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Investigation of Balling Characteristics of Mixture of Iron Oxide Bearing Wastes and Iron Ore Concentrates

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Abstract - Iron oxide bearing wastes in form of dust and sludges are hard to handle because of their micron size particles and moisture content in case of sludge. More often they are stockpiled in large quantities that can occupy large area of real and agricultural estates and cause pollution. Balling or palletization, an agglomeration process was used to process the wastes in order to address the problem of micron size particles and to make them fit for recycling back into metallic iron production route like blast furnace. Balling or green pelletization is the process of forming nearly spherical shaped granules by tumbling moistened particulates with or without binders in balling drums or discs. For a pellet to be effective either for being transported or for being recycled in blast furnace to produce metallic iron without disintegrating to dust its balling characteristics should measure up to required standard. Most outstanding of those balling characteristics include Drop Number, Green or Wet Compression Strength, Dry Compression Strength, Abrasion and Tumbler Indices. In this work iron oxide bearing wastes was mixed with iron ore concentrates in various proportions. These mixes were taken through balling or wet pelletization process using Radicon Balling Disc. The balls formed were taken through Drop number tests adopting the Free Fall method, where balls are made to fall freely from a height of 50 mm on steel surface, Green compression and Dry compression tests using a 5 kN Universal Testing Machine (INSTRON Corp., model 1011 UK) System while Abrasion and Tumbler indices tests were conducted using Tumbler Index cylinder or drum and adopting ASTM method. It was found that Drop number as high as 7.8 times, Green compression strength and Dry compression strength up to 11.7 N/pellet and 25.99 N/pellet respectively were attained by some of the pellets. The Tumbler and Abrasion indices recorded were up to above 95% and 5% respectively. These values are higher than the minimum recommended.

KEYWORDS Iron oxide bearing wastes, Balling, Balling characteristics

1. Introduction

In the steel industry, iron oxide bearing wastes in form of dusts and sludge are produced at every segment of processing stage of sinter, molten iron and steel production. Several technologies are essentially employed to reuse them in the steel industry. The determining factors of the choice of technology include the size distribution (97 – 100 % minus 20 microns), moisture content (25 – 40%) and chemistry (0.03 – 7.8%, zinc or lead) of the wastes (Esezobor, et al, 2008).



Agglomeration and metallization remain the widely used methods for re – utilization of these wastes (Abioye, et al, 2018) . However, introduction of these materials to sinter and pellet charge through conventional methods are restricted due to the poor quality of the prepared charge and the relatively depreciation of the efficiency of sintering machine or pelletizer as well as the quality of sinter or balls (Blast Jurgen, 2007, Esezobor, et al, 2008). These materials are normally taken through balling process to address these deficiencies.

Balling is the process of forming nearly spherical shaped granules by tumbling moistened particulates with or without binders in balling drums or discs. Balling is very important in the iron and steel industry. For instance, the fine grained iron ore dust that are produced in the beneficiation process of low grade iron ore are granulated into balls by balling process before being reduced to metallic iron in the blast furnace (Satry, K.V.S, 1984, Afolalu, et al, 2017). Similarly, powdery iron ore or iron oxide materials are usually processed into balls for easy transportation from one place to another. Balls have the advantage over lump iron ores in that they are characterized by narrow grain spectrum, constant quality and good gas permeation during reduction (Werner, et al, 1979, Indian Bureau of Mines, 2011).

The ability of the moistened particulate materials to form balls of good compressive strength is known as the ballability of the material (Udo, et al, 2018, Abioye, et al, 2017). Materials of high ballability will possess high balling characteristics such as drop number, wet and dry compressive strengths, tumbler and abrasive indices. Ballability of material is influenced by factors such as grain size of the material, moisture content and the binder content in the materials' mix, wettability of the material as well as the processing parameters of the granulator (Udo, et al, 2018).

This work investigates the balling characteristics of iron oxide bearing wastes in order to enhance large scale production of iron oxide pellets from these wastes.

