ResearchGate

See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/373361704

Effect of densification process parameters on the physico-mechanical properties of composite briquettes of corncob and rice husk

Article *in* Materials Today Proceedings · August 2023

DOI: 10.1016/j.matpr.2023.08.253

CITATIONS
12

READS
98

4 authors:

Ibitoye Segun Emmanuel
University of Ilorin
38 PUBLICATIONS **488** CITATIONS
SEE PROFILE

Habeeb A. Ajimotokan
University of Ilorin
57 PUBLICATIONS **562** CITATIONS
SEE PROFILE

Adekunle Adeleke
Nile University of Nigeria
223 PUBLICATIONS **2,255** CITATIONS
SEE PROFILE

Chanchal Loha
CSIR-Central Mechanical Engineering Research Institute
58 PUBLICATIONS **1,762** CITATIONS
SEE PROFILE

All content following this page was uploaded by Ibitoye Segun Emmanuel on 01 November 2024.

The user has requested enhancement of the downloaded file.

ARTICLE IN PRESS

Materials Today: Proceedings xxx (xxxx) xxx

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

Effect of densification process parameters on the physico-mechanical properties of composite briquettes of corncob and rice husk

Segun E. Ibitoye [a,b,*], Habeeb A. Ajimotokan [a], Adekunle A. Adeleke [c], Chanchal Loha [b]

[a] Department of Mechanical Engineering, Faculty of Engineering and Technology, University of Ilorin, Ilorin PMB 1515, Nigeria
[b] Energy Research and Technology Group, CSIR-Central Mechanical Engineering Research Institute, Durgapur, West Bengal 713209, India
[c] Department of Mechanical Engineering, Nile University of Nigeria, Abuja 90001, Nigeria

ARTICLE INFO

Keywords:
Corncob
Rice husk
Mixing ratio
Particle size
Compaction pressure
Durability

ABSTRACT

Fuel briquettes were manufactured from corncob and rice husk in this study. Samples were collected, sorted, and screened into different particle sizes. The mixing ratios of corncob and rice husk samples were 100:0, 80:20, 70:30, 60:40, and 50:50, respectively. The briquettes were produced under varying pressure of 25, 50, and 65 kPa. Compressed and relaxed densities of the briquettes varied from 1.1 to 2.1 g/cm^3 and 0.52 to 0.87 g/cm^3, respectively, while durability changed from 34.43 to 99.13%. The briquette of 50:50 corncob-risk husk of 0.25 mm particle size produced under pressure of 65 kPa has the optimum physico-mechanical properties.

1. Introduction

Energy is a core requirement for daily life. Man needs energy for power generation, cooking, and heating in automotive engines for movement, which is important for social and economic development [1,2]. We have two broad energy categories, renewable and non-renewable [3]. Non-renewable energies are replenishable over a very long period and it is tending to extinction [4]. Examples of such energy are nuclear, fossil fuels such as crude oil, and natural gas. Renewable energy is replenishable over a short period, often cheaply available, and environmentally friendly. Renewable energies are solar, wind, tidal, hydroelectric, geothermal, and biomass. In the last five to six decades, several studies have been conducted focusing on alternative energy to satisfy the ever-increasing energy demand due to high industrialization and urbanization and avoid dependence on fossil fuels [2,5]. Due to the limited fossil fuel reserve, coupled with the environmental impact of the use of fossil fuels, such as global warming resulting from the emission of greenhouse gases, a rise in global mean temperature consequent of the infrared radiation layer thickening has necessitated the need to seek for an alternative, sustainable, renewable and environmentally friendly sources of energy [6].

Biomass is an organic substance that can serve as an alternative energy source and material for industrial and domestic applications [7]. Biomass, such as agro-residues, is a promising feedstock for fuel production due to its renewability, availability, and helpful ecological effects, bringing about no net emission of greenhouse gases such as carbon dioxide [8]. Farmers often dump these agro-wastes in an open field or burn them, releasing harmful gases into the atmosphere. In addition, transportation, storage, low thermal efficiency, and handling of these agro-residues are other problems [9]. Furthermore, the accumulation of this waste can hinder the aesthetics of the environment, causes air and water pollution, and promote diseases such as cholera [10,11]. These could cause public health problems, lead to environmental degradation, and contribute to constraints in the economy of many developing countries. Densification to generate briquettes is one method for mitigating these drawbacks and efficiently utilizing biomass waste as fuel [12].

Briquettes are compacted blocks of dust or other flammable biomass substance, including charcoal, shavings, forest residues, agro-residues, dung, or paper, used as fuel and lighting to create a flame [2]. Firewood and charcoal could be substituted by briquettes for household cooking and industrial activities if handled appropriately at a reasonable cost and made widely accessible to the people [13]. Briquette composition is determined by the type of feedstock utilized, structure, burning properties, level of homogeneity, category of mold used, and operational circumstances such as moisture, temperature, substrate input, and particulate shape and size [12,14,15].

The two main techniques for making briquettes are ram or piston presses and screw extruders. Addressing several implementation issues related to briquetting technology, as well as assuring the raw materials

---

* Corresponding author.
E-mail address: ibitoye.s@unilorin.edu.ng (S.E. Ibitoye).

https://doi.org/10.1016/j.matpr.2023.08.253
Received 6 June 2023; Received in revised form 18 August 2023; Accepted 21 August 2023

2214-7853/Copyright © 2024 Elsevier Ltd. All rights reserved. Selection and peer-review under responsibility of the scientific committee of the 1st International Conference on Advanced Materials, Manufacturing and Industrial Engineering – 2023.

