Ratios of Biomass Waste Briquettes

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Abstract

The hazard constituted by biomass wastes in Nigeria has necessitated research on ways they can be utilized effectively. Transportation and storage problems associated with their low bulk densities has posed serious challenge thus there is need to convert them into briquettes. This research presentsthe correlation analysis of particle sizes and compression ratios of biomass waste briquettes produced using hydraulic briquetting press. Briquettes were produced from four sawdust materials (Stool Wood, Gmelina, Mahogany, Oil bean wood) and rice husk at five particle sizes (160µm,315µm,425µm,630µm and 1250µm) and at three pressures (18bar,20bar,22bar). Starch was used as the binder and the briquettes were produced at material: binder ratio of 89/11 percentage volume. Their bulk densities were calculated before and after briquetting there after the compression ratios were determined. Linear correlation model showed that particle sizes of Stool wood, Gmelina and rice husk has negative correlation with compression ratio with r values of (-0.84,-0.89,-0.92,) for stool wood, and (-0.97,-0.96,-0.89) for rice husk while Gmelina has r values of (-0.22,-0.19,-0.29) at 18, 20 and 22bar respectively. Mahogany and oil bean sawdust showed positive correlation with r values 0.84, 0.85, 0.92 for mahogany and 0.82, 0.65, 0.60 for oil bean at 18, 20 and 22bar respectively. However, increase in pressure increased the compression ratios of the five materials.

Keywords: correlation, grain size, compression ratio, sawdust, rice husk, briquette

1. Introduction

Biomass wastes are remains or waste of renewable, biological material that can be used directly as a fuel, or converted to another forms of usage. The major and most prominent of these wastes are sawdust, rice husk, agricultural straws, grasses, groundnut shells etc. In Nigeria, 9-150 million tons (MT) of these crop wastes are produced annually (Agboro and Ogie 2012; Simonyan and Fasina 2013). From these large quantities of agricultural wastes produced in Nigeria, there is immense potential for their use for energy production and industrial raw materials. The waste generated in sawmill industries inform of bark, sawdust, trimming, split wood, planer shaving and sander dust in year 2010 alone was over 1,000,000m^3 (Ogunwusi 2014) while 748,000 -990,000 ton of rice husk was estimated to have been produced in the same year (Abalaka 2012).

One of the main problems associated with the utilization of sawdust and rice husk wastes is their low bulk density which gives rise to high transport and storage costs and this limits their effective utilization. Biomass compaction technologies has been among the promising ways of overcoming the limitation of low bulk density in biomass wastes because it reduces the volume of biomass wastes and converts them to a solid form which is easier to handle and store when compared to the original material. Briquettes can be used as alternative to wood fuel as the demand for wood fuel especially in the developing countries continue to rise as a result of increasing population and transformation of biomass wastes to briquettes can increase bulk density of the biomass wastes to about tenfold of its original bulk density (Tumuluru et al 2015).

Biomass materials displays different physical characteristics when subjected to compaction technology.Kulig et al. (2012)report on the effect of binder addition on the compacted poplar wood sawdust, studied the effect of binder addition (calcium lignosulphonate, 0% to 20%) and moisture content (10% to 22%) on the parameters of compacted poplar wood sawdust. The susceptibility to compaction of the studied material, changes in material density and the mechanical strength of briquettes were analyzed using different statistical tools. The correlations between the binder content, the moisture content of the examined material and compaction parameters were analyzed in the STATISTICA program at a significance level of $\alpha = 0.05$ and significance of regression coefficients determined by Student's t-test. They found that addition of a binding agent increased compaction by 15.4% and briquette density by 37% on average and resulted in an approximately 7-fold increase in the mechanical strength of briquettes at all analyzed moisture content levels. Karunanithy et al. (2012) also worked on the physiochemical characterization of briquettes made from different feedstock. Their work was aimed at comparing the physiochemical properties of briquettes made from different feedstock such as corn Stover, switch grass, prairie cord grass, sawdust, pigeon pea grass, and cotton stalk which were densified using a briquetting system. Physical characterization studied include particle size distribution, geometrical mean diameter (GMD), densities (bulk and true), porosity, and glass transition temperature. The compositional analysis of control and briquettes was also performed. Statistical analyses confirmed the existence of significant differences in these physical properties and chemical composition of control and briquettes. Correlation analysis confirms the contribution of lignin to bulk density and durability among the feedstock tested while cotton stalk had the highest bulk density of 964kg/m^3 which had an eleven-fold increase compared to control cotton stalk. Corn Stover and pigeon pea grass had the highest (96.6%) and lowest (61%) durability.

