Full Paper

EFFECT OF SELECTED ARTIFICIAL BINDING AGENTS ON THE PELLETABILITY OF ORGANIC FERTILIZER

D.A. Fadare
Mechanical Engineering Department
University of Ibadan, P.M.B. 1, 20002, Ibadan
fadareda@gmail.com

O.A. Bamiro
Mechanical Engineering Department
University of Ibadan, P.M.B. 1, 20002, Ibadan

ABSTRACT

Selection of appropriate binder and its concentration poses great challenge in the application of artificial binding agents for pelletizing of organic fertilizer. In this paper, effects of three (3) artificial binders (kaolin, bentonite and corn starch) at three concentrations (2.5, 10 and 15% by weight) on the mechanical properties (crushing strength, brittle fracture index, axial elastic recovery, durability disintegration time and specific energy requirement) of organic fertilizer pellets were investigated. Cylindrical pellets of 25 mm diameter and 20 mm long were formed using a uniaxial compression machine. The L9 Taguchi orthogonal array design experiment was used to determine the percentage influence of type and concentration of the binders on the variability of the mechanical properties of the pellets. Results showed that the type of binder had the greatest percentage influence of 90.4% (disintegration time), 67.9% (crushing strength), 56.2% (durability), 40.5% (axial elastic recovery), 85.5% (specific energy requirement), while the concentration of the binder showed no significant effect except on the brittle fracture index where the concentration had the highest influence of 36.8%. Corn starch was found to be the best binder with optimal concentrations of 15% for crushing strength, axial elastic recovery, durability and disintegration time, and 10% for brittle fracture index.

Keywords: *Organic fertilizer pellet; binder; mechanical properties; kaolin; bentonite; corn starch*

1. INTRODUCTION

The application of artificial binding agents plays a crucial role in the sustainability of various compaction processes such as: pelletizing, bailing and wafering, briquetting, and tableting. Hence, the choice of appropriate binder and its level of concentration pose great challenges in the use of artificial binding agents in pelletizing of organic fertilizer (Fadare, 2003). Organic fertilizers or compost are produced from controlled decomposition of organic matter. They contains important plant nutrients, which improves the physical, chemical (nutritional) and biological properties of soil and plant growth media (Gould, 2012). The most popular applications of organic fertilizers or compost are as soil amendment and mulch to improve soil health of new and existing installations of plant beds and around trees (Organic Monitor, 2012). The global concern for organic farming is the major driving force for the increase in demand for organic fertilizer and green manure worldwide. Since 1990, the market for organic products has grown from nothing, reaching $55 billion in 2009 (Organic Monitor, 2012). Correspondingly, the total number of organic producers worldwide has increased form 0.2 million in 1999 to about 1.8 million in 2009 (Willer and Kilcher, 2011). Approximately, 37.2 million hectares worldwide are now farmed organically, representing approximately 0.85 percent of total world farmland in 2009 compared with the 11.0 million hectares of organic farmland in 1999 (Willer and Kilcher, 2011). The current global demand potential for organic fertilizer was estimated as 1.06 billion tons annually (Esengun et al., 2007). The use of organic fertilizer or compost is known to be more efficient and environmentally friendly compared to the conventional inorganic fertilizers (Fadare, 2003). Major benefits of using organic fertilizer or compost include: improving soil structure, creating a better plant root environment, supplying significant quantities of organic matter, improving drainage of soil, reducing soil erosion, improving moisture holding capacity of soils, improving and stabilizing soil pH, supplying a variety of nutrients, and supplying the soil with beneficial micro-organisms (Alexander, 2003; Sæbø and Ferrini, 2006; Nevens and Reheul, 2003; Arthur et al., 2011). According to the quantitative analysis of Battelle (2012), the demand for organic fertilizer in the US is about 10 times that of its supply, thus indicating the gross shortage in the supply of organic fertilizer. Despite the high demand for organic fertilizer, its supply has been hindered due to economic factors relating to its "bulkiness" and hence high associated transport and spreading costs compared to that of inorganic fertilizers. In order to overcome this setback, the current trends in composting is towards the compaction of the loose particulates into high density (pelletizing) with main benefits, which includes: reduction in volume, ease of packaging and handling, control of the rate of nutrient release, and improvement in the quality (Weber et al., 2007). Compacting of loose particulates to high density has been widely used with cohesion being achieved through application of pressure and/or temperature with addition of additives such as artificial binders which confer strength to the agglomerates, and as lubricants to reduce friction during the compaction operation. The selection of appropriate binding agent is one of the most critical parameters in pelletizing process. The influence of binding agent on the characteristics of the pellets is both essential in the design and construction of the pelletizing machine and the economic production of the pellets. A comprehensive survey of literature on the effect of binding agent on the pelletability of lignocelluloses agricultural materials has been reported by O'Dogherty (1989). Despite this volume of literature, there is paucity of information on the study of binding agent in the pelletization of organic fertilizer or compost. The energy utilization analysis and energy cost for pelletization of organic fertilizer in Nigeria has been reported by same authors earlier (Fadare et al., 2009; 2010). The work of John et al. (1996) reported the study on the effect of concentration (10 and 20% w/w) of clay as binding agent on the pelletability of composts of poultry droppings and/or sawdust. An increase in pellet's stability/strength was observed with increase in concentration of the binder for compost made from poultry droppings. However, it was also reported that the composts made from sawdust, and the combination of sawdust and poultry manure could not be pelletized satisfactorily under the tested conditions. Other potential artificial binding agents that have not been fully exploited in pelletizing of compost includes kaolin, bentonite and corn starch. The aim of this paper is to investigate the effect of kaolin, bentonite and corn starch at three concentrations (2.5, 10.0 and 15.0% by weight) on the mechanical properties of pellets of organic fertilizer made from co-composted market refuse and abattoir waste. In view of determining optimum process parameters required for design and operation of commercial scale organic fertilizer pelletizing plant.

