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ASSESSMENT OF PHYSICAL PROPERTIES OF PELLETS PRODUCED FROM AJABANOKO IRON ORE TOWARDS UTILIZATION IN DIRECT REDUCED INDUCTION FURNACE FOR PIG IRON PRODUCTION

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ABSTRACT

The addition of Lime (CaO) into pellet mix is proposed as a potential solution to overcome the insufficient compressive strengths of preheated and fired pellets produced using Ajabanoko Iron ore. Lime (Cao) was tested as an alternative binder to bentonite on magnetite pellets produced from Ajabanoko Iron ore. The performances of the tested binder on pellet qualities: balling drop number, Drop resistance, Green compressive strength at 100°C, Dry compressive strength test at 600°C, Indurating compressive strength test at 1200°C, Moisture content per pellet, tumbler index test, Abrasion index test and Micro porosity of pellets have been compared with the performances of reference bentonite binder. The results of the tests showed that the qualities of pellets are insufficient when 0%, 2% and 6% lime addition wereused as binders. While, at 4%addition showed sufficient pellet quality compared with that obtained when bentonite was used as an ISO standard. The former (0 and 2% lime) failed to provide sufficient pre - heated and fired pellet drop numbers and strengths, the latter (6% lime) failed in terms of wet and dry pellet quality due to over binded strength which prevent reduction of iron ore pellet in the smelting furnace. However, good quality wet, dry, preheated and fired pellets could be produced with 4% CaO as binders. In addition, stronger pellets could be produced at lower firing temperatures like 1373 K;thanks to addition of 4%Lime. The bonding mechanism of 4%Lime containing pellets was compared with 4% bentonite (ISO Standard). It was found that the improved preheated and fired compressive strengths of 4% lime-added pellets were due to the physical melting of lime at the contact point of magnetite grains during thermal treatment.

Key Words: - Pellets, Properties, Bonding Mechanism, Compressive Strength, Moisture.

INTRODUCTION

Iron ore pellets are spheres of typically 6-16mm (0.24-0.62 in) to be used as raw material for pig iron production in direct reduced induction furnace.These pellets typically contain 67%-72%Fe and various additional material adjusting the chemical composition and the metallurgical properties of the pellets (Abraham *et al.,* 2012)Typically Limestone, dolomite and Olivine is added and Bentonite is used as binder.The process of pelletizing combines mixing of the raw material, forming the pellet and a thermal treatment baking the soft raw pellet to hard spheres. The raw material is rolled into a ball, then fired in a kiln to sinter the particles into a hard sphere (Satyendra, 2013; Singha*et al*., 2015). In the Europe. Pellets are formed from the raw materials which are fine iron ores and additives of < 0.05 mm - into 9-16 mm spheres using very high temperatures and this is mainly carried on at the site of the mine or its shipping port (Umadevi*et al.*, 2011: SatyendraSarna, 2013).

Additional materials are added to the iron ore (pellet feed) to meet the requirements of the final pellets. This is done by placing the mixture in the pelletizer, which can hold different types of ores and additives, and mixing to adjust the chemical composition and the metallurgic properties of the pellets. In general, the following stages are included in this period of processing: concentration / separation, homogenization of the substance ratios, milling, classification, increasing thickness, homogenization of the pulp and filtering.it is a best process (Meyer,1980; Joseph,*et al.*, 2015)

The facility used for Iron Ore Pelletizationcan be broadly grouped into four sections:

- Iron Ore Pellet feed and additives storage, proportioning and mixing section
- Green balling section
- Indurating Furnace section
- Iron Ore Pellet product stacking and reclaiming section (Pals *et al.,* 2016)

Pellet feed is basically the iron ore concentrate with a minimum of 64% Fe this is ground to 100% minus 100 mesh, with a Blaine index of ~1800 (Geerdes, 2009). Additives are limestone and / or dolomite, bentonite and coal/coke breeze, all ground to minus 200 mesh. While, limestone and / or dolomite are added to control the basicity as needed in the downstream iron making processes, bentonite is used as a binder and coal / coke breeze is a solid fuel supplement (Kumar *et al.,* 2008; Wu *et al.,* 2009).