Particle size distribution is one of the material parameters that affect briquette quality during compaction process. According to Mani (2006), briquettes quality is inversely proportional to the particle size. The effect of particle size distribution was listed as an important material property for forage wafering when comparing leaf to stem ratios, as a higher leaf content was reported to produce a superior densified product. Arzola et al. (2012) reported that average particle size had the most influence on briquette density and according to Lucas and Oladeji (2011) work on predictive models for some densification characteristics of corncob briquettes. The work subjected the corncob residues to three particle size reduction namely 4.7mm, 2.4mm, 0.6mm and at binder ratios of 20%, 25% and 30%by weight of the residue. The briquettes were produced at three pressures (2.4, 4.4, and 6.6MPa). The study found out that particle size has effect on the parameters studied. Ahmad and Aktham (2008) studied effect of particle size on compaction of materials with different deformation mechanisms with and without lubricants. The study which used sieve cuts of microcrystalline cellulose (MCC), starch and diabasic calcium sulphate were tested without lubrication and with 0.5%mg stearate as lubricant reported that tensile strength is dependence on particle size of the materials with or without lubricant. Similarly, Oladeji and Enweremadu (2012) studied the effect of some processing parameters on physical and densification characteristics of corncob briquettes. Three sieve sizes (4.7mm, 2.4mm, 0.6mm), three starch ratios (20%, 25%, 30%) and three compaction pressures (2.1, 4.2, 6.6M/m^2) were used for the analysis.

The initial, maximum and relaxed densities ranged from 151-235 kg/m^3; 533-981kg/m^3 and 307-417kg/m^3 respectively. The compaction ratio ranged from 2.27 to 6.50. The maximum percentage volume reduction was 626%, while the axial and lateral relaxations were in the range of 0.62-9.85% and 0.64-3.63 respectively. For the three processing parameters examined, binder ratio 20%, particle size 0.6mm and pressure 6.6N/m^2 exhibited most positive attributes. It was also found that particle size of decomposed biomass affects the biochemical activities of soil as studied by Bending and Turner (1999) on how biochemical composition interacts with particle size to effect the soil microflora and nitrogen dynamics following incorporation of crop residues into soil. The work used fresh shoot and root crop residues which were cut into coarse and fine particle sizes and incorporated into sandy-loam soil. They found out that the impact of particle size on soil microbial activities and the protection of senescent microbial tissue from microbial attack is dependent on the biochemical quality of the substrate.

In summary, particle sizes affect the use of biomass materials either in the soil, drug formulation, briquetting technology and other areas of its applications. Global researches today are mostly focused on ways of converting bio-wastes into sustainable sources of fuel for both domestic and industrial use and it is based on these potentials of biomass usage that this work was conceived. This work therefore correlated particle sizes of biomass wastes (rice husk and four sawdust materials) with compression ratios of their bulk densities. The study is necessary because particle size has great influence on the briquette production and its effect vary for different biomass materials during compaction process. The trend of the relationship as it relates to briquetting of the biomass material need to be investigated to ascertain performance of a briquetting operation. The study is aimed at finding the relationship between particle sizes of sawdust species and rice husk wastes and their respective compression ratios. To achieve this, the following were the objectives of this study;

- Production of briquettes from rice husk and four sawdust materials at five particle sizes.
- Calculating the compression ratios from densities before and after briquetting.
- Use of Pearson's correlation coefficient (r) to determine the relationship between the particle sizes and compression ratios of the materials.