Please cite this article as: Segun E. Ibitoye et al., *Materials Today: Proceedings*, https://doi.org/10.1016/j.matpr.2023.08.253

that are employed, are critical factors that influence its profitability. Aside from the business component, the significance of this technique lies in the conservation of wood, a commodity widely used in developing nations, resulting in significant forest degradation.

Several researches have been conducted on biomass densification. Obi & Okongwu [16] investigated the properties of fuel briquettes manufactured from rice husk and palm oil mill waste. The proportion of palm oil mill sludge in the mix was discovered to increase the moisture content, volatile matter, thermal efficiency, and elemental constituents of the briquettes. The carbon content and mineral composition, on the other hand, decreased. The 1:1 blend produced the best results, though there was no information on the mechanical qualities of the briquettes. Oladeji [17] evaluated different fuel briquettes derived from corncob and rice husk leftovers. It was discovered that corncob briquettes had more favorable biofuel qualities than rice husk briquettes, and both briquettes do not disintegrate during transportation and storage. The mechanical parameters were not reported, and the samples were not mixed. Ikelle et al. [18] investigated the burning characteristics and characterization of coal and rice husk briquettes. Briquette samples with 60% coal and 40% rice husk were found to have the highest combustion values compared to other briquette blends. Nonetheless, little data was given about the mechanical characteristics of the produced briquettes. As a result, the current research focuses on converting agricultural leftovers (rice husk and corncob) into hybrid briquettes and investigating their physico-mechanical characteristics for industrial and residential applications.

2. Materials and methods

2.1. Materials

The biomasses utilized in this research were maize cob and rice husks from Ilorin, north-central Nigeria. Corncobs were gathered from corn farm wastes in Tanke, Ilorin, and rice husks from rice cultivation farmers in Amoyo, Ilorin. A cassava processing factory in Olorunsogo, Ilorin, supplied the starch.

2.2. Methods

2.2.1. Preparation of biomass samples

The samples (corncobs and rice husks) were sorted to remove any contaminants or foreign objects, including sand, gravel, ashes, and plant remnants that could alter the qualities of a fuel briquette. The sorted samples were sun-dried for 3 days to lessen moistness. A hammer mill crushed the samples for better workability and compactness. A digital weighing balance measured the masses of the samples.

2.2.2. Sieve analysis

Sieve analysis was conducted according to BS EN 15149–2 standard utilizing a shaking sieving machine. The pulverized samples were screened into 0.25, 0.5, and 1.0 mm. The sieves were arranged in decreasing aperture sizes, culminating with the collecting pan. The analysis used 200 g of each sample. The materials were equally distributed on the sieve and shacked for 15 min before measuring and recording the sample weight in each sieve. The proportion of each sieve was determined using Equation (1):

$$\%S = \frac{W_s}{W_t} \tag{1}$$

Where $\%S$ is the percentage of sample, W_s is the weight of sample in each sieve, and W_t is the total weight of the sample.

2.2.3. Binder preparation and briquette formulation

Water was poured into an empty container made of stainless steel and heated to 100 °C. After thoroughly mixing the starch powder with purified water to make a paste mixture, the starch sample was poured into the boiling water and manually stirred until a homogeneous gel of starch was formed. Rice husk, maize cob, and crystallized starch were thoroughly mixed in various amounts to improve the uniformity of the biomass briquettes. Table 1 shows the design of the blends at various particle sizes and compaction pressure. In this investigation, the amount of binder and water used was 5% of the total combinations and remained consistent throughout the mix proportion and various particles.

2.2.4. Production of briquettes

The techniques adopted for producing the briquettes in this study are similar to that of Odusote and Muraina [19]. After thoroughly blending, corncob and rice husk with binder were mixed using an electric agitator. The feedstock was compaction using the 1560 kN compaction machine (model EL31 072), shown in Fig. 1a. Fig. 1b shows the mold utilized for the briquette production. Compaction was accomplished by inserting the mold between the machine's plates before releasing the piston, exerting force on the mixes to make a fuel briquette. For reliability's sake, the dwelling time for every briquette was 60 s, and four samples were manufactured from each blend at 3 compacting pressures. The produced fuel briquettes were sun-dried for five days.

2.2.5. Compressed and relaxed densities

The ratio of measurable mass to estimated volume was used to determine the compacted density of the briquettes instantly as they were discharged out from the mold. Conforming to the requirements of ISO 3131, the relaxed density of the briquettes was assessed 30 days after they were removed from the press. Determining the compressed and relaxed densities was possible using Equation (2).

$$\ell = \frac{M_m}{V_c} \tag{2}$$

Equation (3) was used to compute the briquette's volume:

$$V_c = \pi h(R - r)^2 \tag{3}$$

where ℓ is density, M_m measured mass, and calculated volume, r *denotes the briquettes' inner radius,* R *denotes their outward radius, and* h *denotes their height.*