2. MATERIALS AND METHODS

2.1. Organic Fertilizer Preparation

Samples of market refuse and abattoir waste generated in a typical municipal market located in Ibadan, south-western, Nigeria, were collected. The market refuse was sorted into two fractions consisting of the biodegradable and non-biodegradable. The biodegradable fraction, which includes food waste, paper, fruits and leaves was shredded in a shredding machine to particle size less than 20 mm. The shredded biodegradable fraction was then co-composted aerobically with the abattoir waste at ratio of 3:1 by wet weight inside open windrow for about 60 days. During the composting period, the windrow was sprinkled with water and turned manually using shovels and garden forks for aeration and circulation of oxygen. Turning of the windrow was done once in every three (3) days for the first fifteen (15) days and thereafter, once every seven (7) days to the end of the composting period. After the composting process, the compost was cured for another 60 days by leaving the windrow unturned and without addition of water. The compost was then dried in a rotary dryer at temperature 60^{0}C for 6 hours. The dried compost was then screened with a sorting machine and milled with a pulverizing machine to particle size of 5.27 μm. The detailed composting process and the determination of the physico-mechanical and chemical properties of the compost have been reported earlier (Fadare, 2003).

2.2. Artificial Binding Agents

Corn (*Zea mais*) starch was obtained from the Department of Industrial Pharmacy, University of Ibadan, Nigeria, while kaolin and bentonite samples were supplied by Raw Material Research and Development Council (RMRDC) Abuja, Nigeria. Samples of 1,000 g compost with corresponding weights of binding agents at varying concentrations of 2.5, 10.0 and 15.0% by weight were measured. The binding agents were dispersed in 200 mL of distilled water. Corn starch dispersion was heated in a water bath at temperature of 95^{0}C for 20 min to form starch gel. The compost and the binding agents were mixed manually.

2.3. Experimental Design

A 3-level (L_9) Taguchi Orthogonal Array experimental design (WinRobust, 1995) was used to determine the main effects of the factors (type and concentration of the binding agent) on the properties of the pellets and to determine the optimum combination of the levels of the variables that give favourable properties (crushing strength, brittle fracture index, axial elastic recovery, durability disintegration time and specific energy requirement)_of the pellets. The two (2) factors at three (3) levels of the experimental design are shown in Table 1. The L_9 Taguchi array experimental design matrix is shown in Table 2. Factors (3) and (4) of the array were assigned as error to account for the uncertainties due to interactions between variables, measurement error and uncontrolled factors. A total of nine (9) experiments were conducted for different combinations of factor and levels.

Table 1: Factor and level with code used the experimental design

Factor	Level		
	(1)	(2)	(3)
Type of binder	Kaolin	Corn starch	Bentonite
Concentration of binder (%)	2.5	10.0	15.0

Table 2: The L_9 Taguchi array experimental design matrix

Exp. No.	Type of binder (1)	Conc. of binder (2)	Error (3)	Error (4)
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

2.4. Compression Tests

Compression tests were conducted on a laboratory hydraulic compression rig (AB specimen mount press). Cylindrical pellets with 25 mm diameter and 25 mm long were formed using closed end cylindrical die assembly. Pellets with 3 mm hole in the centre were formed using a lower punch with a 3 mm pin fixed in the centre and the upper punch with a corresponding hole drilled at the centre. 18 g of each sample were compressed at constant compression speed (0.005 ms^{-1}) to a maximum pressure of 79.0 MPa. The maximum pressure was held for 3 minutes before ejecting the pellets. During each test, initial length of pellet before compression (L), displacement (S) and applied pressure (P) were measured. The experimental setup and dimensions of the die assembly are shown in Figures 1 and 2, respectively. Prior to each test the inside of the die assembly was lubricated with soluble oil to facilitate the ejection of the pellets. The compression ratio (r) was calculated (Faborode and O'Callaghan, 1986) as:

$$r = \frac{L}{L - S} \tag{1}$$

Where L is initial length of pellet (mm) and S is displacement (mm).

The compression curve for each experiment was obtained as the plot of applied pressure (P) against compression ratio (r).

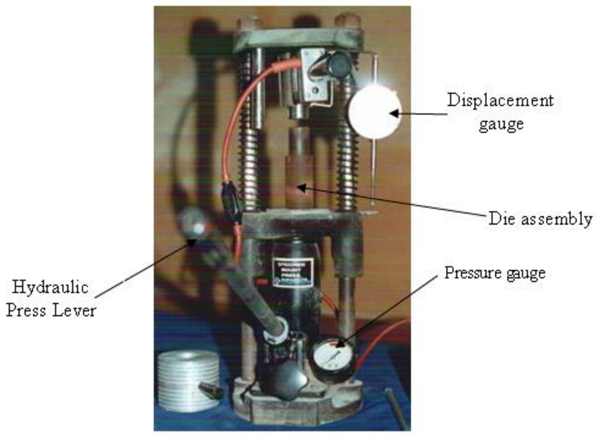

Fig. 1: Experimental setup

2.5. Determination of specific compression energy

The compression curves were modelled using three common mathematical models: exponential model (Equation 2) proposed by Ajayi and Lawal (1995); power model (Equation 3) proposed by O'Dogherty and Wheeler (1982); and the modified exponential model (Equation 4) proposed by Faborode and O'Callaghan (1995):