2.0 Material and methods

2.1 Materials

This study was carried out using the facilities at the material laboratory of Enugu State University of Science and Technology and that of Scientific Equipment Development Institute, Enugu State both in Nigeria.

Materials used for the analysis are Stool wood, Gmelina, Mahogany, Oil bean saw dust and rice husk. The sawdust materials were collected from sawmill at Kanyetta timber, in Enugu state, Nigeria (Fig. 1) while rice husk was sourced from a rice husk winnowing site at Abakaliki rice mill in Ebonyi state (Fig. 2). Moisture content of the materials were maintained within the acceptable moisture content of 8-12%db for making briquettes (Erikkson and Prior, 1990; Jaan, et al. 2010). The binder used was cold water starch (Renew).

Equipment used for the analysis include; digital weighing balance, hammer mill, measuring cylinder, flash dryer, mixer, hydraulic press briquetting machine, veneer caliper and Tyler sieves.

Fig. 1: Sawdust mills at Kenyentta timber, Enugu state.

Fig. 2: Rice husk winnowing site at Abakaliki, Ebonyi State.

2.2 Methods

2.2.1 Sample preparation

The five materials were designated with A, B, C, D, E for stool wood, Gmelina, mahogany, oil bean and rice husk respectively. The materials were then size reduced using a hammer mill and sieved using Tyler sieves. Five particle sizes namely, 1250µm, 630µm, 425µm, 315µm, 160µm were obtained from each of the five materials. Equal volume of 100cm^3 of each sample was measure out and weighed in a digital weighing balance and the mass recorded. Three pressures namely, 18bar, 20bar and 22bar were used to produce briquettes from all the samples of the materials and the experiment was replicated twice. The treatment levels of the analysis was 5×5×3×2 such that a total of 150 briquettes were produced. The bulk density of the loose materials were then calculated using eq.(1) and each of these samples (150) was tied together to the binder (Fig. 3) for the briquetting operation.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \quad (1)$$

Fig. 3: Sample preparation for the five materials

2.2.2Compression operation

Each particle size sample was fed into a bowl and mixed with binder (starch) in percentage compositions of 89:11 percentage volume. The agitating process was done in a mixer to enhance proper blending prior compaction. A steel cylindrical crucible (die) of dimension 82mm height and 50mm in diameter was used for the compaction. The die was freely filled with known amount of weight of each sample mixture and positioned in the hydraulic briquetting press machine for compression. The piston was actuated to compress the samples and the pressure was monitored at 18bar, 20bar, 22bar using the pressure gauge. After pressure was applied at a time to the material in the die, the briquette formed was extruded.

2.2.3 Determination of compression ratio

After compression on the hydraulic briquetting press, the briquettes produced were cylindrically shaped and of equal diameters of 50cm. Height of each briquettes were measured using veneer calipers while the mass was determined using digital weighing balance. The volume was calculated using $\pi r^2 h$ and then bulk densities of the briquettes were calculated using eq. (1). Compression ratio of the samples were then determined using eq. (2).

$$Compression\ ratio = \frac{Density\ \ of\ briquette\ \ after\ briqqeting}{Density\ \ before\ \ briquetting} \tag{2}$$

3.0 Results and Discussions

3.1 Results

Briquettes produced are shown in Fig. 4. The relationship between particle sizes and compression ratios were analyzed using linear correlation analysis; Pearson's correlation coefficient (r). The results are presented in graphical form and are analyzed as follows;

Fig. 4: Samples of briquettes produced

3.1.1 Stool wood

From Fig. 5, it shows that there is strong negative correlation between particle size of stool wood and its compression ratio. This relationship increases as the applied pressure increases. It also shows that the compression ratio increase as particle size of stool wood decreases because of the decrease in the spaces between the particles. Coefficient of correlation (r) is influence by pressure application such that r-values of 0.91, 0.89 and 0.84 were recorded for 22. 20 and 18 bar respectively.