2. Experimental Method

2.1 Materials and Methods

For this study iron ore concentrates were obtained from National Iron Ore Mining Company at Itakpe, Kogi State of Nigeria, electric arc furnace (EAF) dust from Universal Steel (casting and rolling) Company, Ogba, Lagos State, Nigeria and pellet dust from Delta Steel Plant in Aladja, Warri, Delta State, Nigeria. Bentonite and lime were purchased from the local market. These materials were pulverized using a ball mill and classified on Dorr – Oliver Sieve Analysis apparatus with ten sizes ranging from 63 microns to 1000 microns. Chemical analyses of the materials were conducted on an Ex 310 Jordan Valley X–ray fluorescent.

The pulverized materials were divided into 30 different compositional mixes as shown in Table1 and rigorously mixed to ensure uniformity of the mixes. Each of the mixes was granulated into balls using Radicon balling disc of diameter 40cm, depth 10cm, inclined at 45° to the horizontal and rotating at a speed of 30 revolutions per minute. The resident time for balling of each mix with varied moisture content was 5 minutes. The ball diameter was controlled at an average of 10 mm.

Table 1 Weight Percentage of Various Balling Mixes

| Moisture Content (wt. - %) | Concentrate (wt. - %) | | | | | |
|-------------------------------|-----------------------|----|----|----|----|----|
| | A | B | C | D | E | F |
| 6 | 89.5 | 80 | 70 | - | - | - |
| 8 | 87.5 | 78 | 68 | - | - | - |
| 9 | 86.5 | 77 | 67 | 47 | 27 | 87 |
| 10 | 85.5 | 76 | 66 | 46 | 26 | - |
| 11 | 84.5 | 75 | 65 | 45 | 25 | 85 |
| 12 | - | - | - | 44 | 24 | - |
| 13 | - | - | - | - | - | 83 |
| 14 | - | - | - | 42 | 22 | - |
| 15 | - | - | - | - | - | 81 |
| 16 | - | - | - | - | - | 80 |

- control Experiment with 4 % lime and 0.5 %

A bentonite

D – mix with 40 % dust and 4 % lime

B – mix with 10 % dust and 4 % lime

E – mix with 60 % dust and 4 % lime

C – mix with 20 % dust and 4 % lime

F – mix with 4 % lime and dust

2.2 Experiment

The resulting balls from each granulator were air – dried for 12 hours for drop number, green strength and dry strength tests as well as abrasion and tumbler indices tests

Drop Number Test

Drop number test indicates the drop strength of the balls. It gives indications of the ability of the green pellets to withstand the drops they will encounter from the point of discharge after balling to the firing unit. 20 balls from each mix were tested to obtain the value of drop number. The balls were dropped repeatedly from a height of 50cm onto a steel surface. The number of times each ball dropped before shattering is known as the drop number and was recorded.

Compressive Strength Test

Green strength test evaluates the ability of green balls or pellets to retain their shape during handling. Dry compressive strength test evaluates the ability of balls to retain their shape and withstand thermal stresses from the point of induration in the furnace to blast furnace without disintegrating into dust. A minimum of 20 green and 20 dry balls were used for these tests with their average values taken as the compressive strength (wet or dry respectively).

For green compressive strength test the balls were air dried for 12 hours before used for the test. While the green balls were indurated in electric resistance furnace to a temperature of 300°C for 1 hour and then allowed to cool in the furnace before being used to carry out the dry compressive strength test. Each of the balls was allowed to dry under atmospheric condition for 12 hours and then subjected to compressive test on a 5 kN Universal Testing Machine (INSTRON Corp., model 1011 UK) System. The stress attained at the point of shattering of the ball was recorded as the ball's green or dry compressive strength in Newton/pellet.