2.2.6. Shattering index/ durability

The shattering index is a metric that shows how long briquettes will last when handled, stored, and transported. In accordance with Odusote and Muraina [19], the Shatter index was calculated. Four times, the briquettes were thrown on any flat metal plate at an elevation of 1.85 m. Equation (4) illustrates how the shatter index was computed as the ratio of the sample weight of material recovered following four drops to the original weight of the briquettes [19]:

$$S_i = \frac{W_a}{W_i} \times 100 \tag{4}$$

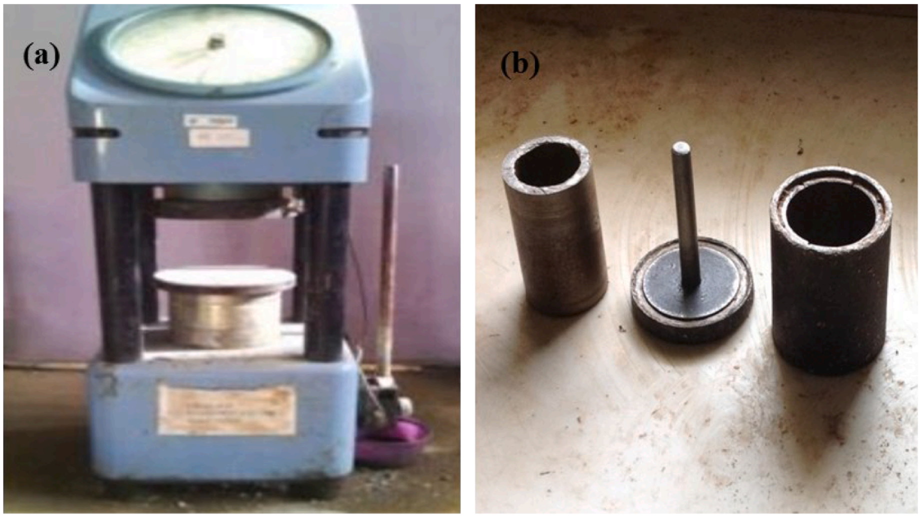
S_i is the shatter index, W_a is the weight of the sample after 4 drops, and W_i is the initial weight of the sample.

2.2.7. Drop to fracture and impact resistance index (IRI)

The method suggested by Richards [20] was used to conduct the impact strength and drop-to-fracture tests to assess the susceptibility of the fuel briquette to impact force. The briquettes were continuously dropped from a height of 2 m onto a concrete floor until they broke. The

Table 1
Blending ratios of rice husk and corncob at different particle sizes.

Sieve sizes (mm)	Compaction pressures (kPa)	Blend ratios (corncob: rice husk) (%)				
0.25	25, 50, 65	100:0	80:20	70:30	60:40	50:50
0.50	25, 50, 65	100:0	80:20	70:30	60:40	50:50
1.00	25, 50, 65	100:0	80:20	70:30	60:40	50:50



(a) Hydraulic jack machine (b) Dismantled mold

Fig. 1. (a) Hydraulic jack machine (b) Dismantled mold.

test was conducted using three different samples for reliability, and the average was reported. The IRI was calculated using Equation (5) [20]:

$$IRI = \frac{N}{n} \times 100 \quad (5)$$

where N is the average number of drops, and n is the typical number of pieces.

2.2.8. *Compressive strength*

The briquettes' cold crushing strength was measured using the ASTM D2166-85 [21] standard. The compressive strength test was conducted using a universal testing machine with a load cell capacity of 40 kN and a cross-head speed of 0.4 mm/min. The test was performed three weeks following densification. Each briquette was placed between the machine's compressing plate and allowed to make tight contact with the jaws. At the end of each test, the highest stress was displayed. Each sample underwent the test three times, and the average was determined and reported.

3. Results and discussion

3.1. *Sieve analysis*

Table 2 displays the sieve analysis results of the raw biomass. It shows that rice husk of 0.5 mm particle size had the highest percentage (33.02%), followed by 1.0, less than 0.25, and 0.25 mm with 32.08, 22.00, and 19.00%, respectively. For the corncob sample, particle size > 1.75 mm had the highest percentage of 75.86%, followed by 1.75 (11.82%) and 1.0 mm (5.91%), and this shows that the rice husk particles are more evenly distributed than corncob. Sieve analysis reflects the porosity, surface area, intermolecular bonding capability, and how the particles are filled with each other to form a small void. The implication is that rice husk will display better physico-mechanical properties due to the even distribution of its particles, resulting in a better structural arrangement of the particles. This is because the medium particle and a small portion of the fine particles filled the void spaces between the coarse particles. However, the degree of sample grinding affects the particle distribution.

Table 2
The result of sieve analysis of pulverized samples.

Sieve Size (mm)	Rice husk		Corncob	
	Amount (g)	Percentage (%)	Amount (g)	Percentage (%)
< 0.25	22	10.38	4	1.97
0.25	19	8.96	2	0.99
0.45	14	6.60	2	0.99
0.50	54	33.02	6	2.96
1.00	62	32.08	11	5.91
1.75	11	5.19	24	11.82
> 1.75	8	3.77	151	75.86
Total sample	200	100.00	200	100.00

The result of this study is close in value to the percentage distribution reported by Ileleji and Zhou [22] for the corn stover briquettes given a range of 0.25 to 4.42 mm and also 0.77 mm used by Li et al. [23] to produce briquettes from corn straw. Therefore, the corncob sample sizes are more distributed around the larger particle sizes, while the rice husk is around the medium and smaller particles. When these samples are blended, the medium and finer particles of the rice husk will fill the void spaces of the corncob's coarse, making them interlock with each other and forming better bonds that improve the mechanical and physical characteristics of the resulting fuel briquettes.