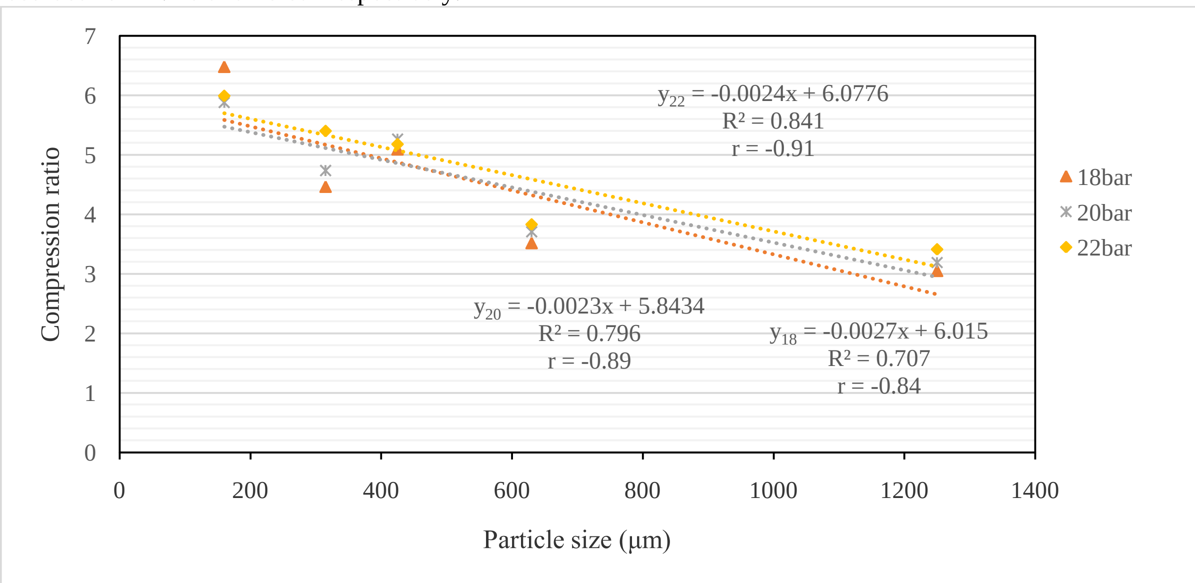

Fig. 5: Plot of particle size and compression ratio of Stool wood

3.1.2 Gmelina

Fig. 6 presents the correlation analysis on Gmelina and it shows that there is no strong relationship between particle size and compression ratios of the material as show their r-values (0.18, 0.28, 0.21). However, increase in applied pressure increased the compression ratio of the material as generally observed for the pressure applications. Compression ratio of gmelina was at its peak at 425µm being 6.7 compression ratio value and reduces as particle size increased for 315µm (6.4), 1250µm (6.1) at 22 bar.