Advantages of Pellets

Iron ore pellet is a kind of agglomerated fines which has better tumbling index when compared with the iron ore and it can be used as a substitute for the same both in the blast furnace and for DRI production (Sharma *et al.,* 2010; .

i. Pellets have good reducibility since they have high porosity (25-30%). Normally pellets are reduced considerably faster than sinter as well as iron ore lumps. High porosity also helps in better metallization in DRI production.
ii. Pellets have a uniform size range generally within a range of 8 -16 mm.
iii. Pellets have spherical shape and open pores which give them good bed permeability.
iv. Pellets have low angle of repose which is a drawback for pellet since it creates uneven binder distribution.
v. The chemical analysis is uniform since it gets controlled during the beneficiation process. Fe content varying from 63% to 68% depending on the Fe content of Ore fines. Absence of LOI is another advantage of the pellets.
vi. Pellets have high and uniform mechanical strength and can be transported to long distances without generation of fines. Further it has got resistance to disintegration. High mechanical and uniform strength of pellets is even under thermal stress in reducing atmosphere (Cornel *et al.,* 2006; Cojić and Kožuh, 2018).

Furthermore, In order to determine the influence of binders on pellets, formed pellets were subjected to the following Physical and Mechanical tests: Drop number test, drop resistance test,Green compressive strength test, dry compressive strength test, Indurating compressive strength test, Moisture content determination, Tumbler index determination and Micro-porosity of pellets (Muwangguzi*et al.*, 2010)

This research is aimed at studying the quality of pellets formed by exploiting the difference in both physical and mechanical properties of the formed pellets using Ajabanoko iron ore concentrate fines with and without lime addition and to determine the optimumpercentage addition level of lime; towards its utilization in direct reduced induction furnace (DRI) operation.

MATERIALS AND METHODS

Materials

Ajabanoko iron ore used in this research was sourced from low grade meta sedimentary Ajabanoko iron ore sourced from a deposit located in the Okene - Kabba - Lokoja triangle which host some other deposits from Kogi State of Nigeria. Ajabanoko is the study area for this project which is located at Okene in Kogi state, Nigeria. Ajabanoko iron ore is on longitude 6^0 14' 0''E and latitude 7^0 33'0'' and lies 4.5km Northwest of Itakpe hill (Adebimpe*et al.*, 2014; Amingu and Ako, 2009). The Ajabanoko deposit areas falls within the Nigerian Precambrian basement complex, and a suite of crystalline rocks exposed in over nearly half of the country extending west Dahomeyan of Benin Republic and east into Cameroon (Amingu and Ako, 2009). Representative sample of this crude iron ore was picked by random sampling and analyzed to determine the chemical composition of the lode deposit iron ore. This was processed using Rapid magnetic separator to a high concentrate of 67%Fe (Alabi, 2016), Lime is sourced from limestone sourced from Bauchi lime stone deposit which contains 56% CaO, in Alkaleri Local Government Area of Bauchi State Nigeria.

Methods

Pellets formation

1.0 Kg of Ajabanoko iron ore assaying 67% Fe ground to 63μm sieve size wascharged into clean moisture free pelletizing disc machine of 2.0 Kg capacity in the mineral laboratory of the National Metallurgical Development Centre, Jos. This was rotated for five minutes to ensure uniform mix of this ore before the addition of 1% (10gms.) lime as the disc was in continues rotation towards proper mixture of these constituents;20mls of water was added to the mix in the rotating disc in droplets while the charge is being scrapped in a continuous manner to prevent the charge from sticking to the disc walls until pellets were formed.This further followed by continuous rotation of the disc in a reduced speed from 60rpm to 30rpm to impact further strength on the pellets formed for 2 minutes (Sharma *et al.,* 2009).The product formed was then discharged into a pellet plates and kept for safety at room temperature. This same procedure was repeated for 2% (20gms.), 4% (40gms.) and 6% (60gms.) lime addition to same quantity of iron ore in a pelletizing disc.

Drop Number Test

Five (5) green pellet balls formed with 1% lime were individually droppedon to a steel plate from a standard distance of 60cm height. The number of drops in pellet just before chattering was noted and recorded. Average of the reading taken was calculated and taken as the actual pellet's drop number within minimal error. This was repeated and recorded for 2%, 4% and 6% lime respectively.

Drop Resistance

Five (5) randomly selected pellet samples were picked in green state from 1% lime and was dropped at varying distance of 72, 60 and 48cmdropped to a steel plate base. Number of drops till chattering was achieved were taken and the average value was taken and recorded. This was repeated for 2%, 4% and 6% lime respectively.