Tumbler and Abrasion Tests

Tumbler and abrasion indices tests were carried out simultaneously. For these tests, 500g of balls of diameter between 6mm and 10mm were selected from oven dried pellet into a well-sealed Tumbler Index cylinder or drum. Then the drum was rotated at 20 rpm for 5 minutes. The product of the drum was passed through a sieve of 500µm. The quantity of the shattered pieces that passed through the sieve as well as the quantity that did not pass through the sieve was measured. The ratio of the weight of quantity that did not pass through the sieve to the total quantity of the material gave the tumbler index while the ratio of the weight of the quantity of the material that passed through the sieve to the total quantity of the material gave the abrasion index (Topiary, et al, 2007).

3. Results and Discussion

The results of the sieve and chemical analyses of the iron bearing materials and the binders are presented in Tables 2 – 4.

The result in Table 2 indicates that over 80 % and 85 % of pulverized iron ore concentrates and iron oxide bearing wastes respectively are within the sizes ranging between 125 to 63 microns – a suitable sieve range for balling (Esezobor, et al, 2015) . While Table 3 shows that iron oxide bearing wastes consist of useful compounds such as iron oxides (FeO, Fe₂O₃), carbon, and slagging oxides in quantities close to what is obtained in iron ore concentrates. This indicates that these wastes are suitable as charge as well as additives to sinter and pellet burden by chemical and granulometrical constituents (Esezobor, et al, 2008).

It can be clearly seen from the results of drop number test in Figure 1 and that of green or wet compression strength test in Figure 2 that the drop number and green compression strength of the balls increase as the moisture content as well as that of iron oxide bearing wastes in the mixture increases at constant mechanical force of the balling disc.

Table2: Sieve Analysis of Iron Concentrate, Iron Oxide Bearing Wastes

| S/ | Materials | Sieve Size, µm | | | | | | | | | |
|----|-----------|----------------|-------|------|------|------|------|------|------|-----|-----|
| N | | +1000 | +710 | +500 | +355 | +250 | +180 | +125 | +90 | +63 | -63 |
| | | | -1000 | -710 | -500 | -355 | -250 | -180 | -125 | -90 | |

| | | | | | | | | | | | |
|----|-----------------------------|-------|------|------|-------|-------|------|-------|-------|-------|-------|
| 1. | Itakpe Iron Ore Concentrate | 14.23 | 4.44 | 10.8 | 20.99 | 36.63 | 6.46 | 3.23 | 1.82 | 0.71 | 0.20 |
| 2 | Ground Concentrate | - | - | - | 0.31 | 0.61 | 4.18 | 14.29 | 45.71 | 26.43 | 8.47 |
| 3 | Ground IROBEWAS | - | 0.10 | 0.20 | 0.61 | 2.04 | 4.18 | 8.36 | 39.65 | 31.81 | 13.05 |