$$P = Ae^{Br} \tag{2}$$

$$P = Ar^{B} \tag{3}$$

$$P = \frac{A}{B}\left[e^{B(r-1)} - 1\right] \tag{4}$$

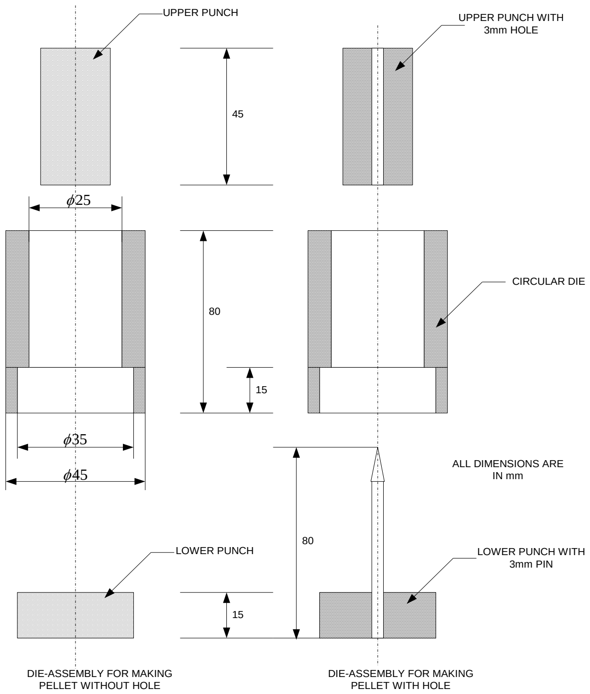

Fig. 2: Dimensions of the die assembly

where, P is applied pressure, r compression ratio, and A and B are empirical constants.

A curve fitting program using unconstrained least square procedure of damped Taylor's series (Spath, 1967) was developed with FORTRAN 90 to determine the model parameters based on Equations 2 - 4. The model predictive performance was evaluated based on the coefficient of determination (r^2). The empirical constants A and B, and the corresponding r^2 for each model were evaluated.

The compression energy (E) requirement for pelletization was determined as the area under the compression curve given by the model with the highest value of coefficient of determination. For the exponential model (Equation 2), the area under the curve was expressed in the general form as:

$$E = \int_{r=0}^{\max r} A\left[\exp^{Br}\right] dr \tag{5}$$

Which upon integration gives:

$$E = \frac{A}{B}\exp(Br)_{\max r} - \frac{A}{B}\exp(Br)_{r=0} \tag{6}$$

2.6. Determination Of Mechanical Properties Of Pellets

The compressive force required to diametrically fracture the pellet was determined by using a tensometer (Type "W", Monsanto, U.K.) and the crushing strength and the brittle fracture index were calculated (Odeku and Itiola, 2002) as:

$$T_D = \frac{2N}{\pi dH} \tag{7}$$

$$T_{D0} = \frac{2N_0}{\pi dH} \tag{8}$$

$$BFI = \frac{T_D - T_{D0}}{2T_{D0}} \tag{9}$$

Where T_D is crushing strength of the pellets without hole (Nm^{-2}); T_{D0} is crushing strength of the pellets with hole (Nm^{-2}); N is compressive force required to diametrically crack/fracture the pellet without hole (N); N_0 is compressive force required to diametrically crack/fracture the pellet with hole (N); d is the diameter of the pellet (m); H is the length of the pellet (m); and BFI is brittle fracture index of pellets.

The axial elastic recovery was calculated using the expression (O'Dogherty and Wheeler, 1982):

$$ER_a = \frac{L_2 - L_1}{L_1} X100\% \tag{10}$$

Where ER_a is axial elastic recovery (%); L_1 is the initial length of pellet before ejection from the die (mm); L_2 is the final length of pellet after ejection (mm).

The durability of the pellets was determined using a laboratory durability tester at the speed of 60 rpm for 5 minute in accordance with the ASAE standards (ASAE, 1998). The initial weights of the pellets before and after the test were measured. The durability of the pellets was calculated as the percentage of the final weight to the initial weight of pellets:

$$\eta = \frac{W_f}{W_i} \times 100\% \tag{11}$$

Where η is durability of pellets (%); W_i is initial weight of pellets before test (kg); W_f is final weight of pellets after test (kg).

The disintegration time (hr) of the pellets was determined as described by Adebayo and Itiola (1998) and Odeku and Itiola (1994) as the time required for the pellets to disintegrate completely into the original particle when in contact or immersed in water.

All measured properties of the pellets were replicated four times.

3. RESULTS AND DISCUSSION

The empirical constants A and B, and the corresponding r^2 of the three compression models investigated are shown in Table 3. The exponential and power law models (Equations 2 and 3) gave consistently high values of r^2 with respective values ranging from 0.9827 - 0.9989 and 0.9634 - 0.9997, while the modified exponential model gave the least with values ranging from 0.7761 - 0.8911. For ease of application, the exponential model (Equation 2) was chosen as the empirical model for the compression curve. Figure 3 shows the exponential compression models for kaolin, bentonite and corn starch at 10.0% concentration, while the exponential compression models for 2.5, 10.0 and 15.0% concentrations of Kaolin are shown in Figure 4.

Samples of pellet formed with hole and without hole with 2.5% concentration of corn starch are shown in Figure 5. The mean values of crushing strength, brittle fracture index, axial elastic recovery, durability, disintegration time and specific energy requirement for compression of the pellets for the different experiments are given in Table 4. The variation in the mechanical properties of the pellets for the different types and concentrations of binding agent are shown in Figures 6 (a-f).

3.1. Effect Of Binder On Pellets Crushing Strength

The variation in the crushing strength of the pellets is shown in Figure 6(a). It was observed that, the crushing strength increased rapidly as the concentration increased for bentonite and kaolin, while for corn starch, crushing strength increased slightly with increase in concentration. For all concentrations investigated, the crushing strength for corn starch was consistently higher than bentonite and kaolin. The order of magnitude was corn starch › bentonite › kaolin.