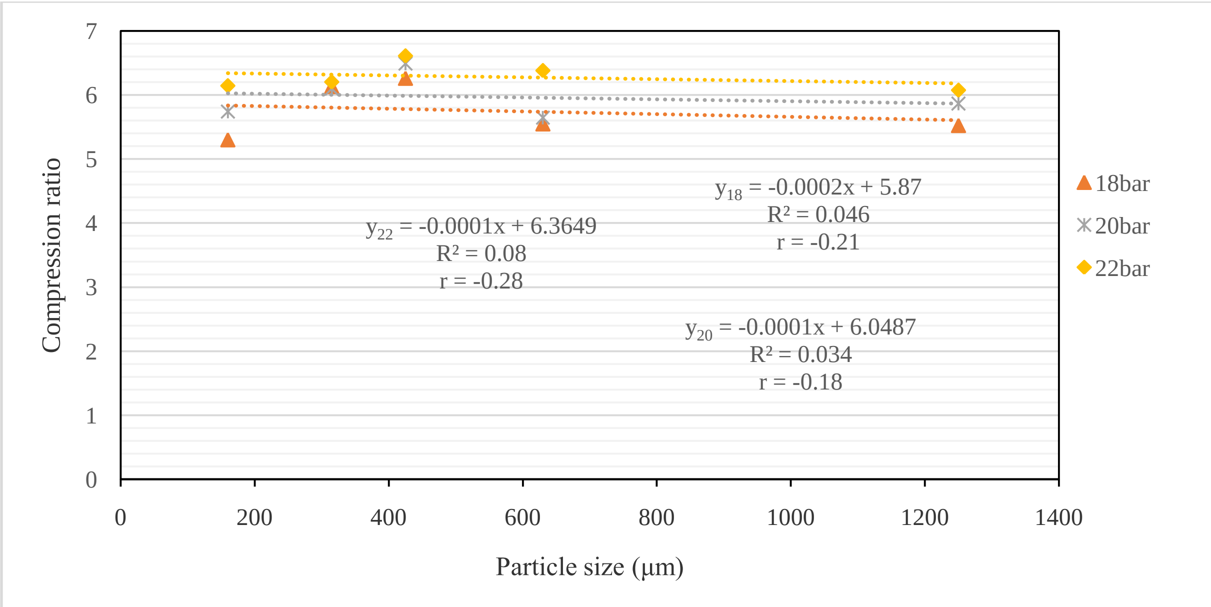

Fig. 6: Plot of particle size and compression ratio of Gmelina

3.1.3 Mahogany

Mahogany sawdust showed positive correlation between particle size and the compression ratio and this increases as the applied pressure increases such that applied pressure at 22bar gave the highest r-value (0.91) as presented in Fig. 7. Unlike Stool wood sawdust, decrease in particle size of the material, decreased the compression ratio such that 1250µm gave the highest compression ratio. This may be attributed to the hardness of Mahogany sawdust in resisting compression. It was also observed in the graph that increase pressure increased the compression ratio.

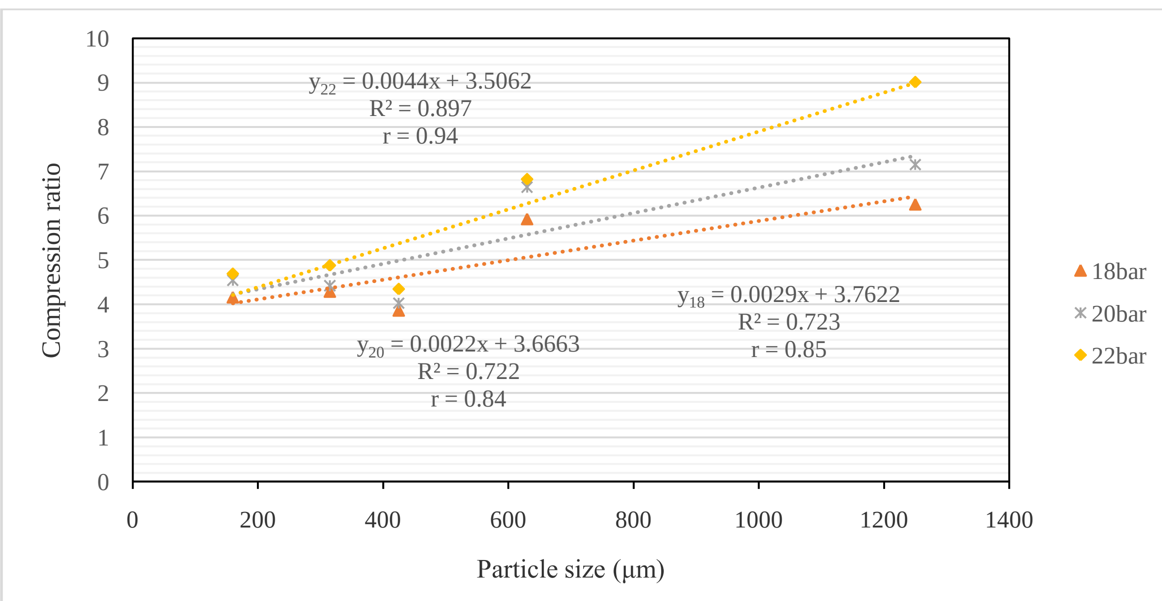

Fig. 7: Plot of particle size and compression ratio of Mahogany

3.1.4 Oilbean

Fig. 8 represents correlation analysis on oil bean sawdust and shows that there is slight positive correlation between particle size and compression ratio and this relationship decreased with increase in pressure and is contrary to that of Mahogany sawdust. The result also show that finer particle sizes have lower compression ratios. However, increase in applied pressure (22bar) increased the compression ratio of the material.