3.2. *Compressed and relaxed densities*

According to Fig. 2, the density of the briquette ranged from 1.1 to 2.1 g/cm^3. The maximum and minimum densities were obtained at 0.25 and 1.0 mm particle sizes, respectively. The biomass briquettes density (relaxed) dropped to a range of 0.49 to 0.87 g/cm^3 after exposure to the sun for five days. The loss of moisture in the briquettes may be the cause of this. The results demonstrated that density increased with both decreasing particle size and increasing the proportion of rice husk in the blends. This is because finer particles are more compact and have a higher density than coarse particles due to their smaller pore gaps and

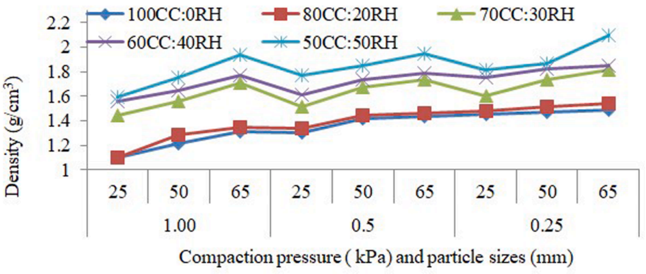


Fig. 2. Density variations due to compaction pressure and particle size.

increased contact surface area.

Similarly, compaction pressure changes considerably impact the density of the fuel briquettes that are generated; as compaction pressure rises, the size of the briquettes decreases while maintaining the same mass. Higher compaction pressure reduced briquette sizes, implying that the calculated volume decreased while maintaining the same mass, thus increasing density. The density of the briquettes also increases as the proportion of rice husk in the blend increases. The effect of the blending ratio on density is shown in Fig. 3, while briquette samples for different particle sizes are shown in Fig. 4. The green density of the briquettes produced in this research is greater than those found in Oladeji and Enweremadu's [24] paper, which varied from 0.533 g/cm^3 to 0.98 g/cm^3 for briquettes produced from corncob and rice husk without blending. The observed variation could be due to the production method adopted and the difference in the feedstock composition utilized in each study. The briquettes produced in Oladeji and Enweremadu [24] were not a composite type (a blend of feedstock), whereas the briquettes generated in the study were blends of the two feedstock. This could influence the density of the produced briquettes. The differences in densification pressure could also contribute to the variation in the values of density reported. The highest density (870 kg/m^3) of the dry briquettes generated in this research is higher than the lowest value of 600 kg/m^3 advised by Gilbert et al. [25] and Mani et al. [26] for management should focus and safekeeping.

3.3. Shatter index

As presented in Fig. 5, the durability of the briquettes varied from 32.32 to 99.13%. The least durability was obtained from a sample of 1.0 mm particle size, 80:20 blending ratio, and 25 kPa compaction pressure, while the highest durability from a sample of 0.25 mm grain size, 50:50 (corncob: rice husk) mixing ratio and 65 kPa compaction pressure. Moreover, it was discovered that durability rises as the total proportion of rice husks increases. This suggests that rice husk was crucial in enhancing the durability of blended fuel briquettes (Fig. 6). This is because, as shown by sieve analysis, rice husk particles are more evenly dispersed and have fewer pore spaces, which improves the interparticle bonding characteristic of the briquettes' particles and so increases their durability properties.

Another critical factor that influences durability is the particle size of the briquette mixture. As particle gets finer, the durability of blended briquettes improves, and this is because smaller particle sizes have a less porous structure and a greater surface area. The mixed particles have stronger cohesive forces, which cause the particles to interconnect and bond together. Similarly, compaction pressure also affects durability, as illustrated in Fig. 5. The illustration shows durability increases as compaction pressure rises since pressure strengthens the interparticle bonding of briquette particles. The application of pressure reduces the pore spaces and intermolecular distance between the particles of the fuel briquettes. Also, it improves the bonding property of the binder used for producing the briquettes. The result shows that finer particles and higher compaction pressure yielded higher durability for the briquettes.

The durability characteristics of the produced briquettes are in trend and even better compared with what was reported by previous studies. Odusote and Muraina [19] found that the mesocarp fiber and palm kernel shell briquette had an 88.43 to 97.6% durability range. Sawdust and wheat straw briquettes were found to have a range of 46.5 to 88.4% by Wamukonya and Jenkins [27], and paper waste and coconut husk intermixing briquettes were found to have a range of 93.3 to 98.5% by Olorunsola [28]. The higher durability ranges reported in Olorunsola [28] could be due to the addition of paper waste in the blends. Paper wastes have been reported to function as suitable binders in biomass briquette production, which could be responsible for the enhanced durability [29,30]. The maximum durability values obtained in this study are higher than the maximum values reported in Olorunsola [28], Wamukonya and Jenkins [27], and Odusote and Muraina [19], and this could be due to the binder (cassava starch) utilized for the production of the briquettes. The variations in the results obtained in the present study compared to others could be traced to the different types of material used and possibly the production techniques adopted.

3.4. Drop to fracture

The drop-to-fracture number required to break the fuel briquettes into smaller pieces is shown in Table 3. The highest number of drops before fracture was 13 and was obtained with samples of 0.25 mm particles, 65 kPa compaction pressures, and a 50:50 blending ratio. At the same time, 2 was the least number of drops and was observed with samples of 1.0 mm particle size, 25 kPa compaction pressures, and 100CC: 0RH blending ratio. As the particle size became finer, the number of drops to fracture was observed to increase, which implies that the finer the particle size, the higher the drop fracture number, hence the better the resistance of the briquettes to fracture. Higher compaction pressure was also observed to improve the drop-to-fracture number and the blending ratio. Table 3 demonstrates that the more rice husk there is in the mixture, the higher the drop to fracture number, and this might be due to the nature of the rice husk material and its particle distribution. The present study was compared with Zhong et al. [31] for briquettes made from coal using a blend of molasses and pitch as a binder which reported a drop to fracture of 57 times/2m. The results of this present study are lower than that of Zhong et al. [31], which might be due to the kind of binder employed, the composition of the feedstock, and the process utilized to create the fuel briquettes.