Green Compressive Strength Test

Five (5) pellets from 1% lime were used by subjecting the pellets in green stage to chattering test by applying load on a piece of pellet stationed on the stage, using Form and test seidner compressive strength testing machine (model GMBH-7940), readings were taken, The actual readings was taken by calculating the average of the five pellets drops and recorded. Same procedure was used for 2%, 4% and 6% lime addition pellets.

Dry Compressive Strengths Test

A certain crushing strength is necessary in order that the pellets can withstand the compression load in the pellet bed on a belt conveyor, drying grate or in a shaft furnace. Five 1% lime added pellet samples were selected randomly for used. These were heated in the furnace to 600^0C, after which they were put one after the other on stage and subjected to compression load to read the compressive strength test values directly from the machine. Reading were taken and average calculated and recorded. These procedure was repeated for samples from 2%, 4% and 6% lime respectively.

Indurating Compressive Strength Test

Five green 1% lime addition pellet samples were randomly picked from group of formed pellets and were heated in a furnace to 1200^0c before subjected to compressive test using the form and test seidner compressive strength testing machine of the National Metallurgical Development Centre, Jos; after which average of the values taken and recorded.And was repeated for 2%, 4% and 6% lime added pellets respectively.

Moisture Content Determination

100gms of Ajabanoko iron of sieve size 63μm was charged into a known weight ceramic crucible. This was heated at 105^0C and was weighed at 2 hours intervals until a constant weight reading was attained.

The initial weight of Crucible + Sample =W_1 (1)

The Final weight of Crucible + Sample = W_2 (2)

Volume of water expended = W_1 - W_2 = W_T (3)

Volume of moisture evolved = W_T (4)

However, Moiture content per pellet produced was calculated thus: Volume of moisture evolved (W_T) + [Volume of water added to produce pellets (W_p) divided by the number of pellet produced (N_p)].i,e. Volume of water in pellet produced = $W_T + \frac{Wp}{Np}$ (5)

Tumbler Testing

This consists of two tests; basically, the tumbler index test and abrasion Index test. 20 samples of pellets dried to 150°C in a Leco oven, model at the refractories section of NMDC, Jos. These were then charged into a tumbling drum with diameter 0.5m, length 0.2mand height of 0.5m in dimension. This drum was rotated at 50 rpm for five minutes, the product was then charged into sieve of -500μm + 63 for screening. After which the resulting product at -500μm and +63μm were collected separately.Thus, the percentage of fractions in proportion to the feed weight is the value of tumbler index (i.e +63μm) and that of abrasion is (-500μm).

Tumbler index = $\frac{Wt\ of + 63\mu m}{Total\ weight\ of\ pellets}$ (6)

Abrasion Index $= \frac{Wt\ of -500\mu m}{Total\ \ weight\ of\ pellets}$ (7)

Micro Porosity

One (1) representative pellet sample was randomly picked for this experiment.This was heated in a furnace to 1000°C. After it cools down it was then dipped into benzene solution in a cruciblewith a suspended tiny rope up to just the middle point of the benzene constituentin 100mls. Pyrex beaker. Bubbles were released until it seizes. The sample was then brought out to dry in air and weighed. This continued until two uniform weight were obtained.

Porosity $= \frac{wt\ of\ pellet\ in\ Benzane\ (D) - Wt\ of\ sample\ measured\ (d)}{Wt\ of\ Pellet\ in\ Benzane\ (D)}$ (8)

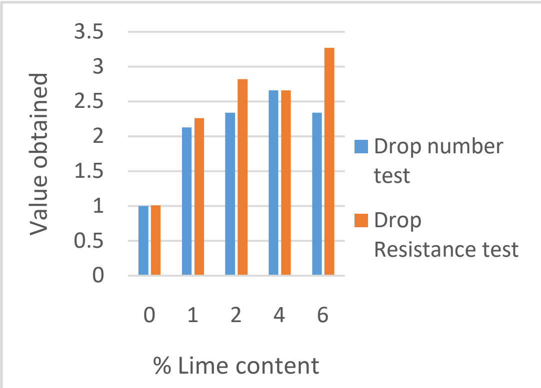
$= \frac{D-d}{D}\ X\ 100\%$(9)

RESULTS AND DISCUSSION

Results

Table 1: Results of Physical and Mechanical Properties of Ajabanoko Iron ore Pellets