Table 3: Chemical Analysis of the Iron Ore Concentrate and IROBEWAS

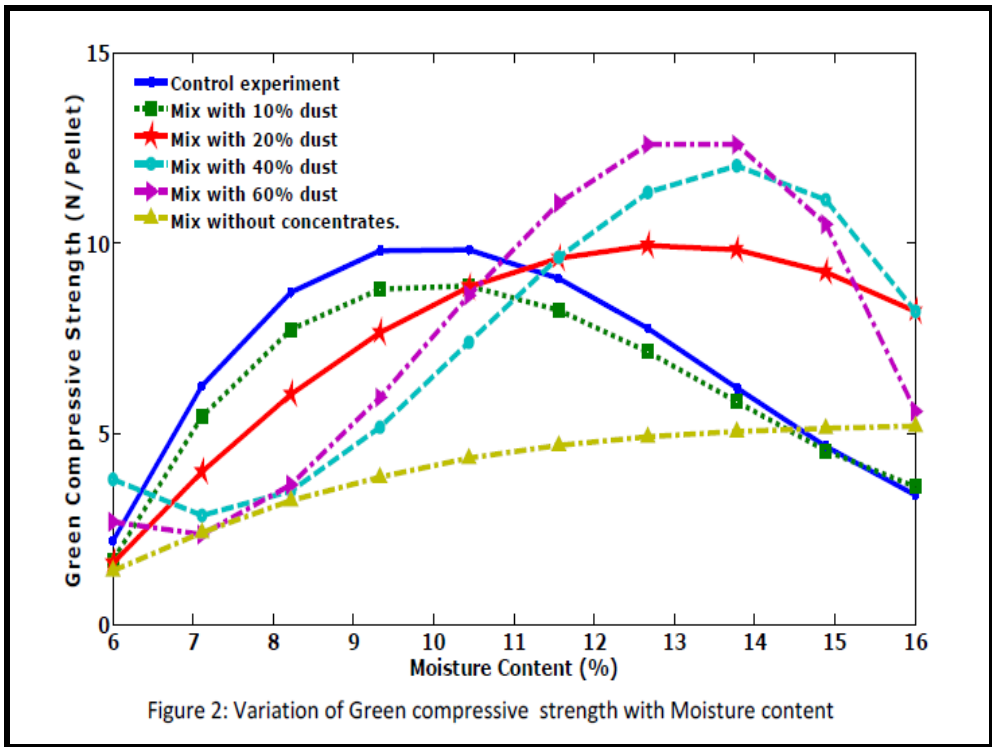
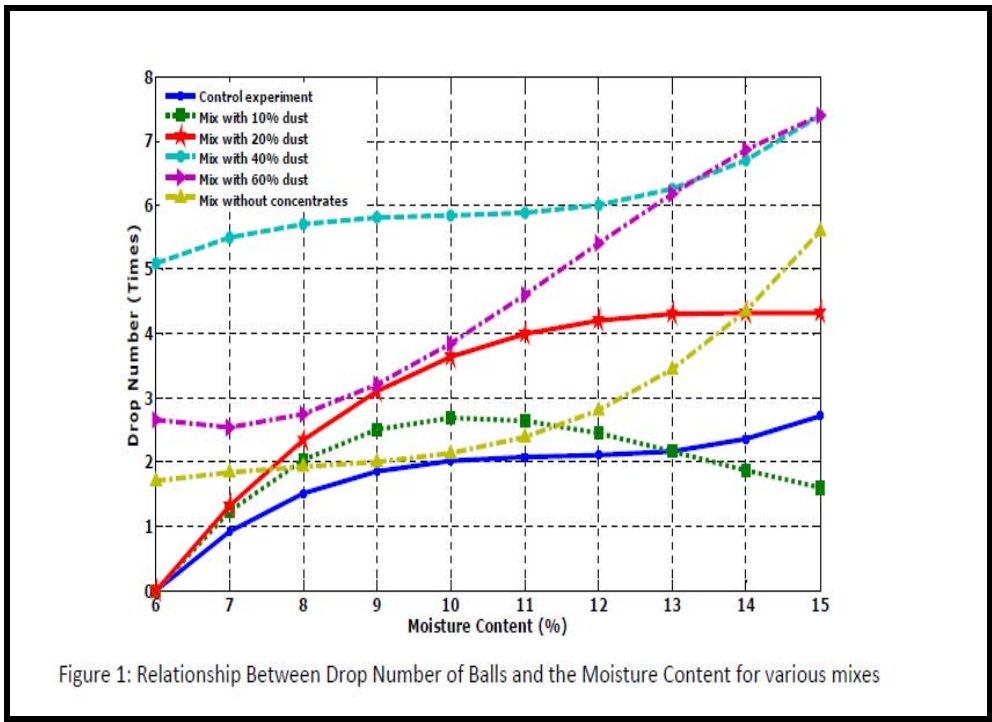
| S/No | Compound | Composition, wt % | | | | | | | | | | | | | | |
|------|-----------------------------|-------------------|--------------------------------|--------|--------------------------------|------------------|------|------|---|------------------|-------------------|------------------|-------------------------------|-------|------|-----|
| | | Fe _T | Fe ₂ O ₃ | L.O. I | Al ₂ O ₃ | SiO ₂ | Mg O | CaO | S | TiO ₂ | Na ₂ O | K ₂ O | P ₂ O ₅ | ZnO | Mn O | C |
| 1* | Itakpe Iron ore concentrate | 63.0 | 88.9 | 0.26 | 0.6 | 8.6 | 0.02 | 0.15 | 2 | 0.3 | 0.11 | 0.01 | 0.06 | ND | ND | - |
| 2 | Universal Steel EAF Dust | 35.73 | 51.09 | 7.08 | 2 | 3.2 | 0.25 | 1.28 | 9 | 0.3 | 0.39 | 0.94 | 0.10 | 29.50 | 2.17 | 2.6 |
| 3 | Delta Steel Pellet Dust | 54.34 | 77.64 | 6.43 | 0 | 7.03 | 0.25 | 4.17 | - | 0.27 | 0.27 | 0.03 | ND | ND | 0.14 | 2.5 |
| 4 | IROBEW AS | 47.3 | 74.5 | | 0.6 | 5.1 | 0.24 | 2.41 | 1 | 0.3 | 0.34 | 0.49 | 0.10 | 13.2 | 1.16 | 2.6 |