3.5. Impact resistance index (IRI)

Fig. 7 shows the influence of compaction pressure and particle size on IRI at various blending ratios, ranging from 10 to 650. The graph demonstrates that IRI increases as compaction pressure increases and particle size decreases, corresponding to the drop to fracture results. At 1.0 mm particle size, 25 kPa compaction pressure, and 100CC:0RH (corncob: rice husk), the susceptibility to impact force was found to be

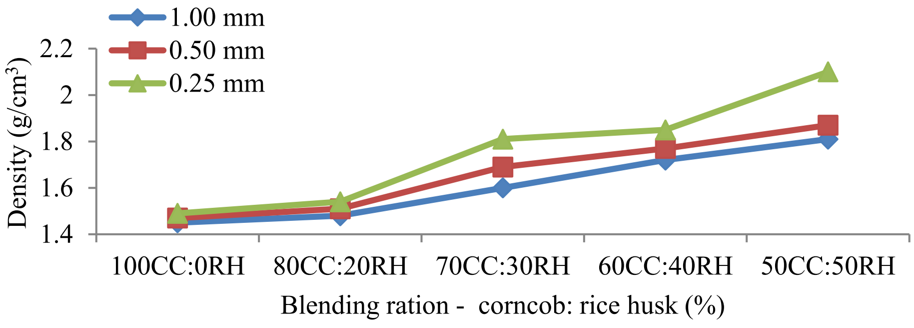
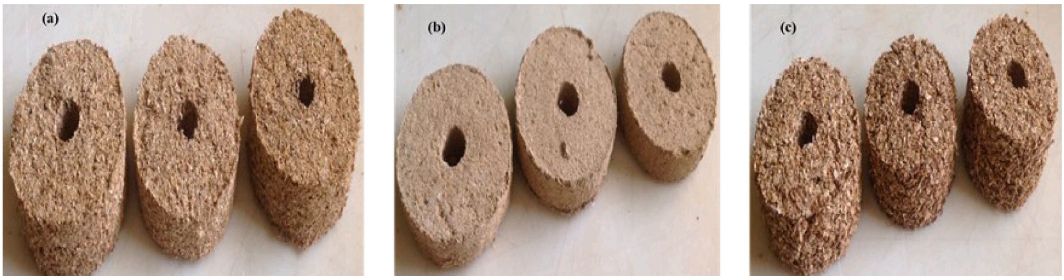


Fig. 3. Effect of blending ratio on density.



(a) 0.5mm (b) 0.25mm (c) 1.0 mm

Fig. 4. Briquettes samples for different particle sizes- (a) 0.5 mm, (b) 0.25 mm, and (c) 1.0 mm.

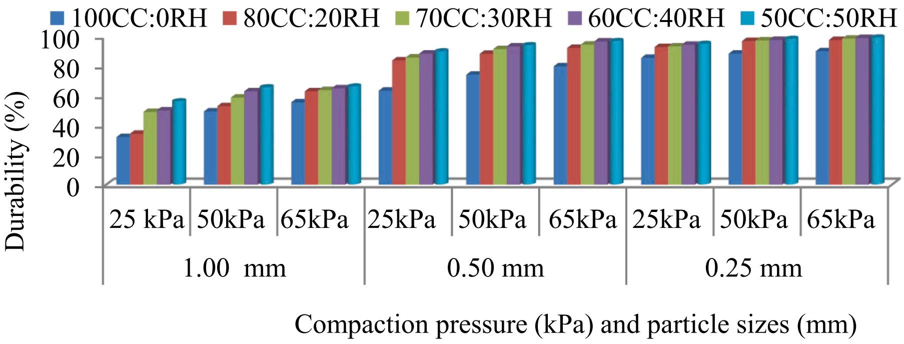


Fig. 5. Effect of compaction pressure and particle size on durability.

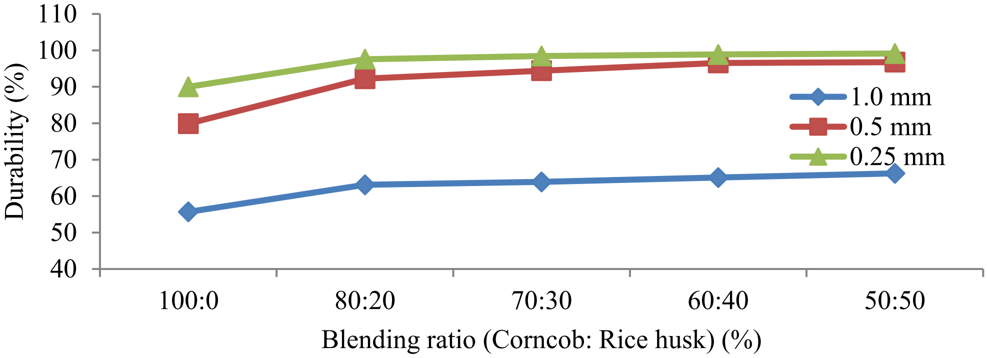


Fig. 6. Variations in durability based on the different blending ratios.

Table 3
Effect of particle size, compaction pressure, and mixing ratio on the drop to fracture.

