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EVALUATING THE EFFECT OF ADDING STEEL MACHINING CHIPS ON THE PROPERTIES OF CLAY

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Abstract: Steel machining waste known as chips is a kind of waste that can be returned to the process of raw material for steel fabrication or else be traded as co-product of other industrial activities. The reuse of this product is of great importance owing to the economic and environmental aspects. This work investigates the effect of steel machining chips as additive on the properties of clay. The physical properties of the clay and steel machining chips composite were determined. The clay sample was collected from a deposit in Minna, Niger State, Nigeria. It was cleaned, soaked, dried, crushed, sieved and then moulded to some definite shapes depending on the type of test carried out on the various clay samples. Compositions were prepared with additions of steel machining chips of 0, 5 and 10 wt.% in the clay sample. Particles size distribution was determined by sieving and sedimentation methods. The qualitative mineralogical phase identification was performed by X-ray diffraction (XRD) in powder samples using an Analytical Empyrean, diffraction DY674. Results obtained showed that the linear shrinkage decreases with addition of steel machining chips from 2.40% to 2.28% and increases in the crushing strength from 256.41 kg/m^2 to 394.74 kg/m^2 without changing the other properties of the clay. This result proves the viability of using steel machining chips as additive to clay to enhance its engineering properties for advanced usage.

1. INTRODUCTION

Most wastes are toxic and hazardous to humans and its environment. Some steel machining workshop disposes their waste without knowing the economic benefit (Anunuso, 2015).

Today's industrial activities and human consuming habits are generating an ever-growing amount of all kinds of wastes. In response, considerable efforts are being conducted to find practical and economical uses for any existing waste (Smith, 1976). If viable the waste should then become a by-product with an associate market value. For instance, PET plastic bottles and aluminium cans are now regularly collected as valuable raw materials for recyclable products (Duston, 1993).

In spite of these efforts, a huge quantity of innumerable types of gas, liquid and solid wastes are increasingly being disposed into the environment without treatment and generating serious consequences (Carless, 1976).

A technically efficient and cost-effective solution is the incorporation of solid wastes into relatively low cost and inert products that are manufactured in large amounts. Red ceramics such as bricks and roofing tiles made from clayey raw materials is currently one of the best alternatives for solid wastes incorporation (Naga and El-Maghraby, 2003).

Clay is a very fine grained, unconsolidated rock matter, which is plastic when wet, but becomes hard and stony when heated. When mixed with water, it becomes plastic and mouldable and becomes hard again on drying and firing. It has its origin in natural processes, mostly complex weathering, transported and deposited by sedimentation within geological periods. Clay is composed of silica (SiO_2), Alumina (Al_2O_3) and water (H_2O) plus appreciable concentration of oxides of iron, alkali and alkaline earth, etc.; and contains groups of crystalline substances known as clay minerals such as quartz, feldspar and mica. Clay is used in various fields such as geology, chemistry, soil science, engineering and ceramic technology (Folaranmi, 2009).

In recent years, there has been an increasing interest in utilizing clay minerals such as bentonite, kaolinite, diatomite and fullers earth for their capacity to absorb not only inorganic but also organic molecules (Nayak and Singh, 2007). Different researches have been carried out to find suitable means of recycling certain kind of wastes by incorporating them into red ceramics (Kadir and Mohajerani, 2011; Ugheoke *et al.,* 2006; and Chan, 2011). Faria and Holanda (2013) investigated the Incorporation of sugarcane bagasse ash waste as an alternative raw material for red ceramic.

The incorporation into common red ceramics is nowadays a solution for the disposal of a wide range of solid wastes. The natural variability of the characteristics of clays (Dondi *et al.*, 1997), the use of relatively simple processing techniques, as well as the low technical performance required for the products, permit the presence of high amounts of impurities.

Steel machining waste known as chips is a kind of waste that can be returned to the process of raw material for steel fabrication or else be traded as co-product of other industrial activities (Anunuso, 2015). The reuse of this product is of great importance owing to its economic and environmental aspects. The need to find an environmentally correct alternative to recycling a waste from a steel-machining process was one of the objectives of this research; and the main aim of this research was to evaluate the effect of adding steel machining chips on the properties of clay.