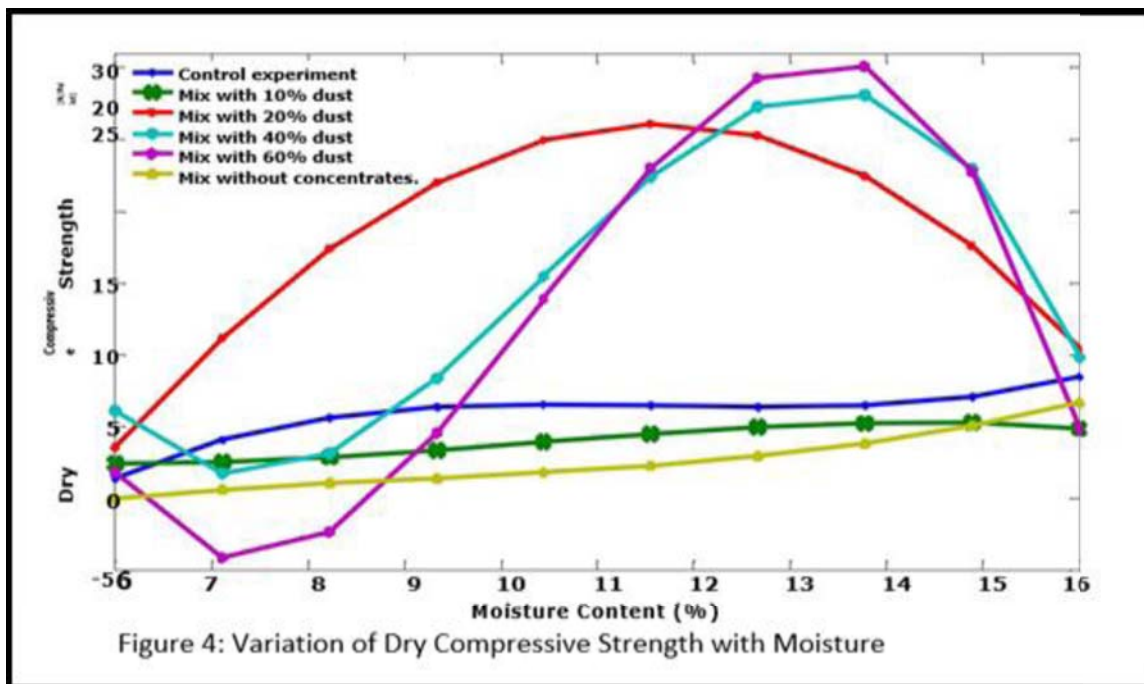
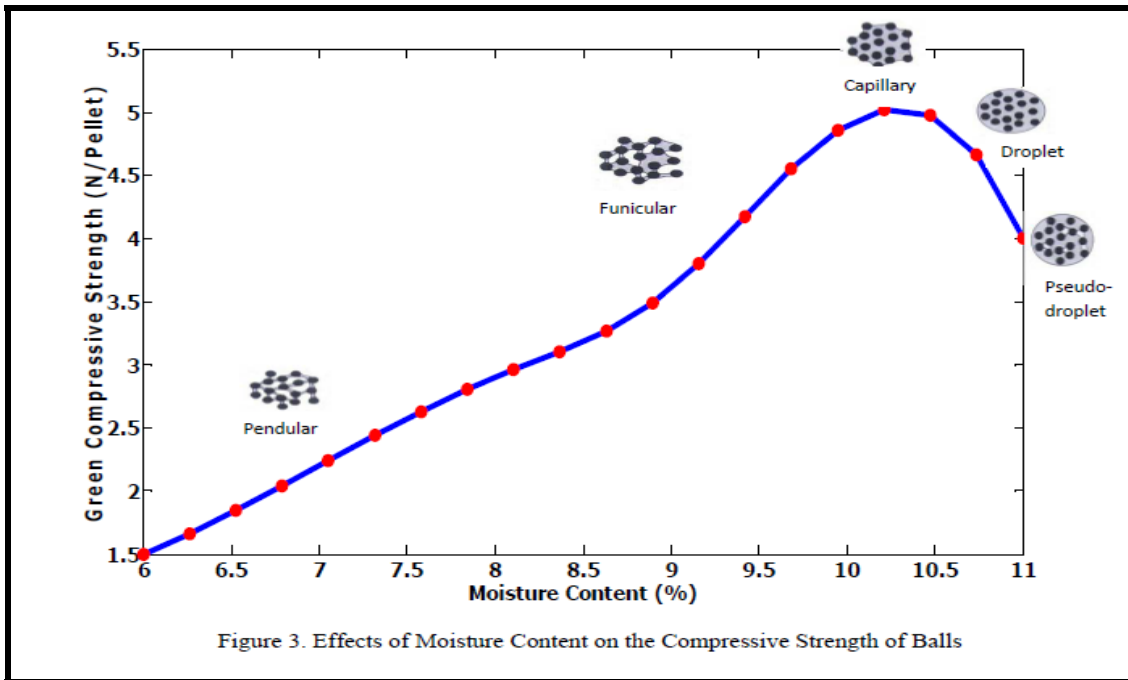
*FeO = 1.0, SO₃ = 0.01

