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Original Research Article

Investigation of Excessive Wear of Ashaka Coal Mill Riser Duct and Idendifying the Optimum Solution

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Abstract

Cement plants use fuel in burning limestone to make clinker in kilns. Due to high cost of fuels, most Cement plants are changing from high-cost liquid fuel like heavy fuel to cheap solid fuel like coal. Ashaka adopt the later. The coal is first pulverised in a ball mill and leaves the mill through a riser duct by pneumatic transport before been used in the kiln as fuel. The riser duct undergoes excessive wear which result in frequent downtime and affect the intendent purpose of fuel substitution. Also, the pulverised coal escaping under pressure through eroded areas on the duct increase the risk of fire and reduce the overall safety of the workshop. Current method which involved patching the duct by welding fail to solve the problem. This work investigates the root cause of the frequent wear of the riser duct by checking the abrasiveness of the coal being transported, checking the effect of the duct profile on wear through simulation using computational fluid dynamics (CFD). Checking the duct material rate of wear and providing the best solution in terms of cost and feasibility. After simulation using CFD it was revealed that the duct profile contributed to the wear rate. Since changing the profile will be costly, a different solution approach was considered i.e., surface finishing. Different Material samples suggested to be used as surface finishing on the duct were tested for wear at different angles using an abrasive test equipment. The test equipment which conforms with ASTM was designed, simulated using CFD and constructed. The best material with good wear resistance was found to be galvanised steel coated with automobile anti gravel and grounded with P1000. Coating the internal of the riser duct with the above material is considered to be the optimum solution in terms of cost and feasibility.

Keywords: Limestone, Clinker, Cement, Gravel, Riser duct, Kiln.

1.0 INTRODUCTION

1.1. Background of the Study

Rising energy and raw material cost as well as weak cement demand are putting pressure on the profitability of cement plants in Nigeria. Fuel cost has been a major cost driver in the manufacturing cost of cement. Therefore, optimisation efforts to reduce cost include development of schemes to improve efficiency of the burning line in order to reduce the amount of fuel expended to produce a tone of clinker, which is the major component of cement. Other strategies involved changing the operation of the kiln from high-cost fuels such as Heavy fuel (LPFO) to relatively cheaper fuels like coal. In Ashaka, the second approach was adopted.

A closed-circuit air swept ball mill is utilised for the grinding of the coal. The ball mill is equipped with a centrifugal fan that conveys the product from the mill through a riser duct in to the static separator, where fine products are separated from the coarse product. The coarse product is recycled back to the milling circuit for further grinding, while the fine product, which is about 15- 18 % reject on 90µm sieve and less than 2% on 200µm sieve is then transported to the back filter for trapping the product from the transporting air, the product is now conveyed to the silo bin by FK pumps. The product in the bin is used for the kiln firing instead of the liquid fuel. Significant downtime has been associated with the failure of the outlet riser duct. Periodic thickness measurement of the riser duct indicates an abnormal rate of wear. Therefore, factors that affect the abrasiveness of coal such as mineral matter composition, Hard grove grind-ability index (HGI), moisture, duct contour etc. need to be evaluated and systematically used to determine the suitability of the choice of material for the fabrication of the riser duct This work will study the effect of these factors with specific reference to the Ashaka coal mill to identify the most relevant factors and therefore, determine how effective design and choice of material of construction can be used to improve the reliability of the grinding shop. Surface finishing will also be investigated to identify its role in protecting the mill riser duct.

The operating and maintenance cost of the mill contributes to realisation of the overall objectives of lowering the total cement production cost by using coal as the main fuel for kiln burning. The maintenance cost has been significantly affected by the high rate of replacement of the mill internal components. The frequent failure of the mill components significantly affects the overall reliability of the mill, thereby impacting on the availability of coal to be utilised for kiln burning. Abrasive wear is caused by the sliding of hard particles over a surface, or between two surfaces. In power plants, the main areas of concern are in coal handling, crushing and milling equipment, where abrasive wear of metal components in contact with the mineral constituents of the coal can affect the performance of the equipment, and can be a significant contributor to the maintenance costs. Erosive wear is associated with the impact of hard particles, carried in a fluid at significant impact velocities, on metallic and other surfaces. The key areas of concern in coal-fired plant are the internal surfaces of coal mills, the pulverised coal pipe work, and the burner internals, where erosive wear due to the impact of pulverised coal particles can have an effect on the performance of items of equipment and can increase plant maintenance costs. Erosive wear of boiler tubes and other surfaces in the convective section, either by ash impact erosion or due to the action of the soot blowers, is also of concern. Knowledge of expected abrasion and erosion wear rates for particular coals is necessary to allow equipment suppliers to design for the intended fuel and provide guaranty of equipment lifetimes and to allow operators to plan maintenance schedules. This is particularly important in the case of coal fired plants that utilise high ash coals, where the costs of abrasive and erosive wear can be very significant.