Test carried out	0%	1%	2%	4%	6%
Drop Number Test at 60cm	1.0	2.13	2.34	2.66	2.34
Drop Resistance Test at 48,60 and 72cm	1.01	2.26	2.62	3.51	2.67
Green Compressive Strength Test (N/p)	4.62	9.68	11.01	11.83	11.47
Dry Compressive Strength Test (N/p)	9.66	28.92	24.96	34.60	43.83
Indurating Compressive Strength Test (N/P)	233.12	1266.67	2358.33	2583.6	3475.12
Moisture Content Per pellet (mls.)	5.16	4.91	4.82	1.62	1.23
Tumbler Index Test (%)	52.34	76.77	78.62	86.98	92.04
Abrasion Index Test (%)	47.66	23.23	21.38	13.02	7.96
Micro porosity of pellet (%)	5.97	4.72	4.26	2.86	1.72



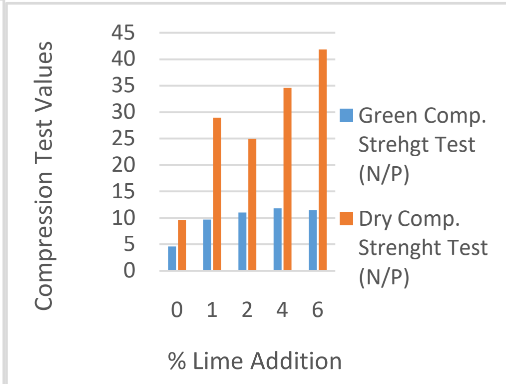
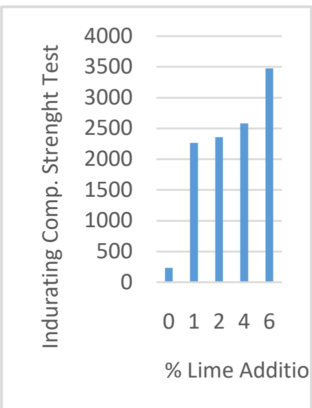
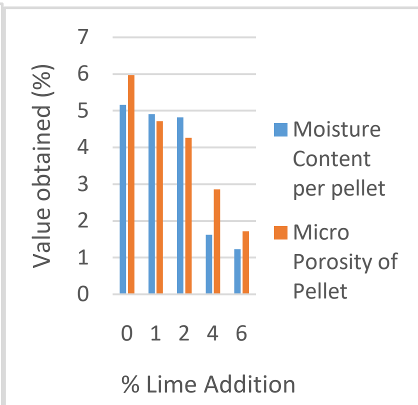


Fig.1: Pellet Drop Number Test and Drop Resistance Fig.2: Green and Dry CompressiveStrength Test against % Lime addition.





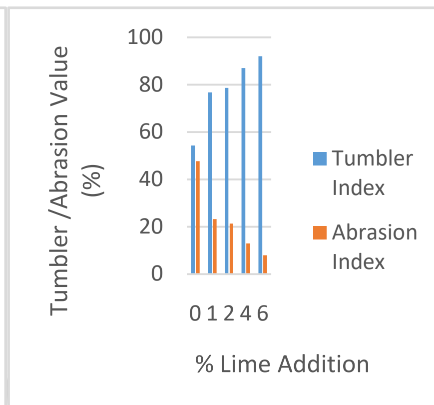


Fig. 3 Fig. 4 Fig.5

Figure 3: Indurating compressive strength test against % Lime Addition

Figure 4: Moisture content and Micro porosity against % Lime Addition

Figure 5: Tumbler and Abrasion Index against % Lime Addition

Discussion

Table 1 and Figures 1 - 5 show the results of physical and mechanical properties tested in Ajabanoko iron ore pellets produced towards utilization in blast furnace for molten metal production.

Table 1, Figure 1 show the drop number at 60cm distance above the steel platform. It shows a weak drop number of 1 and 2.13 at the 0 and 1% addition of lime; this shows that the pellet has no strength at all at these percentage mix. While is shows it increases to 2.34 at 2% addition of lime until it gets to 2.66 at 4% lime addition, but shows a sharp decrease to 2.34 on further addition of 6% lime. With this, it shows that the optimum addition limit of lime to Ajabanoko iron ore is at 4% lime, where at any increase it gave a drop numbers which is still within the bentonite specification of 2 – 4.