Particle sizes (mm)	Compaction pressure (kPa)	Drop to fracture (times/2m); Blend ratios (corncob: rice husk)				
		100:00	80:20	70:30	60:40	50:50
1.00	25	2	2	3	3	4
	50	3	5	6	6	7
	65	4	5	6	8	8
0.50	25	3	4	4	5	5
	50	3	4	5	7	7
	65	5	5	6	9	10
0.25	25	4	6	6	10	11
	50	7	8	9	11	12
	65	7	8	10	12	13

the poorest, while the strongest resistance to impact was observed at 50CCC:50RH, 0.25 mm particle size, and 65 kPa compaction pressure. Briquettes from 50CC:50RH exhibited the highest impact resistance. This was expected as these briquettes have higher compressed and relaxed density. Increased compressed density and finer particle sizes enhance durability, drop to fracture, and IRI. The bonding property of the binder was enhanced by applying compaction pressure. This is because an increase in compacting pressure led to an increase in temperature within the compressed compartment that accommodated the feedstock during the briquetting process, which enhances the intermolecular bonding of the particles of the briquettes and binder, making it resistant to impact loads. It was also discovered that increasing the percentage of corncob in the blend decreased the resistance of the briquettes to impact force, which was due to the poor particle distribution of corncob revealed by the sieve analysis result and poor resistance to impact force, which could also be attributed to the feedstock type.

Furthermore, the smaller particle has a larger surface area with a lesser interstitial distance between the particles, which makes the particles closely parked, improving intermolecular force and enhancing the fuel briquettes' resistance to impact forces. The IRI of the produced briquettes in this research is greater than the 50 proposed briquettes used for industrial application by Richard [20] and Thoms et al. [32].

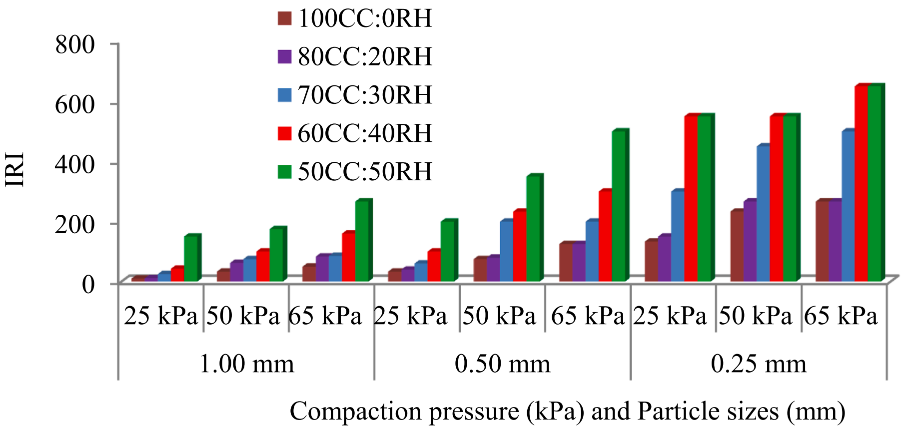


Fig. 7. Effect of compaction pressure and particle size on IRI.

Nevertheless, some samples with IRI less than 50 were found around 1.0 mm particle sizes, which is traceable to the particle distribution and lesser amount of rice husk in the briquette blends. The particles are loosely packed, which has a negative impact on the IRI. Also, the values of IRI obtained in this study are less than 1000, as Blesa et al. [33] recommended for briquettes used for industrial and domestic applications. The type of materials utilized and the process employed to make the briquettes could impact the discrepancy and the mechanical properties.

3.6. *Compressive strength*

The outcome of the compressive strength at various mixing ratios and particle sizes is shown in Table 4. The highest compressive strength of 116 kN/m^2 was achieved with briquettes made at 80CC:20RH mix proportion, 0.25 mm particle size, and 65 kPa compaction pressure, whereas briquettes with a 50:50 mix proportion, 1.00 mm particle size, and 25 kPa compaction pressure have the lowest value of 42 kN/m^2. Compressive strength increases as the briquettes particle get finer and as the compaction pressure increases. This can be associated with the type and amount of binder used. The amount of gelatinized starch increases the viscosity of the binding agent. Following Kaliyan and Morey [15], very viscous binders like gelatinized starch cling to the interfaces of feedstock particles to produce solid bridge-like strong connections. Many viscous binders cool and harden, forming a solid bridge that increases the strength to withstand cold pressure.

It may also be due to fewer interstitial spaces by applying pressure. Table 4 also reveals that the compressive strength drops with a rise in the amount of rice husk in the mixture. This may be due to the composition of the material, which shows that more rice husk in the mixture may weaken the fuel briquettes.

According to Tuates et al. [34], briquettes manufactured from carbonized rice husk and corncob had compressive strengths of 0.24 and 1.13 kN/m^2, respectively, which was observed to be smaller when compared with the results of this present study. The differences in the compressive strength could be due to the carbonization treatment approach adopted by Tuates et al. [34] for the briquette production. This is because thermal treatment processes such as carbonization has been reported to reduce the amount of lignin available in the feedstock for binding to take place during briquette production- thermal treatment results in the decomposition of the lignin in the biomass, which could result in low compressive strength. However, Oliveira et al. [35] reported a compressive strength of 360 kN/m^2 for briquettes made from banana leaf waste. The physico-mechanical qualities of briquettes produced by a screw press differed from those produced by a piston press. Therefore the variances may be caused by the type of binder and feedstock used to produce the briquettes and the method utilized for manufacturing the briquettes [34].