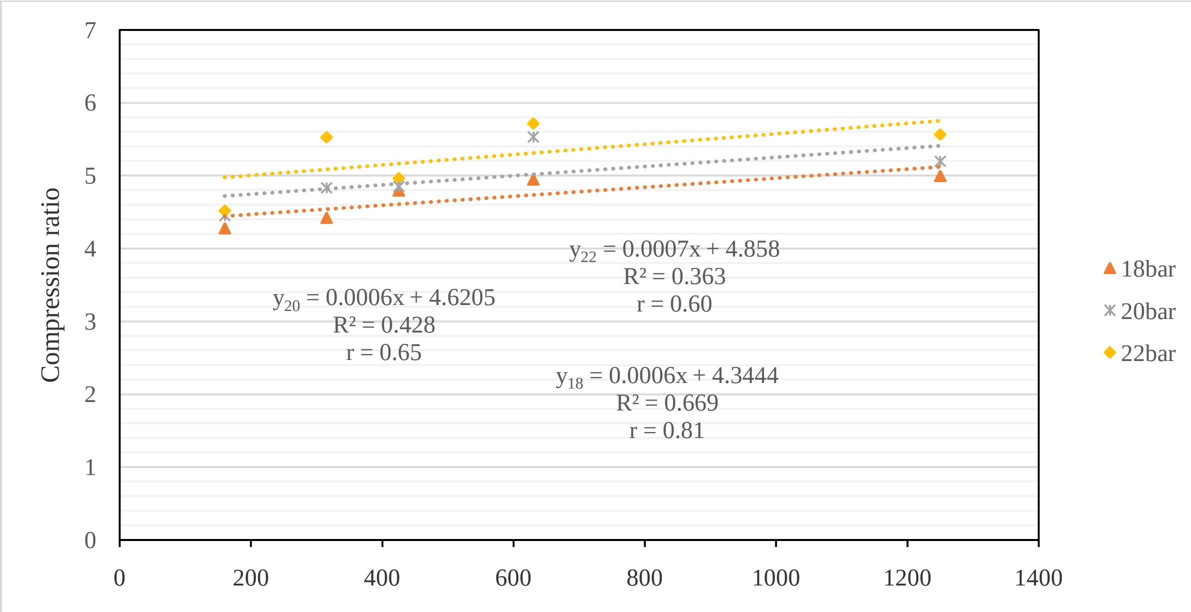

Fig. 8: Plot of particle size and compression ratio of Oil bean

3.1.5 Rice *husk*

Rice husk sawdust correlation analysis imitated that of oil bean sawdust except that the relationship is negative (Fig. 9). The r values decreased from 0.96 to 0.88 as pressure increases. Highest correlation value was recorded at 18 and 20bar. Also, highest compression ratio was obtained from very fine particle size (160µm) at 22bar.