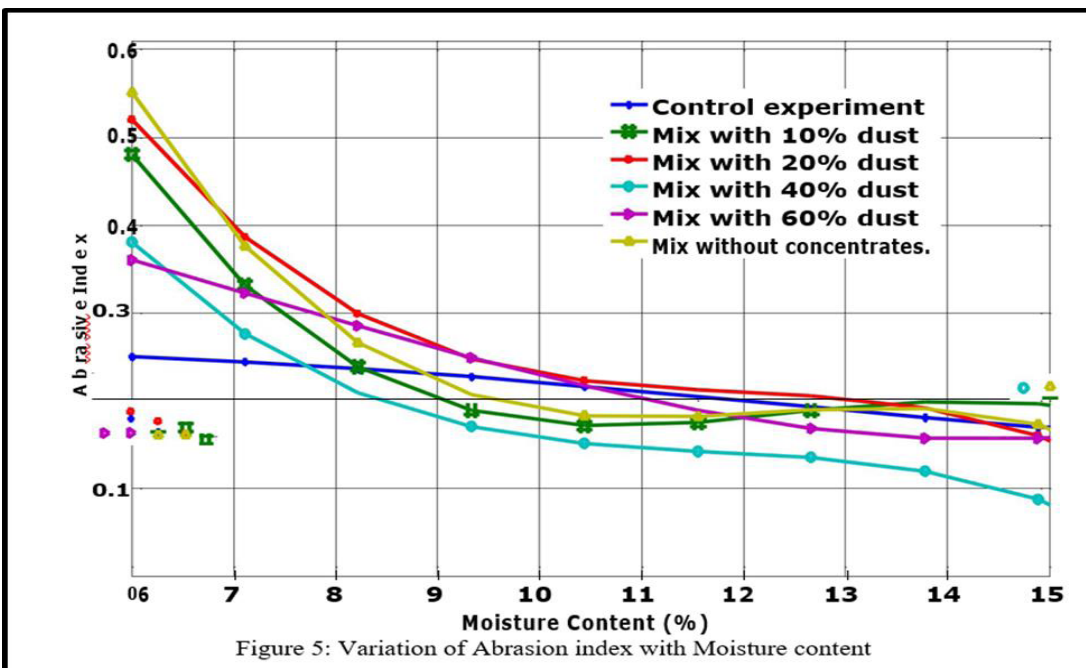
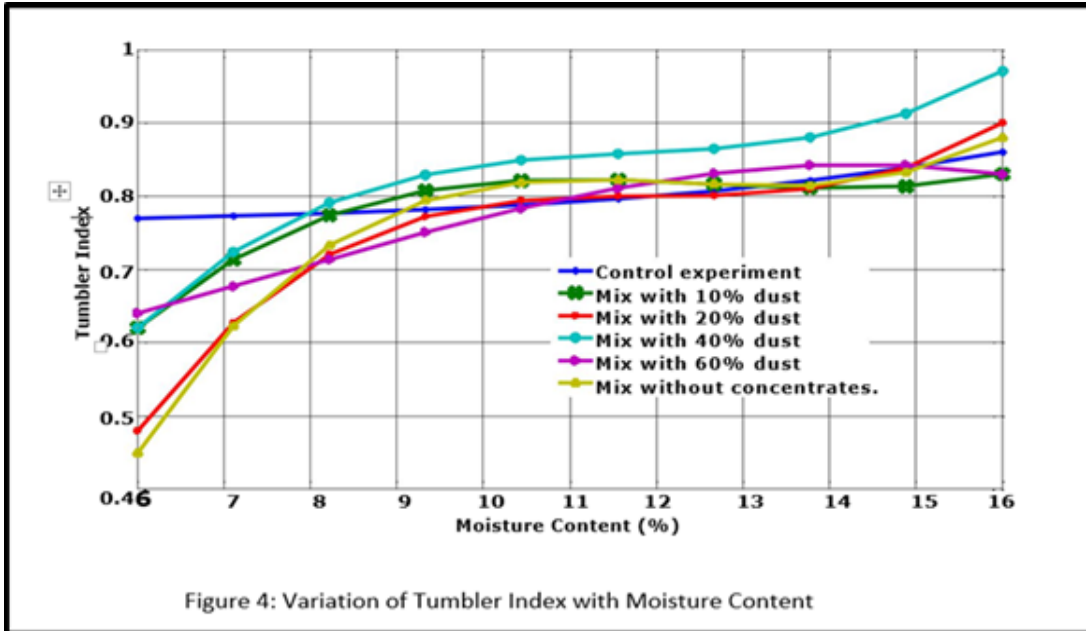
Table 4: Chemical Analysis of Bentonite and Lime