The main variables that influence erosion are the size, shape, velocity, angle of impact, and composition of the eroding particles, the properties of the surface being eroded, and the temperature of the system. Other variables the gas chemistry and properties of the particles being transferred.

1.2 Statement of the Problem

The excessive wear rate of the coal mill outlet riser duct in Ashaka coal grinding shop as a result of the transportation of pulverized coal from the mill to the bag filter system has frequently resulted in significant downtime of the coal mill and this negatively affects the cost of clinker production and maintenance cost of the coal workshop. Current maintenance intervention approach that involves patching the damaged portion with a piece of metal has failed to resolve the issue. Therefore, a different approach is dictated by the circumstances to help resolve the issue.

1.3 Aim and Objectives of the Study

The goal of the current study is to determine the root cause of Ashaka cement coal mill riser duct excessive wear rate and to establish the basis for selecting the right material of construction for the riser duct or the necessary surface finishing required with minimal cost. This will be achieved via the following objectives:

a) To check the extent of abrasiveness of Maiganga coal
b) To check the current design of the riser duct profile and its effect on the wear rate of the existing riser duct by simulation.
c) To construct abrasion testing equipment and to test abrasion resistance of different materials.
d) To study the possibility of using surface finishing techniques to improve the wear resistance of the existing riser duct.
e) To select the best solution in terms of optimum cost and performance. Cost analysis.

1.4 Justification

Fuel cost has been a major cost driver in the manufacturing cost of cement. Therefore, optimisation efforts to reduce the cost include development of schemes to improve efficiency of the burning line in order to reduce the amount of fuel expended to produce a ton of clinker, which is the major component of cement. The research if carried out will increase profit by minimizing downtime and maintenance cost. In addition to that it will improve safety of the workshop. The investigation will provide solution to the wear of the coal duct by selecting the right material for the duct construction.

The knowledge and information obtained from this work can be applied to other equipment used in handling the coal and can also help in selecting the right material in material transportation.

1.5 Scope and Limitation

The current study will be limited to investigating the causes of Ashaka cement coal mill riser duct excessive wear rate through evaluating the abrasiveness of Maiganga coal and its effect on the abrasive and erosive wear and simulating the flow of the pulverised coal inside the coal mill outlet riser duct.

The work will have the following limitation

1. For the wear test equipment there will be no instrument to measure the particle velocity

instead a steady and uniform velocity will be maintained through air pressure gauge and pressure regulator.

2. Silicon oxide (SiO_2) will be used as the test particle instead of the pulverised coal.

II. MATERIALS AND METHOD

2.1 Materials and Equipment

1. Stainless steel
2. Ply wood
3. Hardened Glass
4. Mild steel
5. Air filter regulator
6. Galvanised steel
7. Weight Scale
8. XRF Machine

2.2 Design Procedure

Design of the abrasion test equipment is done based on design calculations as follows.

2.2.1 Hopper Design

The Hopper was design using Carleton Equation:

$$\frac{4V_o^2 \sin\theta}{B} + \frac{15\rho_{air}^{1/3}\mu_{air}^{2/3}V_o^{4/3}}{\rho_p d_p^{5/3}} = g \quad \ldots (1)$$

And continuity Equation:

$$\dot{m} = \rho_b A V_o \quad \ldots (2)$$

Where;

V_o – average velocity of solids discharging (m/s)
A – Area of outlet opening (m)
B- Outlet diameter
μ, ρ- viscosity and density of air
ρ_p- Particle density
dp- Particle diameter
ρ_b- Bulk density

The sand used as the abrasive material contains 97.578% of SiO (See appendix B) Angle of internal resistance of the sand sample was found using angle of repose as 30 degree and wall friction angle between the sand and steel as 25 degrees which correspond to the value given by Caputo (1986) as 25 degrees also it is prove using the correlation.