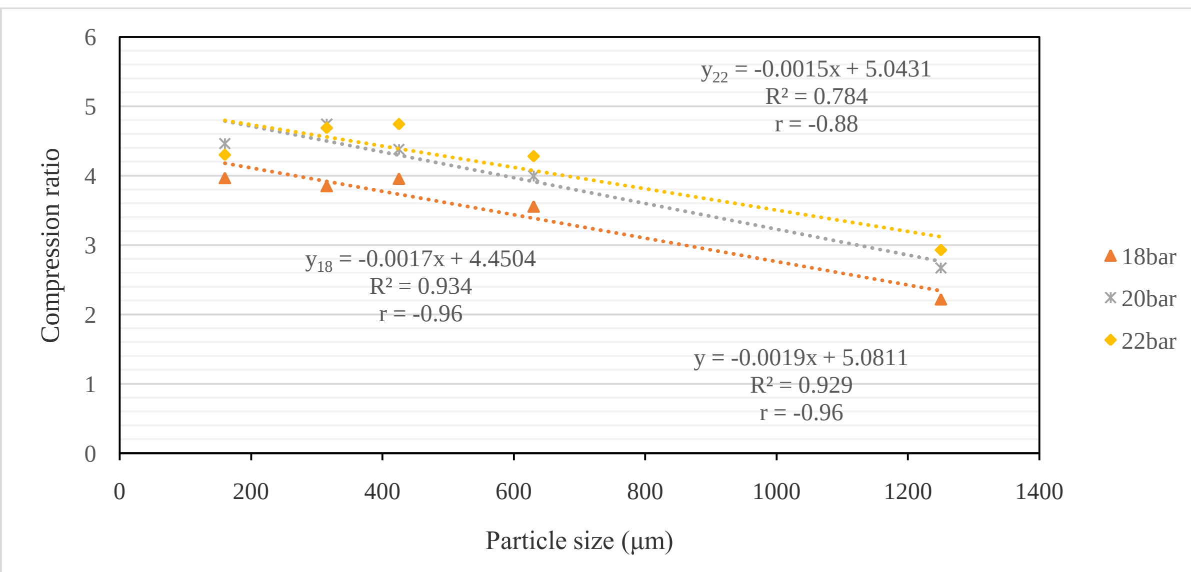

Fig. 9: Plot of particle size and compression ratio of Rice husk

3.2 Discussion

An average record of 60 -70% compression ratio at 22bar for stool wood sawdust, gmelina sawdust and rice husk briquettes at 160µm particle size is comparable to those obtained in other briquettes produced from other biomass materials (Ali *et al.*, 2015). This compression ratio is also commonly observed in pharmaceutical industries in drug formulations (Wiacek et al. 2017). Hamad et al. (2015) reported that fine particles does not necessarily mean the higher the compressibility. But form the result obtained, the finer the particles the higher the compressibility of stool wood sawdust, gmelina sawdust and rice husk but this was not so for mahogany and oil bean sawdust While stool wood sawdust, gmelina sawdust and rice husk briquettes compressions are negatively correlated to particle size, mahogany and oil bean are negatively correlated.

However, the discrepancy in the compression of the materials is as a result of their differences in composition. This indicates that arrangement of particles before compression at each particle sizes differs for a given material such that pressure application aids in rearrangement of the particles and collapse all inter particle spaces that were existing prior compression. Compression ratio for those materials that are positively correlated to particle size was also found to decrease by 52%, 40% and 33% for 22, 20 and 18 bar respectively as particle size decreases from 1250μm to 425μm. This trend is in accordance with results obtained in Forero-Nunez (2015). It also expounds that large inter particle spaces are at 1250μm and requires closure during densification. It is obvious that higher particle size has higher compression ratio for Mahogany and oil bean sawdust which was not as observed in that of Stool wood and Gmelina sawdust. This behavior occurred due to the different densification mechanisms that took place during compression, e.g., air releasing, solid particles rearrangement, fragmentation, and elastic and plastic deformation which differed for each of the materials.

4.0. Conclusion

In agreement with previous work on effect of particle size on briquetting production, this study has established that there is strong correlation between particle sizes and compression ratio of the materials under study and this is most pronounced in rice husk, mahogany, stool wood and oil bean saw dust materials as indicated by their r-values. The r-value for Gmelina shows low correlation between the two parameters. Stool wood, Gmelina and rice husk show negative correlation while Mahogany and oil bean sawdust showed positive correlation. This relationship increased as pressure increases for stool wood and mahogany while that for oil beans and rice husk decreased. This implies that correlation between particle sizes and compression ratio for different materials differed depending on the nature of the materials. The analysis also show that compression ratios increased with increase in applied pressure such that highest compression ratios were obtained at 22bar for each of the sample.

5.0 Recommendation

Further studies should be carried out on the composition of the biomass waste material prior to briquetting in order to establish the effect of material composition on the compression ratios of the briquetting operation.

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