Except at lower concentration (2.5%) where the crushing strength for kaolin was higher than that of bentonite. The results could be attributed to the smaller particle size and higher fluidity of corn starch compared to bentonite and kaolin. Corn starch tended to flow easily within the crevice of the particulate to form a stronger bond. Hence, when the crevice is saturated, increase in concentration tends to have no effect on the binding strength for corn starch. Whereas, unsaturation due to low fluidity of bentonite and kaolin resulted in increase in crushing strength with increased concentration. Crushing strength is the measure of the binding strength and the resistance of the pellet to impact force, thus indicating ability of the pellet to retain its shape and size during handling. Hence, high crushing strength is recommended for pellet.

Table 3: Compression curve model parameters

Exp. No.	Exponential law model (Equation 2)			Power law model (Equation 3)			Modified exponential model (Equation. 4)		
	A	b	R^2	A	b	R^2	Ax(E-20)	Bx(E-08)	R^2
1	0.0216	3.6979	0.9912	0.3761	6.5203	0.9826	0.0149	7.5444	0.7761
2	0.0094	4.1990	0.9989	0.2266	7.4863	0.9997	0.6352	4.8997	0.7691
3	0.0172	3.9166	0.9945	0.3673	6.8464	0.9871	0.0100	6.1628	0.7656
4	0.1239	2.9015	0.9889	1.4131	4.8118	0.9736	0.0102	6.2243	0.8482
5	0.1499	2.9074	0.9827	1.9300	4.5898	0.9634	0.1306	2.2134	0.8593
6	0.1611	2.9348	0.9948	2.1500	4.5942	0.9834	4.2856	1.2643	0.8911
7	0.0701	3.376	0.9976	1.2222	5.5370	0.9975	4.5698	1.3059	0.8724
8	0.0711	3.3302	0.9979	1.1853	5.4444	0.9906	9.7704	1.9128	0.8538
9	0.101	3.1777	0.9847	1.5714	5.0824	0.9761	5.0512	1.3732	0.8686

Table 4: The measured mechanical properties of pellets

Exp No.	Response (Mechanical property)					
	Crushing strength T_D (kNm^{-2})	Brittle fracture index	Axial Elastic recovery (%)	Durability (%)	Disintegration time (hr)	Specific compression energy (MJ/ton)
1	49.49	4.75	4.12	23.50	1.20	469.97
2	123.18	0.42	4.06	64.20	1.40	489.95
3	151.13	0.34	3.98	75.60	1.50	547.21
4	348.95	0.09	3.45	98.50	27.70	689.06
5	387.56	0.04	2.14	99.50	31.50	842.02
6	406.74	0.06	2.12	99.60	48.80	947.91
7	10.65	1.83	5.02	5.30	0.90	875.41
8	172.81	0.49	3.91	53.10	1.60	820.79
9	329.25	0.97	2.17	74.30	2.40	898.21

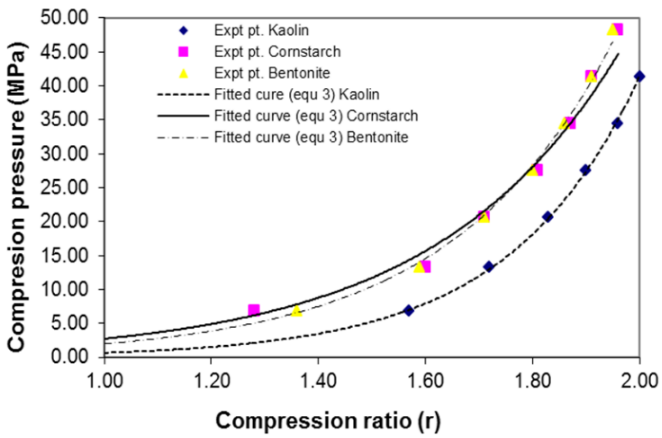

Fig. 3: Exponential compression models for kaolin, bentonite and corn starch at 10% concentration.

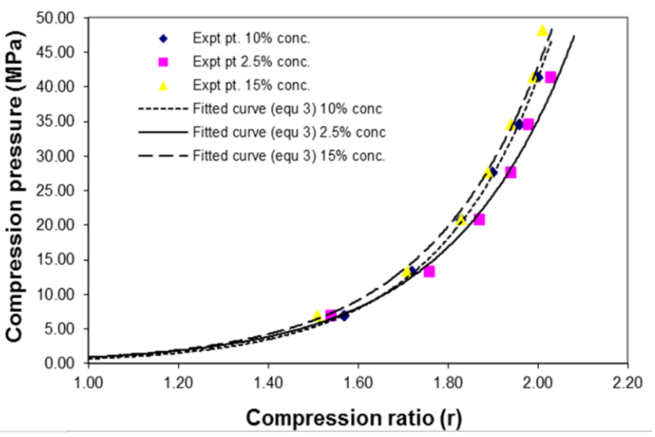

Fig.4: Exponential compression models for 2.5, 10.0 and 15.0% concentrations of Kaolin

This result suggests corn starch as a favourable binder from the point of view of binding strength. Similar increase in crushing strength with increase in concentration of binding agents has been commonly reported by many investigators (Ajayi and Lawal, 1995; Chaplin, 1975; Wealti and Dobie, 1973; Dobie and Walker, 1977).