| S/No | Compound | Composition, wt % | | | | | | | | |
|------|-----------|--------------------------------|--------------------------------|-------|------------------|-------------------|------------------|------|-------|-------|
| | | Fe ₂ O ₃ | Al ₂ O ₃ | CaO | SiO ₂ | Na ₂ O | K ₂ O | Mn O | Moist | Imp |
| 1 | Bentonite | 0.32 | 18.85 | 0.24 | 62.24 | 0.91 | 10.65 | 2.86 | 1.67 | - |
| 2 | Lime | ND | ND | 52.06 | ND | ND | ND | ND | 20.24 | 15.32 |

ND – Not identifiable; Moist – Moisture Content; Imp - Impurity







The rise in the values of green compression strength and the drop number with increase in moisture content can be attributed to the binding forces (capillary forces) which depend on the rate at which the particulate materials in the balls are saturated with water. The reverse trend occurs when the optimum level of the water saturation is exceeded. This phenomenon can be explained by the capillary theory put forth by Newitt, et al,

1958 (Udo, et al, 2018). The theory postulates five levels of saturation of ball with water which include pendular, funicular, capillary, droplet and pseudo - droplet levels or stages.

At pendular level, balls have the least liquid saturation: particulate materials are held together by liquid bridges and the capillary force at this stage is at its lowest value. At funicular stage, the liquid saturation is higher and the capillary force is stronger than at pendular stage. At capillary stage all the capillaries in the balls' pore structure are saturated with water and concave surface is found in the opening of the capillaries due to capillary force tending to draw in the water on the balls periphery. The capillary force and therefore, binding force is highest at this stage. There is a rise in water saturations at droplet and pseudo – droplet stages that give rise to low binding force (see Figure 3). This results in the collapse of the balls under much weight.

The green compressive strength and drop number increase as the percentage of IROBEWAS in the mix increases due to the presence of slaked lime in iron oxide bearing wastes (Figures 1 and 2). The reaction of slaked lime with water results in the formation of calcium hydroxide $[\text{Ca}(\text{OH})_2]$ which is a good binder for

iron oxide materials (Orlov, et al, 1993; Ahmed, et al, 2005). Therefore, the presence of iron oxide bearing wastes in the mix enhances the balling processes. This results in higher wet or green strength values. It should also be noted that the more the quantity of iron oxide bearing wastes in the mix the more the quantity of water that would be required to give the optimum value of green strength for that amount of the wastes. This is because of the hydrophobic nature of iron oxide bearing wastes. When balls' particulate materials are well bonded by capillary forces from water and plasticity forces from the binder, the balls will have the strength to withstand the compressive stresses and the drops they will encounter without disintegrating back into dust.

The highest green strength and drop number values in this work are 11.7 N/pellet and 7.8 times respectively recorded in the mix with 60 % iron oxide bearing wastes at 14 % moisture contents.

The dry compressive strength of the balls increases as the percentages of moisture and iron oxide bearing wastes increase in the mix (Figure 4). This can be attributed to the hardening of binding agents, precipitation of dissolved salts, friction and interlocking between particles, and electrostatic, magnetic and Vander Waals interaction (Satry, 1984). The highest dry strength value of 25.99 N/pellet is obtained from mix with 14 % moisture and 60 % iron oxide bearing wastes contents.

Figures 5 and 6 show the results of tumbler index and abrasion index tests respectively. They show that balls made with iron oxide bearing wastes can have good values of these indices. High values of tumbler index and low values of abrasion index of balls indicate a good binding quality in the ball structure that will disallow easy disintegration of the balls into dust. A high tumbler index of over 95% and corresponding low abrasive index of below 5% were attained by balls made from the mixture of iron oxide bearing wastes and iron ore concentrates.

4. Conclusion

The study revealed

- ❖ Iron oxide bearing wastes exhibit good balling properties:
 - Drop Number up to 7.8 times (standard minimum = 3 times)
 - Wet Compressive Strength up to 11.7 N/pellet (standard minimum value = 9 N/pellet)
 - Dry Compressive Strength up to 25.99 N/pellet (standard minimum value = 15 N/pellet)
 - Tumbler Indices up to 95% (standard minimum value = 85%)
 - Abrasive Index up to 4% (standard minimum value = 15%)
- ❖ Major balling properties of iron oxide bearing wastes that is Drop Number, Wet and Dry Compressive Strengths, Tumbler and Abrasive Indices are affected by moisture content of the mix
- ❖ Pulverized iron oxide bearing wastes is similar in composition to pellet charge. It may therefore be used as suitable additives to the charge.
- ❖ The grain sizes of iron oxide bearing wastes are poly-dimensional with narrower intervals of dispersion. The pulverized wastes consist of particles less than 125 μm (about 84.5 % with average diameters of 90 μm). The materials are in sizes identical to those of the pulverized concentrates for balling (Table2).

- ❖ Iron oxide bearing wastes exhibit good binding property due to the presence of slaked lime in form of Ca (OH)₂

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