This study finds relevance in the facts that steel machining chips can be added into clay to improve its mechanical strength without affecting the properties of clay. Hence, the incorporation of the steel machining chips into clay is to aid in the reinforcement of the ceramics body. This product has improved properties and is capable of creating better opportunity and cheaper alternative for the consumer in the market.

2. MATERIALS AND METHOD

2.1 Materials

The materials used in this research were Steel machining chips (obtained from the work shop department of Scientific Equipment Development Institute (S.E.D.I), Minna), Kaolinitic clay (obtained from Bida, Minna) and Water. The equipment includes Oven, Weighing balance, Sieve shaker and sieve pan, Venier calliper, Thermometer (mercury in glass), and X-ray diffraction machine.

The clay sample and was characterized in terms of its physical composition as well as morphological aspects. X-ray diffraction (XRD) analysis of the clay sample and the sample with steel machining chips was done according to Jaya *et al.*, (2015).

2.2 Determination of Physical Properties

The samples were observed visually with the naked eye, and the physical appearance was observed to be Light Red. Plate 1 shows a pictorial view of the clay sample.

Plate 1: Pictorial View of the Clay Samples

2.3 Sieve Analysis of Components

The particle size distribution was determined by both, sieving and sedimentation methods, a known mass of 200g of clay was placed on the sieve to be used and this was later placed on mechanical sieve shaker. The sieve was arranged placing the coarsest on the top then followed by less coarse, all along till the last one, which was followed by a pan. Sizes of sieve used were 850, 600, 425, 300, 150, 125, 63, 3.35, and 2.00 (microns). The time taken to be sieved was recorded when the machine has finally stopped. Each sieve was removed in turns, that is one after the other and the retained clay grains were carefully weighed on a digital weighing balance and the weight of each retained clay grains was recorded against the sieve number of each sieve tray. The Sieve Apparatus were: Test sieve of various sizes, Mechanical sieve shaker with timing device, Weighing balance, and Brush.

2.4 Determination of Green Permeability

This was carried out with the test standard specimen of about 170 bulk density rammed and left in the cylinder tube. It was placed in the central position of the permeability meter with the sample uppermost. Theknurled ring was sealed and the motor speed control rheostat was adjusted to obtain a pressure reading of exactly 100 mm permeability on the pressure gauge. Finally, the control level was moved to test position and permeability was read directly from the red outer scale.

2.5 Determination of Green Compressive Strength

This test was carried out using the universal strength-testing machine. With the aid of the appropriate accessories, compression and shear strengths of mould clay was determined by means of a dead weight loading. The steps and procedure taken were: The compression head was placed in its position; The standard specimen was inserted between the compression heads as the weight arm was raised slightly so that the face that was uppermost in the ramming operation faced the right hand compression head, the machine was switched on or energized by the start button, when the specimen collapsed the machine reversed and returned to zero; The reading was recorded on the lower edge of the magnetic rider, reading the scale designated as “Green Compression” strength; The clay was then removed from the compression head.

2.6 Determination of Green Shear Strength

The shear test heads were placed in the lower position in the machine with the head having the half round holder attached to it in the pusher arm. The shear load application was carried out and the value was read off a scale at lower edge of the rider designated Green Shear.

2.7 Determination of Dry Compressive and Shear Strength

The compression heads and shear heads were placed alternately in the top position of the machine and the load application was carried out.

2.8 Determination of Moisture Content

To determine the moisture content of the clay, 10 g of the sample with varying proportion of water was successively taken; and in carrying out the moisture content test of the clay sample, slabs of the wet samples were weighed with the container as M_1. The samples were then oven dried for 24 hours. After drying, it was then weighed again as M_2.The weight of the empty mould was measured as M_3. The mass of the moisture was taken as (M_1-M_2) g and the mass of the dry sample was taken as (M_2-M_3) g.

$$\%\,Moisture\ content = \frac{M1-M2}{M2-M3} \times 100 \quad (1)$$

2.9 Los of Ignition Test (LOI)

Organic combustion matter present as impurity leads to gas evolution and reduces the refractoriness of the clay. The amount of combustible matter is estimated by heating a weighed clay sample at 875^{o}C for 1 hour, cooling and finding the percentage loss in weight; this value is called loss on ignition.