Drop resistance test at 48, 60 and 72 cm above the steel platform shows similar characteristics as that of the drop number test in that it increases from 0% addition of lime to 4% addition of lime before it now dropped to 2.67 at the addition of 6% lime and met the bentonite standard specification of 3 drops.

Green compressive strength test (GCST) result on Table 1. Shows that the GCST increases from 0% to 4% with Values of 4.63 – 11.83 N/P but shows a loss in green strength at 6% addition to give 11.47 N/p;which shows that the 4% lime addition is more within the standard specification of 10 – 12 N/P for pellets with 10 -15 mm diameter for green strength.However, 2%, 4% and 6% are within this specification, but 4% lime addition show more and better result and should be taken as optimum.

However, Dry compressive strength test (DCST)pellet shows non - stable state as it show a very low strength of 9.66 N/P at 0% lime addition, it increases to 28.92 N/P at 1% lime addition but decreases to 24.96 as the lime addition tends to 2% which invariably rise to 34.6 and 41.83% at the addition of 4% and 6% lime. In according to standard using lime DCST should not be less than or exceed 40N/P for pellets at 10 – 15 mm diameter to allow easy penetration of heat from tuyeres during the firing operation. From the result it is only 4% lime addition that met the standard, while at 6% over strength was noticed, a property not suitable for Iron and Steel production because it abrasion and dustiness (Meyer,1980; Joseph *et al.*, 2015).

Indurating compressive strength test (ICST) shows increasing in value from 0%,1%,4% and 6% addition of lime with a value of 233.17,1266.17,2358.33,2583.6 and 3475.12 N/P, the standard stipulated for pellet bonded with bentonite to be between 2500 – 3000 N/P. From this only 4% addition met the standard while 0 – 2% gave a lower value which may give room to shattering of pellets before getting to the belly of the blast furnace or pellet not reduced because of over strength.

Moisture content per pellet.It was researched that the moisture content of pellet should be minimal to allow for good reduction process during metallization. If we have more mixture on charging, the pellets tends to crack and losses strength, while if the moisture is too low it tends to over hardened the pellet and there will be no reduction process to cause metallization. Only 4% lime addition with pellets moisture at 1.62mls is within the standard of 1.5 – 2mls moisture per pellet as against 5.16, 4.91, 4.82 and 1.23 of 0, 1, 2 and 6% lime addition.

Tumbler Index Test shows good tumbler index in 4% and 6% lime addition. However, at 4% addition it was noticed that the pellet did not over hardened beyond specification limit of between 80 -90% tumbler index, while 6% addition shows over hardened which means it will not allow reduction of pellets to take place easily as no void for heat transmission present in it.

Table 1, Figure 5, shows the results of abrasion index test, which is the opposite of tumbler index. This shows that the abrasion index values are decreasing from 0, 1, 2, 4% but shows an increases at 6% lime addition at a value ranges of 47.66,23.23,21.38,13.02 and 7.96% respectively,only 4% lime addition was able to meet the standard specification of 10 -15% for abrasion index occurrence to give pellet good reduction in the blast furnace towards molten iron metal production.

Micro – Porosity, the lower the micro porosity the better the strength of pellet and the better the reduction process as the pores will not be blocked to allow the flow of heat from tuyeres through it and will not be too porous to prevent the strength of the pellets to withstand the flow of the heat between the pellets that will aid the iron reduction towards metal formation. The standard therefore, stipulated the value to be between 2 – 3% mls.per pellet to allow for good reduction process. Table 1, Figure 4, shows that decrease in micro porosity from 0 – 6%lime addition has 5.97, 4.72, 4.26,2.86, and 1.72% in which only 4% addition met the standard porosity of 2.86.

CONCLUSION

From the results and discussion on the assessment of physical properties of pellets produced from Ajabanoko iron ore towards utilization in direct reduced induction furnace for pig iron production.It can therefore be concluded that:

i. 4% lime is adequate to be added to Ajabanoko Iron at sieve size to produce pellet that will give a good drop number, drop resistance, green compressive strength, dry compressive strength,indurating compressive strength test with good moisture content, tumbler index, abrasion index and a comparably standard micro porosity that is needed to produce good molten iron during direct reduced induction furnace operation, and;

ii. finally, pellet formed is of good quality and 4% lime addition shows optimum percentage addition level towards utilization indirect reduced induction furnace operation towards iron production.

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