Table 4
Relationship between the compressive strength and the particle size, compaction pressure, and blending ratio.

Particle sizes (mm)	Cold crushing strength (kN/m^2); Blending ratio- (CC: RH)				
	Compaction pressure (kPa)	80:20	7030	60:40	50:50
1.00	25	63	52	44	42
	50	80	65	47	46
	65	94	68	50	48
0.50	25	83	59	55	51
	50	98	68	62	59
	65	102	88	76	71
0.25	25	84	65	61	55
	50	101	74	70	62
	65	116	90	88	75

4. Conclusion

This study produced briquettes from a mixture of rice husk and corncob and characterized their physical and mechanical properties. The following conclusions were reached:

i. Density rises as compaction force, and the amount of rice husk in the mixture rises and as particle sizes decrease;
ii. The durability improves with finer particle sizes and is directly correlated with compaction pressure;
iii. As the fraction of corncobs and particle sizes rise, drop to fracture and impact resistance decrease; and
iv. As particle size decreases, cold crushing strength increases. Additionally, it increases when the blend's compaction pressure and corncob content both increase.

The mixing ratio, particle size, and compaction force greatly impact the physical and mechanical characteristics of the produced briquettes.

The findings presented in this study point to potential advances in biomass briquette composition and processing methods for energy generation. This could result in cleaner and more effective fuel sources, increasing the sustainability of energy production and lowering harmful emissions. Agricultural residue such as rice husks and corncobs could address waste issues through large-scale collection and processing while supporting a circular economy. Furthermore, using biomass briquettes in renewable energy systems, including co-firing with coal, offers the potential to diversify and improve energy-generating sustainability.

CRediT authorship contribution statement

Segun E. Ibitoye: Conceptualizes the reseach, carried out the research and wrote the orignal ariticle. **Habeeb A. Ajimotokan:** Supervision. **Adekunle A. Adeleke:** Methodology, Data curation. **Chanchal Loha:** Writing – review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

References

[1] H.A. Ajimotokan, S.E. Ibitoye, J.K. Odusote, O.A. Adesoye, P.O. Omoniyi, Physico-mechanical properties of composite briquettes from corncob and rice, J. Bioresour. Bioprod. 4 (3) (2019) 159–165, https://doi.org/10.12162/jbb.v4i3.004.

[2] S.E. Ibitoye, T.C. Jen, R.M. Mahamood, E.T. Akinlabi, Densification of agro-residues for sustainable energy generation: an overview, Bioresour. Bioprocess. 8 (1) (2021) 1–19, https://doi.org/10.1186/s40643-021-00427-w.

[3] S.E. Ibitoye, R.M. Mahamood, T.-C. Jen, E.T. Akinlabi, Combustion, physical, and mechanical characterization of composites fuel briquettes from carbonized banana stalk and corncob, Int. J. Renew. Energy Dev. 11 (2) (2022) 435–447, https://doi.org/10.14710/ijred.2022.41290.

[4] A. Adewuyi, Challenges and prospects of renewable energy in Nigeria : A case of bioethanol and biodiesel production, Energy Rep. 6 (2020) 77–88, https://doi.org/10.1016/j.egyr.2019.12.002.

[5] H.A. Ajimotokan, S.E. Ibitoye, J.K. Odusote, O.A. Adesoye, P.O. Omoniyi, Physico-mechanical characterisation of fuel briquettes made from blends of corncob and rice husk, J. Phys. Conf. Ser. 1378 (02200) (2019) 1–12, https://doi.org/10.1088/1742-6596/1378/2/022008.

[6] S. E. Ibitoye, "M.Eng Thesis: Production and characterization of fuel briquettes made from blend of corncob and rice husk," Department of Mechanical Engineering, Faculty of Engineering and Technology, University of Ilorin, 2018.

[7] S.E. Ibitoye, T. Jen, R.M. Mahamood, E.T. Akinlabi, Improving the combustion properties of corncob biomass via torrefaction for solid fuel applications, J. Compos. Sci. 5 (10) (2021) 1–15.

[8] C. Karunanithy, Y. Wang, K. Muthukumarappan, S. Pugalendhi, Physiochemical characterization of briquettes made from different feedstocks, Biotechnol. Res. Int. 2012 (165202) (2012) 1–12, https://doi.org/10.1155/2012/165202.

[9] P.D. Grover S.K. Mishra Biomass briquetting: technology and practices no. 46 1996 Bangkok, Thailand.

[10] S. E. Ibitoye, R. M. Mahamood, T.-C. Jen, and E. T. Akinlabi, "Combined Torrefaction and Densification of Rice Husk: Effect of Process Parameters," in *Advances in Material Science and Engineeering: Lecture Notes in Mechanical Engineering*, Springer, 2023, pp. 201–211.

[11] H. Bhakta, A.K. Sarmah, B. Dubey, Hydrothermal carbonization of renewable waste biomass for solid biofuel production: A discussion on process mechanism, the influence of process parameters, environmental performance and fuel properties of hydrochar, Renew. Sustain. Energy Rev. 123 (2020) 1–22, https://doi.org/10.1016/j.rser.2020.109761.

[12] J.T. Oladeji, Theoretical aspects of biomass briquetting : A review study, J. Energy Technol. Policy 5 (3) (2015) 72–82.

[13] P. Wilaipon, Physical characteristics of maize cob briquette under moderate die pressure, Mech. Eng. Dep., Eng. Fac., Naresuan Univ. 4 (12) (2007) 995–998.