20 g of oven-dried clay representing each test sample was cooled in the desiccator. The porcelain crucible was cleaned, dried and weighed to an accuracy of 0.001 g (M_1). The dried test clay sample was placed in the crucible, and the crucible together with the test clay was weighed to an accuracy of 0.001 g (M_2). The crucible containing the clay sample was placed in a muffle furnace and heated to a temperature of 800^{o}C. The crucible and its content (test clay) were allowed to cool in desiccators and then weighed to an accuracy of 0.001g (M_3).

The ignition loss was calculated from the relationship given below:

$$Loss\ of\ ignition = \frac{M2-M3}{M2-M1} \times 100\% \qquad (2)$$

Where:

M_1 = mass of dried porcelain crucible

M_2=mass of sample clay and porcelain crucible

M_3 = mass of heated clay sample and porcelain crucible.

2.10 Determination of Bulk Properties

The determination of the bulk properties of clay specimen required standard prepared sample. The standard test sample was to determine the bulk properties required, namely: (a) Refractoriness, and (b) Cold crushing strength

2.11 Refractoriness Test (Fusion Temperature)

Refractoriness is the maximum temperature a material can withstand after which it will fail or break. Refractoriness test was carried out by mixing the clay sample aggregates with sufficient quantity of water level to make the clay become plastic and moulded by hand. The sample was dried and later fired to a temperature of 1050^{o}C in an electric furnace. The temperature was determined by means of an optical pyrometer.

2.12 Cold Crushing Strength

This test is a measure of the cold strength and the report may be used to show whether or not clay products like tiles have been fired properly. The test might also indicate whether the product can be transported readily without damage to edges and corners.

The test pieces were cut each from the original refractory test specimen with a cut-off way, measuring about 50 mm wide and 50mm height. The test pieces were then dried in an oven at an operating temperature of 110^{o}C for 24 hours then fired in a furnace at a temperature of 1050^{o}C for 6 hours. It was removed and cooled in air for 2 hours to room temperature.

The specimen was then taken to tensometer where a load was applied axially along the axis of the diameter until the piece show a sign of crack. The load at which cracks are visible were recorded, which represents the lap required for determining cold crushing strength of the test specimen.

Cold crushing strength can be determined mathematically by the formula below:

$$\text{Cold crushing streng(CSS)} = \frac{Applied\ Load\ (N)}{Area\ Applied\ (m2)} \qquad (3)$$

2.13 Incorporation of Steel Machining Chips into Clay

Incorporations of 0 wt.%, 5 wt.% and 10 wt.% of steel machining chips into clay body were performed in a pan mill. Test specimens (530×230×50 mm) was obtained by uniaxial press moulding, dried at 110ºC for 24hours and then fired at 1050ºC in a laboratory furnace. The heating rate was 3ºC/minute with one hour soaking at the maximum temperature. Cooling occurred by natural convection inside the furnace after it was turned off. These specimens were tested for water absorption, linear shrinkage. Both the dry bulk density and the fired bulk density were measured by dividing the mass by the external volume for each specimen. The water absorption was determined according to standard procedure. The linear shrinkage was obtained by measuring the length of the samples, before and after the firing stage, using a calliper with ± 0.01 mm precision.

3. RESULT AND DISCUSSION

3.1 Physical Properties

Grain size distribution is one of the principal factor influencing the permeability and surface fineness and this has some imperative effects upon the strength and other properties. The grain size distribution also determines the manner in which the grains are packed together with less pores space between them. Table 1 shows the experimental results obtained from the grain size analysis of clay samples and steel machining chips, while Figure 1 is the graph of particle size distribution.

3.2 Grain Size Analysis

Table 1: Grain Size Analysis of Clay

Sieve No	Sieve size (µm)	Weight of Sieve g	Weight Sieve + sample g	Weight Retained g	% Retained	Cumulative Wt.% retained	Cumulative Wt.% passing
6	3350	472.16	503.16	31.0	15.6	15.6	84.4
10	2000	420.64	435.14	14.5	7.28	22.88	77.28
16	1180	391.81	415.6	23.8	11.9	34.78	65.22
20	850	359.11	394.21	35.1	17.6	52.38	47.62
30	600	338.32	363.22	24.9	12.5	64.88	35.12
40	425	329.50	359.5	30.0	15.1	90.48	9.52
50	300	317.10	338.10	21.0	10.5	90.48	9.52
100	150	297.93	312.03	14.1	7.1	97.58	2.42
120	125	213.13	216.23	3.1	1.56	99.14	0.86
230	63	284.12	284.62	0.5	0.26	99.40	0.6
Pan	Pan	315.14	316.34	1.2	0.06	100.00	
Total				199.2	100.0		