Plate-I: Measuring Angle of Repose for Sand Abrasive Material

For dry fine sand,

$\delta/\emptyset = 0.84$ … (3)

Where,

δ = wall friction angle, $\delta = 25.2^\circ$

∅ = angle of internal friction

From continuity equation,

$$V_o = \frac{\dot{m}}{\rho_b A} \quad \ldots (4)$$

Where $A = \frac{\pi d^2}{4}$ … (5)

$$V_o = \frac{4\dot{m}}{\rho_b \pi B^2} \quad \ldots (6)$$

Substituting (6) in equation (1) and solving for B

$$\frac{4\left[\frac{4\dot{m}}{\rho_b \pi B^2}\right]^2 \sin\theta}{B} + \frac{15\rho^{1/3}\mu^{2/3}\left[\frac{4\dot{m}}{\rho_p \pi B^2}\right]^{4/3}}{\rho_p d_p^{5/3}} = g$$

Mass flow rate, m= 0.0065kg/s
Density of sand ρ= 1612kg/m^3
Simi inclusive angle, θ= 16°
Density of air ρ = 1.184
Viscosity of air, $\mu = 1\times10^{-5}$
Average diameter of sand particle, d_p = 0.0004m

Using excel,

$$\frac{(((4*0.0065)/(1612*PI()))^{\wedge}2)*4*SIN(RADIANS(16))}{B^5} + \frac{((15*1.184^{\wedge}(1/3)*(0.00001)^{\wedge}(2/3))*((4*0.0065)/(1612*PI()))^{\wedge}(4/3))/(1612*0.0004^{\wedge}(5/3))}{B^{8/3}} = 9.81$$

Using goal seek future in excel the value of B was obtained (See Appendix A)

$9.81B^5 - 1.86361E - 07B^{7/3} - 2.90613E - 11 = 0$… (7)

A solution with value 0.000 is obtain with four undefined value and one real value of 0.005m.

Hence the hopper outlet diameter is,
0.005m

From equation (31) Average velocity of solid discharge, V_o

$$V_o = \frac{4\dot{m}}{\rho_b \pi B^2}$$

= 0.2m/s

Volume of conical section + volume of Bin

$$V = \frac{\pi}{24tan\theta}(D^3 - B^3) + \frac{\pi}{4}D^2H \quad \ldots (8)$$

Where,
B is the bin diameter
H = bin height
B= hopper outlet diameter
θ = Simi inclusive angle
Assumed,

$$H/D = 5 \quad \ldots (9)$$

Total volume of sand required for 5 min of Test,
Hopper discharge = 7g/s
5 minutes discharge = 2.1 kg $\rho = \frac{m}{V}$
Density of sand particles, ρ = 1612kg/m^3
Hence volume required, V
=0.0013m^3

From equation (8) $0.0013 = \frac{\pi}{24 \tan 16}(D^3 - 0.005^3) + \frac{5\pi}{4}D^3$
D= 0.0666879533243931m

Say 66.7mm
From equation (9), H=5D, ***H= 333.5mm***

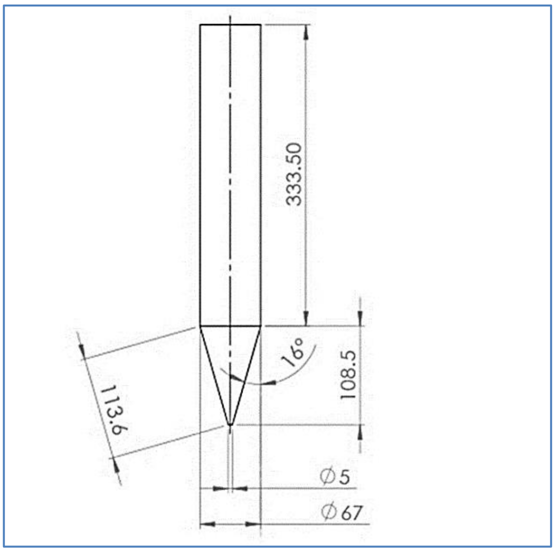

Fig-1: Hopper design drawing with dimension

2.2.2 *Eductor Pump Design*

The Eductor pump been part of the equipment is the one responsible for sucking the abrasive Silicon oxide and propelling it at a very high velocity in such a way that it causes wear on the test part within a short period of time. The component was design using design parameters given by Tao, 2004, Modification was done after a series of simulations using CFD before construction. The construction was done using lathe and milling machine. The design was made in such a way that the nozzle position can be adjusted to fine tune the rate of suction according desired need or amount of pressure of the motive fluid.

Parts of the Ejector pump contains

i. the entrance,
ii. lock nuts,
iii. converging nozzle,
iv. mixing chamber,
v. suction tube,
vi. recovery section or extension and
vii. The nozzle.