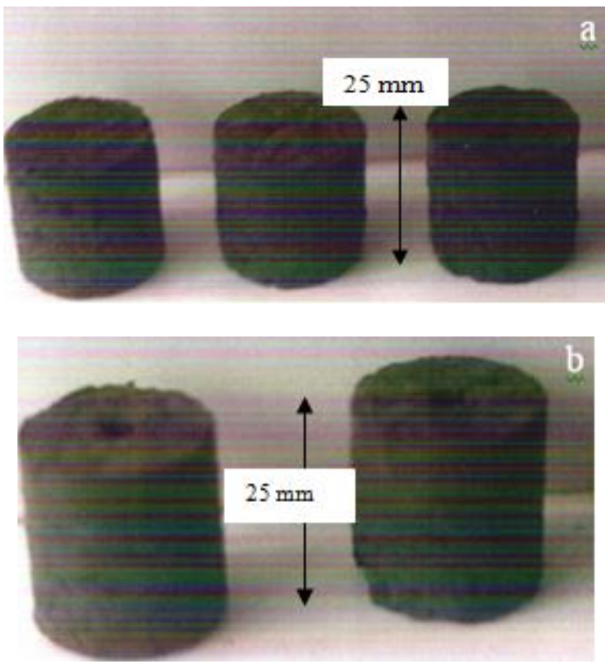

Fig. 5: Samples of pellets without hole (a) and pellets with hole (b) formed with 2.5% concentration of corn starch

3.2. Effect Of Binder On Pellets Brittle Fracture Index

Figure 6(b) shows the influence of the binders on the brittle fracture index of the pellets. The results showed that for kaolin and bentonite the brittle fracture index decreased initially with increased in concentration from 2.5 – 10.0%. With further increase in concentration above 10.0% the brittle fracture index increased for bentonite, while the brittle fracture index decreased slightly for kaolin. For corn starch the brittle fracture index was lower and remained constant as the concentration increased. The brittle fracture index is the measure of the binding efficacy of the binder at inter-particulate junctions of the particles, which facilitates plastic deformation for the relief of localized stresses and hence limits the lamination tendency in pellets. Hence, a lower brittle fracture index is normally preferred in selection of appropriate binder. From this point of view, corn starch appeared to be more favoured compared to bentonite and kaolin. Odeku and Itiola (1998 and 2002) reported reduction in brittle fracture index with increase in concentration of different binders used for tableting of pharmaceutical products.

3.3. Effect Of Binder On Pellets Axial Elastic Recovery

Figure 6(c) shows the effect of the binders on the axial elastic recovery of the pellets. It can be seen that the axial elastic recovery decreased generally with increase in concentrations for corn starch. For kaolin, the axial elastic recovery remained fairly unchanged, while for bentonite, axial elastic recovery decreased initially with increase in concentration from 2.5–10.0% and remained unchanged with further increase in concentration above 10.0%. Generally, as the crushing strength increases with concentration of binder, the elastic recovery tended to reduce. Elastic recovery is the measure of the tendency of pellets to relax or increase in dimensions after the release of the applied load. Hence, lower elastic recovery is preferred in the selection of binder. In this case, corn starch appeared to be the most preferred binder. Axial recovery ranging up to 85% of initial length and insignificant radial recovery ranging between 2.8 to 4.6%, which tends to reduce with increase in binder concenstration has been reported for compression of sawdust (Ajayi and Lawal, 1995).

3.4. Effect of Binder On Pellets Durability

Figure 6(d) shows the variation in the durability of the pellets. It was observed that the durability increased linearly as the concentration increased for bentonite and kaolin. For corn starch the durability was higher and remained unchanged with increase in concentration. The pellets stability or durability is the measure of its resistance against abrasive wears and impact during handling. It is the ability of the pellet to retain its shape and size form without disintegrating during handling. Hence, high value of durability is generally preferred in the selection of binder. In this case, corn starch appeared to be the most preferred binder. A general increase in the durability has been reported with the use of binding agents (Ajayi and Lawal, 1995; Chaplin, 1975).

3.5. Effect of Binder on Pellets Disintegration Time

The effect of the binding agent on disintegration time is shown in Figure 6(e). For corn starch, the disintegration time increased slightly with increase in concentration from 2.5-10.0% and increased rapidly with concentration above 10.0%. The disintegration time for kaolin and bentonite showed similar trend, with lower values compared to corn starch and fairly constant with increase in concentration. Disintegration time of 5.1, 1.7 and 10.4 min have been reported for paracetamol tablets with 4.0% concentration of Khaya gum, PVP and gelatin respectively (Odeku and Itiola, 2002; 2003). Similar values of 1.1 and 4.5 min have been reported for tablets formed with 10% concentration of yam starch and corn starch respectively (Odeku and Itiola., 1998).

3.6. Effect Of Binder On Specific Compression Energy

Figure 6(f) shows the variation in specific compression energy with concentration of the binders. It can be observed that for range of concentrations used, kaolin required the least energy input. At lower concentrations, less than 10%, bentonite required the highest energy input and the ranking of the value of compression energy was in the order: bentonite › corn starch › kaolin, while at concentration above 10% corn starch required the highest energy in order: corn starch › bentonite › kaolin. The energy requirement for pelletization generally ranged between 469.97 - 947.9 kJ/ton. For compressing grass and lucerne, Shepperson and Marchant (1978) observed a high range of specific energy requirements of 120 - 220 MJ/ton and for wafering of straw a range of 90 - 180 MJ/t was reported by Chaplin (1975). The observed values for the compression of the compost were generally lower than other published works. In terms of energy efficiency, kaolin with the least energy requirement is considered the best binder.