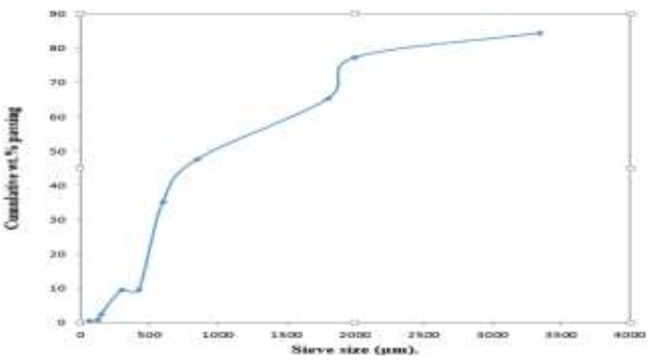

Figure 1: Particle Size Distribution of Bida Clay

3.3 Measured Properties of Raw Material

Table 2 shows the results of the measured properties of clay such as the green permeability, green compression strength, green shear strength and dry compression strength.

Table 2: Measured Properties of Clay

Water (ml)	Green permeability	Green compression strength (N/cm^2)	Green shear strength (N/cm^2)	Dry compression and shear Strength (N/cm^2)
30	215	4.4	0.9	10.5
40	210	2.8	0.7	18.0
50	205	2.0	0.5	25.2
60	195	1.6	0.4	30.0
70	184	1.3	0.3	36.4

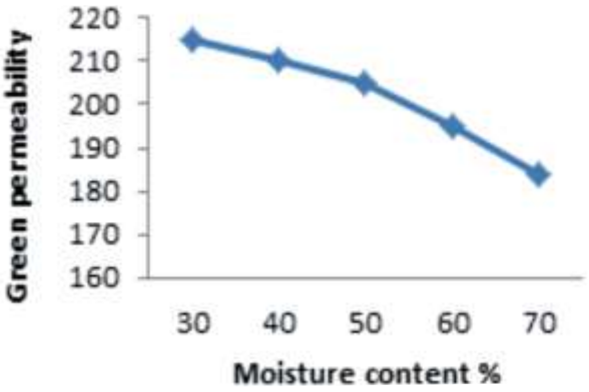

Figure 2: Effect of Moisture Content (%) on Permeability.

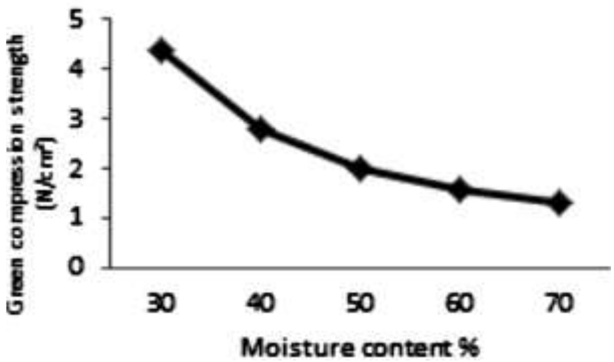

Figure 3: Effect of Moisture Content (%) on the Green Compression Strength, GCS (N/cm^2).

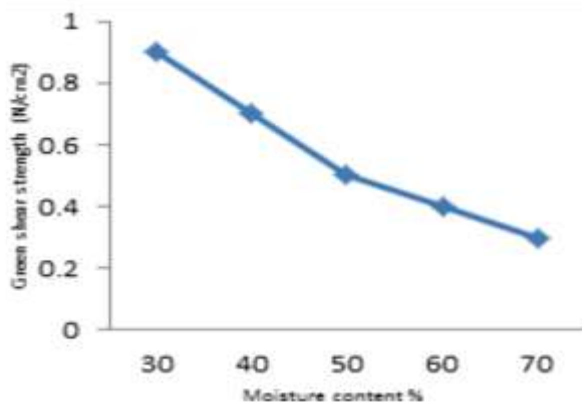

Figure 4: Effect of Moisture Content (%) on the Green Shear Strength, GSS (N/cm^2).