[14] S.E. Ibitoye, R.M. Mahamood, T.-C. Jen, C. Loha, E.T. Akinlabi, Design and fabrication of biomass densification machine for teaching and research purposes, Biomass Convers. Biorefinery (2023) 1–12, https://doi.org/10.1007/s13399-023-04455-8.

[15] N.V. Kaliyan, R. Morey, Factors affecting strength and durability of densified biomass products, Biomass Bioenergy 33 (3) (2009) 337–359, https://doi.org/10.1016/j.biombioe.2008. 08.005.

[16] O.F. Obi, K.C. Okongwu, Characterization of fuel briquettes made from a blend of rice husk and palm oil mill sludge, Biomass Convers. Biorefinery 6 (2016) 449–456, https://doi.org/10.1007/s13399-016-0206-x.

[17] J.T. Oladeji, Fuel characterization of briquettes produced from corncob and rice husk resides, Pacific J. Sci. Technol. 11 (1) (2010) 101–106.

[18] I. I. Ikelle, A. Chukwuma, and S. O. Ivoms, "The Characterization of the Heating Properties of Briquettes of Coal and Rice Husk," *IOSR J. Appl. Chem.*, vol. 7, no. 5, pp. 100–105, 2014, [Online]. Available: www.iosrjournals.org.

[19] J.K. Odusote, H.O. Muraina, Mechanical and combustion characteristics of oil palm biomass fuel briquette, J. Eng. Technol. 8 (1) (2017) 14–29.

[20] S.R. Richard, Briquetting peat and peat-coal mixtures, Fuel Process. Technol. 25 (1990) 175–190.

[21] Astm d2166–85, "Standard Test Methods for Compressive Strength," ASTM International 2008 West Conshohocken, PA www.astm.prg.

[22] K.E. Ileleji, B. Zhou, The angle of repose of bulk corn stover particles, Powder Technol. 187 (2008) 110–118, https://doi.org/10.1016/j.powtec.2008.01.029.

[23] Z. Li, W. Zhao, B. Meng, C. Liu, Q. Zhu, G. Zhao, Kinetic study of corn straw pyrolysis : Comparison of two different three-pseudocomponent models, Bioresour. Technol. 99 (2008) 7616–7622, https://doi.org/10.1016/j.biortech.2008.02.003.

[24] J. T. Oladeji and C. C. Enweremadu, "The Effects of Some Processing Parameters on Physical and Densification Characteristics of Corncob Briquettes," *Int. J. Energy Eng. 2012,* vol. 2, no. 1, pp. 22–27, 2012, doi: 10.5923/j.ijee.20120201.04.

[25] P. Gilbert, C. Ryu, V. Sharifi, J. Swithenbank, Effect of process parameters on pelletization of herbaceous crops, Fuel 88 (8) (2009) 1491–1497, https://doi.org/10.1016/j.fuel.2009.03.015.

[26] S. Mani, L. G. Tabil, and S. Sokhansanj, "Specific energy requirement for compacting corn stover," *Bioresour. Technol. 97*, vol. 97, pp. 1420–1426, 2006, doi: 10.1016/j.biortech.2005.06.019.

[27] L. Wamukonya, B. Jenkins, Durability and relaxation of swadust and wheat-straw briquettes as possibility for Kenya, Biomass Bioenergy 8 (3) (1995) 175–179.

[28] A. Olorunsola, "Production of Fuel Briquettes from Waste Paper and Coconut Husk," *Agric. Eng. Int. CIGR E-journal*, vol. 9, no. Manuscript EE 06 006, pp. 1–11, 2007.

[29] O.A. Oyelaran, B.O. Bolaji, M.A. Waheed, M.F. Adekunle, Characterization of briquettes produced from groundnut shell and waste paper admixture, Iran. J. Energy Environ. J. 6 (1) (2015) 34–38, https://doi.org/10.5829/idosi.ijee.2015.06.01.07.

[30] I.H. Gado, S.K. OuimingaDaho, T. Daho, A.H. Yonli, M. Sougoti, J. Koulidiati, Characterization of briquettes coming from compaction of paper and cardboard waste at low and medium pressures, Waste Biomass Valoriz. (December) (2013) 1–12, https://doi.org/10.1007/s12649-013-9282-3.

[31] Q. Zhong, Y. Yang, Q. Li, B. Xu, T. Jiang, Coal tar pitch and molasses blended binder for production of formed coal briquettes from high volatile coal blending carbonizin briquetting drying, Fuel Process. Technol. 157 (2017) 12–19, https://doi.org/10.1016/j.fuproc.2016.11.005.

[32] L.J. Thoms, C.E. Snape, D. Taylor, Physical characteristics of cold cured anthracite/coke breeze briquettes prepared from a coal tar acid resin, Fuel 78 (14) (1999) 1691–1695, https://doi.org/10.1016/S0016-2361(99)00116-7.

[33] M.J. Blesa, J.L. Miranda, M.T. Izquierdo, R. Moliner, Curing time effect on mechanical strength of smokeless fuel briquettes, Fuel Process. Technol. 80 (2003) 155–167.

[34] A.M. Tuates, A.R. Ligisan, O.A. Capariño, Physico-chemical and thermal properties of fuel briquettes derived from biomass furnaces as by-products, J. Japan Inst. Energ 95 (9) (2016) 859–867.

[35] B.G. De Oliveira, O. Souza, C. Marangoni, Production and characterization of fuel briquettes from banana leaves, Chem. Eng. Trans. 37 (2015) 439–444, https://doi.org/10.3303/CET1437074.

View publication stats