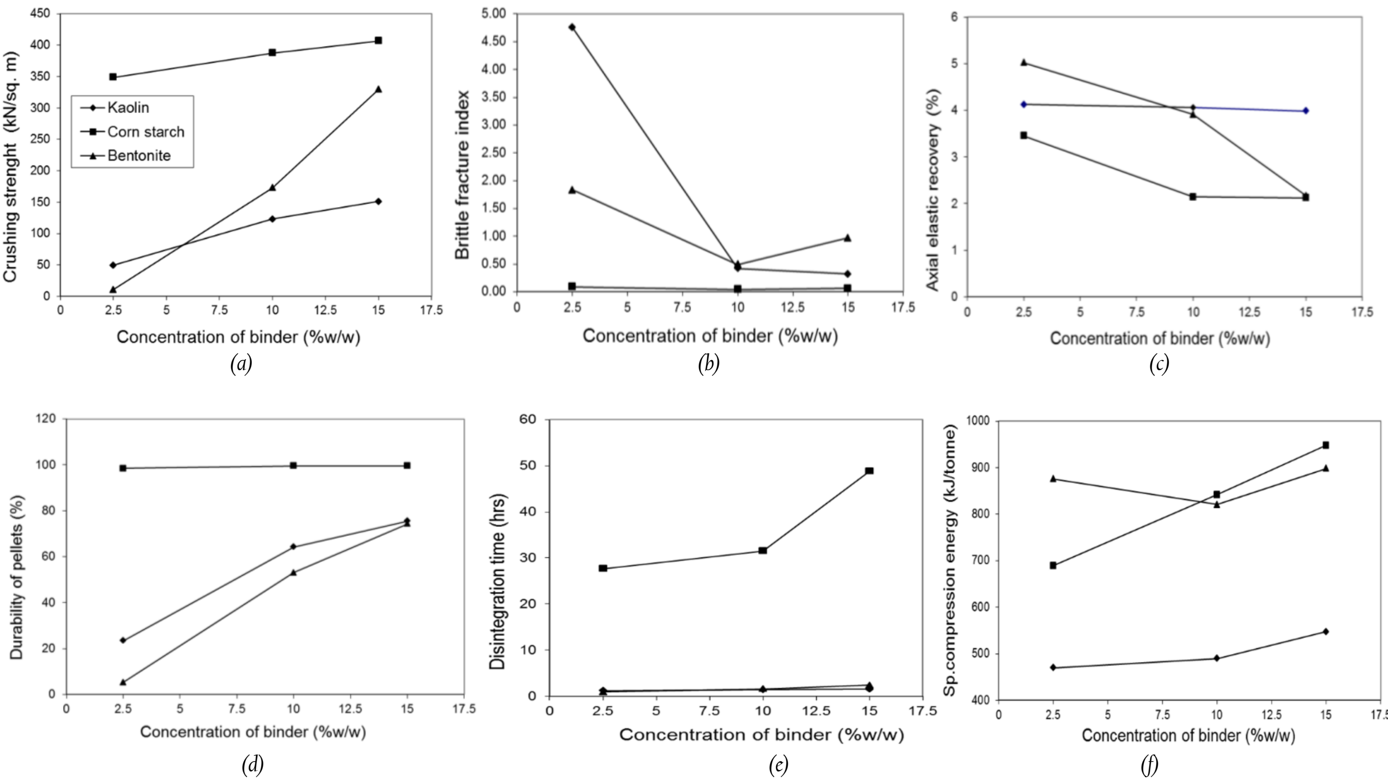

Fig. 6: Effect of binding agents on the properties of pellets: (a) crushing strength; (b) brittle fracture; (c) axial elastic recovery; (d) durability; (e) disintegration time and (f) specific compression energy requirement

3.7. Determination of Optimum Process Parameters

The optimum process conditions that gave the highest favourable magnitude of the properties are summarised in Table 6. The 90% confidence intervals for the predicted properties were 23.5, 16.5, 6.1, 18.8 and 5.3 for crushing strength, brittle fracture index, elastic recovery, durability and disintegration time respectively. Figure 5 shows the order of magnitude of influence of each factor on the properties. It showed that the type of binding agent had the greatest magnitude influence of 90.4% (Disintegration time), 67.9% (Crushing strength), 56.2% (Durability), 40.5% (Axial elastic recovery), and 85.5% (specific energy requirement),

3.8. Analysis of Variance (ANOVA)

The analysis of variance (ANOVA) of the factors on the properties of the pellets is shown in Table 5. The main effect plots of the factors on the pellet's mechanical properties are shown in Figure 6. It can be seen that variation in type and concentration of the binder agents had different effect on properties of the pellets. The relationships between the process variables (type and concentration of binder) and the mechanical properties of the pellet were modelled with the additive model (Phadke, 1989):

$$\Pr op = \overline{T}_i + \overline{C}_i - \overline{Q} \text{ , i = 1-3} \qquad (12)$$

Where, Prop is the predicted mechanical property, $\overline{T}_i$ is the mean of all the experimental data with type of binder at level i, $\overline{C}_i$ is the mean of all the experimental data with concentration of binder at level i, and $\overline{Q}$ is the overall mean of all the experimental data.

4. CONCLUSIONS

The effect of three artificial binders (kaolin, bentonite and corn starch) at three concentrations (2.5, 10 and 15% by weight) on the mechanical properties (crushing strength, brittle fracture index, axial elastic recovery, durability and disintegration time) of the organic fertilizer pellets have been investigated using L9 Taguchi orthogonal array. Based on the analysis of results obtained in the study, it can be the concluded that the type of binding agent has the greatest magnitude influence of 90.4% for disintegration time, 67.9% for crushing strength, 56.2% for durability, 40.5% for axial elastic recovery, and 85.5% for specific energy requirement. The order of magnitude of influence for crushing strength, axial elastic recovery durability and specific energy requirement was Type of binder › Concentration of binder › Error. For disintegration time the order was Type of binder › Error › Concentration of binder, while for brittle fracture index the concentration of binder has the highest magnitude of influence of 36.8% in the order Concentration of binder › Error › Type of binder. Corn starch was found to be the best binder for optimal properties of the pellets with optimal concentrations of 15% for crushing strength, axial elastic recovery, durability and disintegration time, and 10% for brittle fracture index. The trends observed suggest need for further works to confirm correlations.