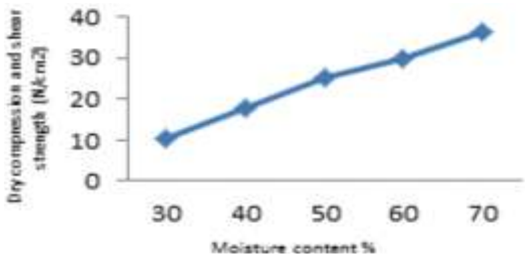

Figure 5: Effect of Moisture Content (%) on Dry Compression and Shear Strength, DCS (N/cm^2).

The physical analysis of the clay revealed its red colour. The particles were fine when pulverized using roller mill. The clay was found to have swelling index of 1.0, the physical characteristics of the mixture showed considerable variation with change in water content.

From figure 3, the Green Compression Strength (GCS) of the moulding sand mixture decreased from 4.4 N/cm^2 to 1.3 N/cm^2 of 30 ml and 70 ml water addition respectively. This shows that Bida clay has good bonding characteristic at 30 ml water addition. Metals can be cast with 30 ml water addition to the moulding sand mixture, mould wall erosion could occur during pouring of hot liquid metal as a result of friable nature of the mould.

As depicted on Figure 4, the Green Shear Strength (GSS) of the moulding sand mixture was observed to be decreasing from 0.9 N/cm^2 to 0.3 N/cm^2 of 30 ml and 70 ml water addition respectively. The Dry Compression Strength (DCS) for 30 ml water content was 10.5 N/cm^2 and this value increased with further increase in moisture content of the mixture reaching the maximum value of 36.4 N/cm^2. It was discovered that the strength of the dry sample was greater than that of calibrated strength on the universal testing machine. The dry shear strength of sample of moulding mixture was observed to increase with moisture content reaching a maximum at 70 ml water addition, as depicted on Figure 5.

3.4 Grain Size Analysis of Steel Machining Chips

Total weight of sample = 130.29 g.
µm = microns and
wt = weight.

Let weight of sieve = x,
Weight of sieve sample = Y.
Weight of sample retained = Y- x.
Percentage weight retained =

$$\%WR = \frac{(Y-x)}{Total\ Wt.of sample} \times 100\%$$

(4)

Percentage cumulative weight retained = %CMR.
Percentage passing = 100 - %CMR = %PS.
(5)
Nearest percentage passing = %NP.

Table 3: Grain Size Analysis of Steel Machining Chips

Sieve size (µm)	x (g)	Y (g)	(Y-x) (g)	% WR	% CMR	% PS	% NP
5000	480.77	481.71	0.94	0.72	0.72	99.28	99
3500	469.22	470.39	1.17	0.90	1.62	98.38	98
2360	437.90	439.72	1.82	1.40	3.02	96.98	97
1180	390.92	412.14	21.22	16.29	19.31	80.69	81
600	335.49	385.28	49.79	38.22	57.53	42.47	43
425	328.72	349.04	20.32	15.60	73.13	26.87	27
212	305.01	328.11	23.10	17.73	90.86	9.14	9
63	288.09	298.96	10.87	8.34	99.20	0.8	1
Pan	270.99	272.03	1.04	0.80	100.00	0	0

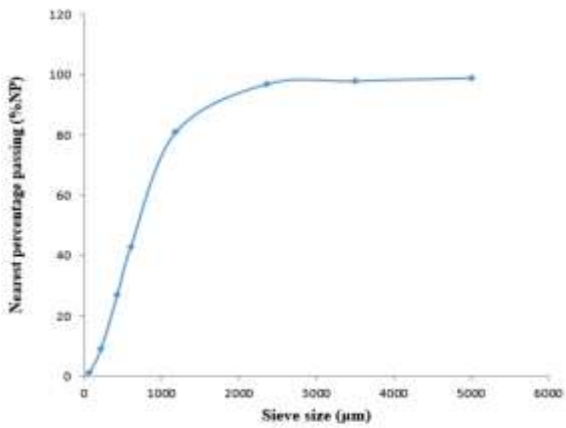

Figure 6: Particle Size Distribution of the Steel Machining Chips.

According to Figure 6, the steel machining chips shows a distribution of fine particles with equivalent spherical diameter higher than 3500 µm as well as a mean particle size of 1667.5 µm. This characteristic of the steel machining chips is appropriate for red ceramic processing, that normally uses materials with particle size lower than 2500 µm (Anunuso, 2015). The density of the steel chips was found to be 7.8 g/cm^3.

3.5 Incorporation of Steel Machining Chips into Clay

Table 4 shows the properties of the clay sample with the steel machining chips as additives.

Table 4: Variation of the Properties of Clay Sample with Steel Machining Chips.

Steel machining chips (%)	**0**	**5**	**10**
Bulk density (g/cm^3)	2.350	2.300	2.220
Porosity	29.4	18.61	9.97
Linear shrinkage (%)	2.40	2.33	2.28
Cold crushing strength CCS (kg/m^2)	256.41	350.00	394.74
Sintering point (^oC)	1050	1050	1050

From table 4, it was observed that at 1050ºC the linear shrinkage decreased with addition of steel machining chips. Also, the water absorption suddenly decreases, hence, making the clay sample from Bida to display a sharp decrease in porosity as a consequence of the verification process. It was observed that the steel chips mainly constitute hematite, Fe_2O_3, at 1050^{o}C. The hematite is considered as a refractory material (Li-Li *et al., 2016).*

In the variation of the cold crushing strength, it was noticed that the addition of 5 and 10 wt.% of steel machining chips do not change the property of the clay at the investigated temperature. Since the mechanical strength is strongly dependent on the microstructural characteristics of the fired clay, the obtained results show that additions up to 10 wt.% do not introduce pore or cracks into the clay microstructure. The refractoriness for the clay was 1050°C, as determined by means of an optical pyrometer.

3.6 Microstructure

Scanning electron micrographs of the fracture surface of bodies without addition of steel chips, and with 10 wt.% of steel chips, are shown in Plate 2.

It was observed that both bodies present a rough fractured surface. This is expected for kaolinitic clayey material fired at 1050°C. At this temperature the amount of liquid phase and its viscosity is not sufficient to efficiently close the open porosity. The micrograph with 10 wt.% of steel chips shows clearly that steel chip agglomerates, according to arrows, are well distributed in the microstructure of the clay. It is observed that the steel chips additions do not change the major crystalline phases of the fired clay, such as hematite, micaceous mineral, probably muscovite mica, quartz and sanidine, a potash feldspar formed at high temperatures.

From the XRD analysis, the following phases were identified: mica muscovite, sanidine, quartz and hematite. Phases identified from XRD analysis agreed with those in obtained for clay and fired clay in leteratures (Faria and Holanda, 2013; and Nayak and Singh, 2007). Presence of kaolinite, mica and quartz shows the nature of parent material (Jaya *et al.*, 2015*).*
As final remarks, this work shows that the steel chips are a type of waste that can be recycled by incorporation into red ceramic body.

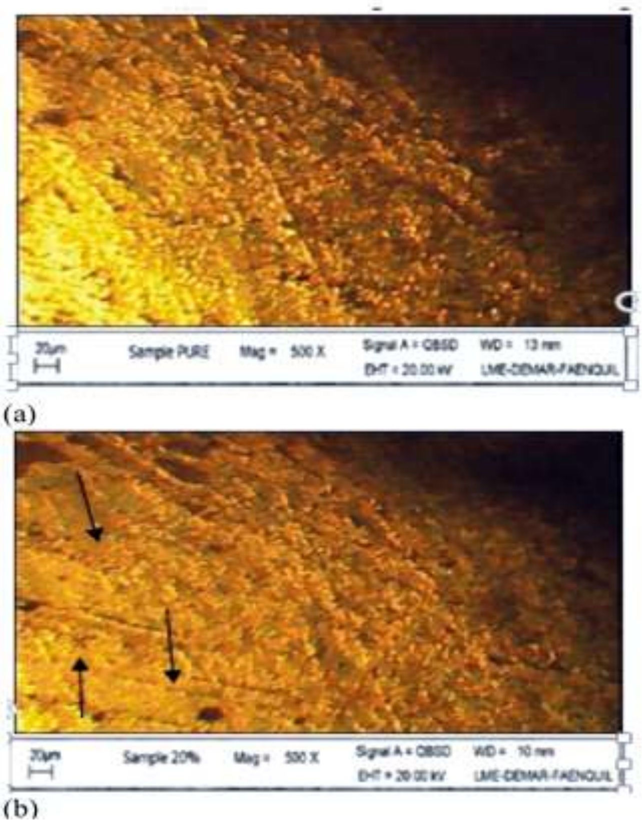

Plate 2: SEM photomicrographs of fractured region of the compositions (a) without steel chips and (b) with 10 wt. % of steel chips.