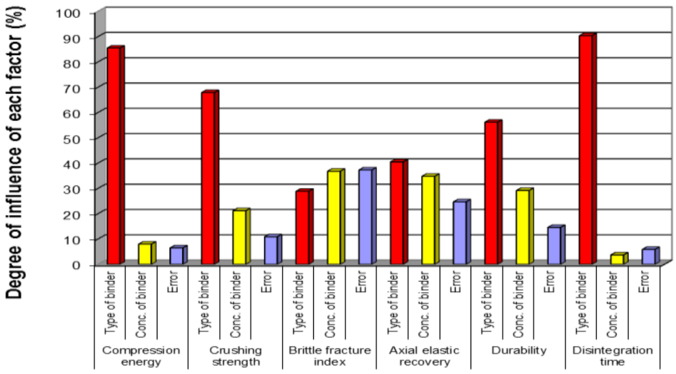

Fig. 7: Degree of influence of each factor on the mechanical properties of the pellets

Table 6: Optimum process conditions

Property	Optimum factor	
	Type of binder	Concentration of binder (%)
Crushing strength	Cornstarch	15
Brittle fracture index	Cornstarch	10
Elastic recovery	Cornstarch	15
Durability	Cornstarch	15
Disintegration time	Cornstarch	15
Specific compression energy	Kaolin	2.5

Table 5: Analysis of variance (ANOVA) for the properties of the pellets

Mechanical properties	Factors	SS	DOF	MS	F	P	DF (%)
Crushing strength	Type of binder	122751.8	2	61375.9	12.5		67.9
	Conc. of binder	38364.6	2	19182.3	3.9		21.2
	Error	19640.6	4	4910.1			10.9
Brittle fracture index	Type of binder	4.8	2	2.4	-		28.9
	Conc. of binder	6.8	2	3.4	-		36.8
	Error	6.9	4	1.7			37.3
Axial elastic recovery	Type of binder	3.6	2	1.8	3.3		40.5
	Conc. of binder	3.1	2	1.6	2.9		34.8
	Error	2.2	4	0.5			24.7
Durability	Type of binder	5129.4	2	2564.7	7.7		56.2
	Conc. of binder	2668.1	2	1334.0	4.0		29.2
	Error	1331.4	4	332.9			14.6
Disintegration time	Type of binder	2380.6	2	1190.3	30.4		90.4
	Conc. of binder	97.5	2	48.8	-		3.7
	Error	156.63	4	39.2			5.9

Key: SS- Sun of squares; DOF- Degree of freedom; MS- Mean square; F- ; P- Probability; DF(%)- Percentage degreed of influence of each factor

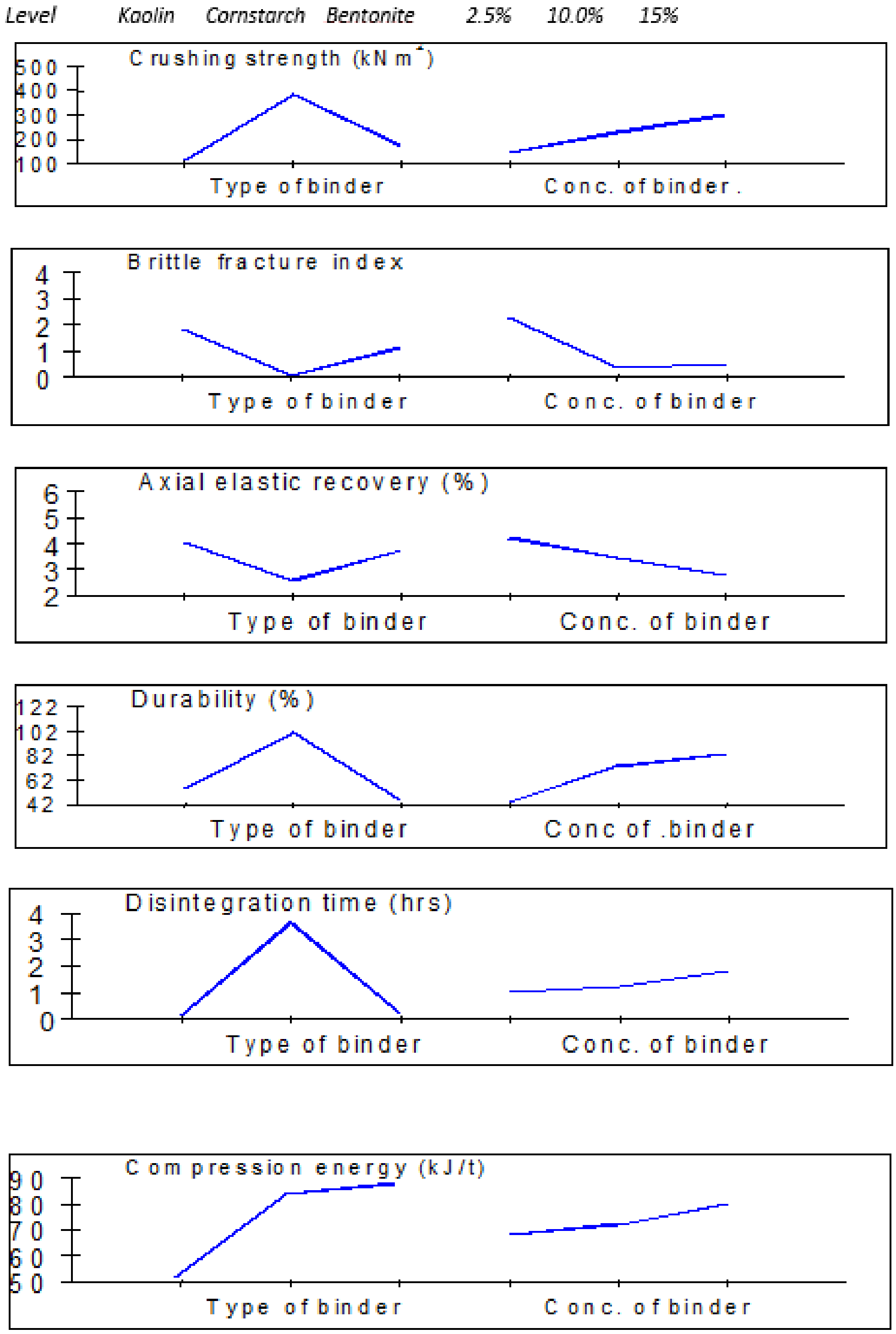

Fig. 8: Main effects plot of each factor on mechanical properties of the pellets

REFERENCES

Adebayo, A.S. and Itiola, O.A., "Evaluation of breadfruit and cocoyam starches as exodisintegrants in a paracetamol tablet formulation". Pharm. Pharmacol. Commun., 4: 385-389, 1998.