As final remarks, this work shows that the steel chips are a type of waste that can be recycled by incorporation into red ceramic body. Incorporation in low amount, approximately 5 wt.%, can be advantageous for the red ceramic processing by decreasing in the fired linear shrinkage without increasing the water absorption. The incorporation does not decrease the mechanical strength. Moreover, incorporations of low amounts of steel chips into red ceramics can also contribute to facilitate the drying stage of the green piece as well as decreasing the drying shrinkage.

CONCLUSION

The investigations on the effect of steel machining chips additives on the properties of clay was carried out, and the result reveal a significant improvement in the material properties of clay when incorporated with steel machining chips. The steel machining chips is a waste predominantly composed of Fe metallic, Fe oxides (magnetite and wustite) and calcium carbonate (calcite). This waste which was sort by sieve method shows a fine particle size, average of 1667.5µm that is appropriate for incorporation into ceramics.

It was observed that at a temperature of 1050ºC, the linear shrinkage decreases with additions of steel machining chips from 2.40% to 2.28% and increases in the crushing strength from 256.41 kg/m^2 to 394.74 kg/m^2 without changing the properties of the clay.

To complement this research, further research work should be carried out to determine the effect of water absorption, and linear shrinkage on the steel waste incorporated on clay. Fabrication of roofing tiles should be carried out by incorporating steel machining chips into clay.

REFERENCES

Anunuso J. C. (2015). Effect of Steel Machining Chips as Additives on the Properties of Bida Clay.

Carless J. (1976). *Taking out the trash*, Washington, Island press, pp.56-61.

Chan C. M. (2011). "Effect of Natural Fibres Inclusion in Clay Bricks: Physico – Mechanical Properties. *World Academy of Science, Engineering and Technology,* pp.51-57.

Dondi M., Marsigli M., Fabbri B. (1997). Recycling of industrial and urban wastes in brick production: a review (Part 1). *Tile and Brick Int.,*Vol.13 No.3, pp.218-225.

Duston T. E. (1993). Recycling solid waste, the first choice for private and public-sector management. *Westport*, Vol.153, pp.*58-64.*

Faria K. C. P. and Holanda J. N. F. (2013). Incorporation of Sugarcane Bagasse Ash Waste as an Alternative Raw material for Red Ceramic. Cerâmica. Vol. 59**,** pp.473-480.

Folaranmi (2009). Effect of Sawdust Additive on the properties of Clay. *Australian Journal of Technology,* Vol.13 No.1, pp.53-56.

Jaya N. S., Walia C. S., Nayan A., Harjit S., Vishal G. and Vishal K. (2015). Characterization and Clay Minerals Composition of Soils Derived from Metamorphic Formation of Kumaon Himalayas. *Clay Research, Vol. 34, No. 1, pp. 15-24.*

Kadir A. A. and Mohajerani A. A., (2011). Recycling Cigarette Butts In Light-Weight Fired Clay Bricks. *Journal of Construction Materials, Proceedings of the Institution of Civil Engineers (UK)*, Vol. 164, No. 5, pp.219-229.

Li-Li W., Hai-Bin K. and Liang-Liang Y. (2016). Application of Refractory Hematite in Pellets. *Advances in Engineering Research*, Vol.103, pp.252-256.

Matthew P. (1977). Investigation of properties and processing of synthetic foundry sand mixture prepared from local material B.Sc. project, Ahmadu Bello University, Zaria,pp.23-56.

Naga S. M. and El-maghraby A. (2003). Industrial waste as raw materials for tile making, silicates industrial, *African Journal of Engineering Research*, Vol.2 No.1, pp.89-92.

Nayak P. S. and Singh B. K. (2007). Instrumental Characterization of Clay by XRF, XRD and FTIR. Bulletin of Material Science, Vol. 30, No. 3, pp. 235–238.

Smith D. G. W., ed. (1976). Short Course in Microbeam Techniques: Mineralogical Association of Canada, Toronto, pp. 186.

Ugheoke B. I., Onche E. O., Namessan O. N. and Asikpo G. A., (2006). Property Optimization of Kaolin-Rice Husk Insulating Fire-Bricks. *Leonardo Electronic Journal of Practices and Technologies*, Vol. 9, pp.167-178.