Ajayi, O.A. and Lawal, C.T., "Some quality indicators of sawdust/palm oil sludge briquettes", Journal of Agricultural. Engineering Technology, 3: 55-65. 1995.

Alexander, R., "Compost Marketing Guide", Alexander Associates, Inc., United States, 2003.

Arthur, E., Cornelis, W.M., Vermang, J. and De Rocker, E., "Effect of compost on erodibility of loamy sand under simulated rainfall", CATENA, 85(1): 67-72, 2011.

ASAE Standards, "America Society Agricultural Engineering Standards", St. Joseph, Mich. 45th Ed., 1998.

Battelle, "Compost supply and demand", A report of Environmental Services Industry, United State, 2012. Available at: http://www.faqs.org/abstracts/Environmental-services-industry/Compost-supply-and-demand-Using-compost-to-treat-wastewater-effluent.html#ixzz1Riza2FxM , Accessed January 2012.

Chaplin, R.V., Straw wafering tests. Department Note DN/FC/614/1390, National Institute of Agricultural Engineering, Silsoe, 1975.

Dobie, J.B. and Walker, H.G., "Effects of NaOH and NH_3 on cubality and digestibility of rice straw", Transactions of American Society of Agricultural Engineers, 20(6): 1018–1021, 1977.

Esengun, K., Erdal, G., Gunduz, O. and Erdal, H., "An economic analysis and energy use in stake-tomato production in Tokat province of Turkey", Renewable Energy,32: 1873-1881, 2007.
Faborode, M.O. and O'Callaghan, J.R., "Theoretical analysis of the compression of fibrous agricultural materials", Journal of Agricultural Engineering Research. 35: 175 – 191, 1986.
Fadare, D.A., "Development of an organo-mineral fertilizer processing plant", A Ph.D. Thesis of Department of Mechanical Engineering, University of Ibadan, Ibadan, Nigeria, Pp. 343, 2003.
Fadare, D.A., Bamiro, O.A. and Oni, A.O., "Energy analysis of an organic fertilizer plant in Ibadan, Nigeria", Journal of Research in Engineering, 6(2): 112-120, 2009.
Fadare, D.A., Bamiro, O.A., and Oni, A.O., "Energy and cost analysis of organic fertilizer production in Nigeria", The International Journal of Energy, 35(1): 332-340, 2010.
Gould, M.C., "Current practices and market demand potential for compost produced by small to medum sized farms in Michigan: a market research report", Extension Educator-Nutrient Management, Michigan State University Extension, 2012. Available at: www.newag.msu.edu/LinkClick.aspx?fileticket=W5nhJooXJm4%3D&tabid=37, Accessed January 2012.
John, N.M., Adeoye, G.O., Sridhar, M.K.C., "Compost pelletization eases end use in Nigeria", Biocycle, June 1996 p. 55-56, 1996.
Nevens, F. and Reheul, D., "The application of vegetable, fruit and garden waste (VFG) compost in addition to cattle slurry in a silage maize monoculture: nitrogen availability and use", European Journal of Agronomy, 19(2): 189-203, 2003.
O'Dogherty, M.J., "A review of the mechanical behaviour of straw when compressed to high densities", J. Agric. Engng. Res., 44: 241-265, 1989.
O'Dogherty, M.J. and Wheeler, J.A., "The effect of die, mode of loading and chopping on the compression of straw to high densities in closed cylindrical dies", Divisional Note DN/1103, National Institute of Agricultural Engineering, Silsoe, 1982.
Odeku, O.A. and Itiola, O.A., "Characterization of Khaya gum as a binder in a paracetamol tablet formulation", Drug Development and Industrial Pharmacy. 28(3): 329 – 337, 2002.
Odeku, O.A. and Itiola, O.A., "Evaluation of Khaya gum as a binder in a paracetamol tablet formulation", Pharm. Pharmacol. Commun. 4:183– 188, 1998.
Odeku, O.A. and Itiola, O.A., "Evaluation of the binding properties of khaya gum", A paper presented at the National Symposium on Pharmaceutical Technology, University of Ibadan. June 6–10, 1994.
Organic Monitor, "Quality of organic compost", United State, 2012. Available at: www.organicmonitor.com, Accessed January 2012.
Phadke, M.S. "Quality engineering using robust design", Prentice-Hall Int. Inc., US, pp 334, 1989.
Sæbø, A. and Ferrini, F., "The use of compost in urban green areas – A review for practical application", Urban Forestry Camp; Urban Greening, 4(3–4): 159-169, 2006.
Shepperson, G. and Marchant, W.T.B. "Production of grass and alfalfa cobs using an experimental ring die press", Proceedings of 2nd International Green Crop Drying Conference, Saskatoon, pp. 264–270, 1978.
Wealti, H. and Dobie, J.B., "Cubability of rice straw as affected by various binders", Transactions of American Society of Agricultural Engineers, 16(2): 380–383, 1973.
Weber, J., Karczewska, A., Drozd, J., Licznar M., Licznar S., Jamroz E. and Kocowicz A., "Agricultural and ecological aspects of a sandy soil as affected by the application of municipal solid waste composts", Soil Biology and Biochemistry, 39(6): 1294-1302, 2007.
Willer, H. and Kilcher, L., "The world of organic agriculture: statistics and emerging trends". Bonn; FiBL, Frick: IFOAM, 2011. Available at: www.organic-world.net. Accessed January 2012.
WinRobust "WinRobust version 1.02: User guide", 1995.