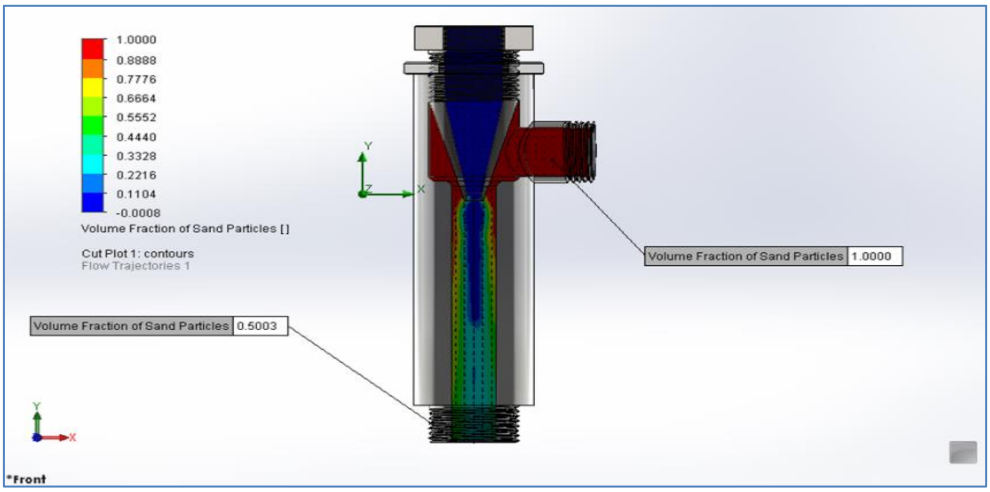

Fig-2: Venturi volume fraction of sand particles from suction to discharge

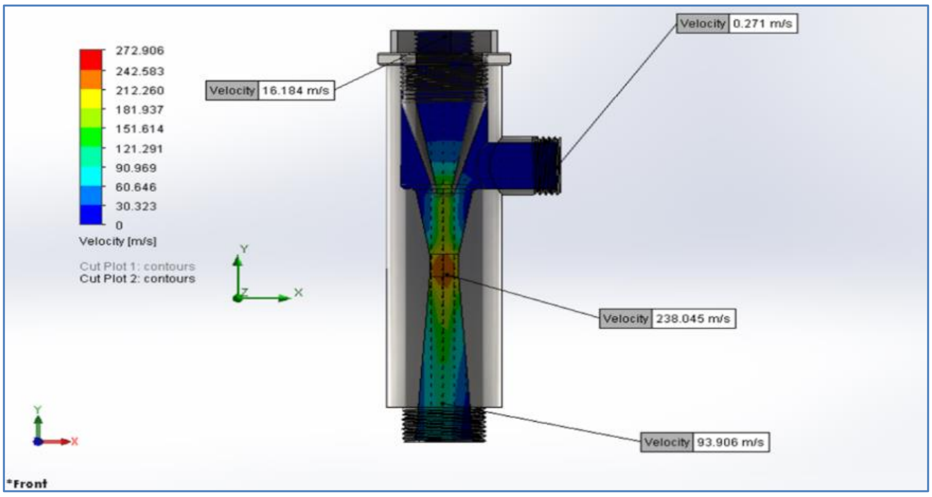

Fig-3: Venturi with a converging Diverging nozzle

The shape of the venturi was changed from a convergent divergent nozzle to a straight shape this is due to the fact that the C-D nozzle affects the velocity at exit which drops drastically especially after mounting the exit nozzle however changing the shape to straight the velocity appreciates at the exit as seen in figure 4. Since the aim is to obtain a good jet velocity at the exit that can accelerate the abrasive particles in such a way that they can cause wear the straight shape was adopted.

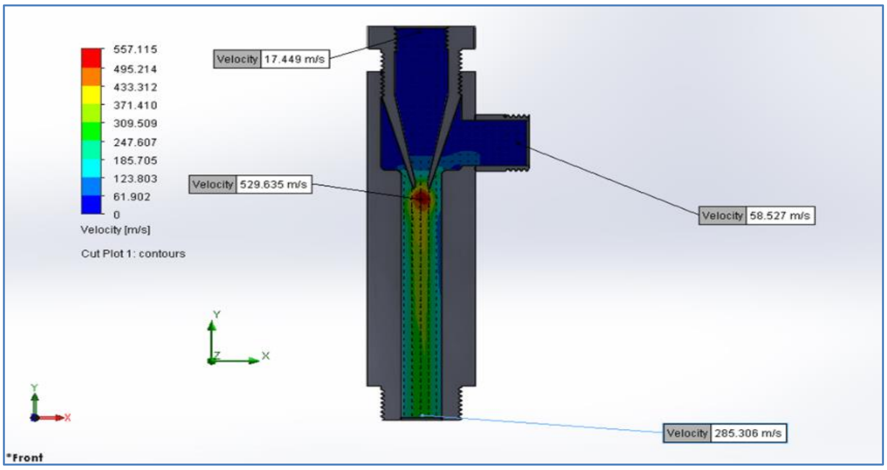

Fig-4: Velocity profile of a Venturi with a straight shape after the mixing chamber to prevent pressure recovery and velocity drop

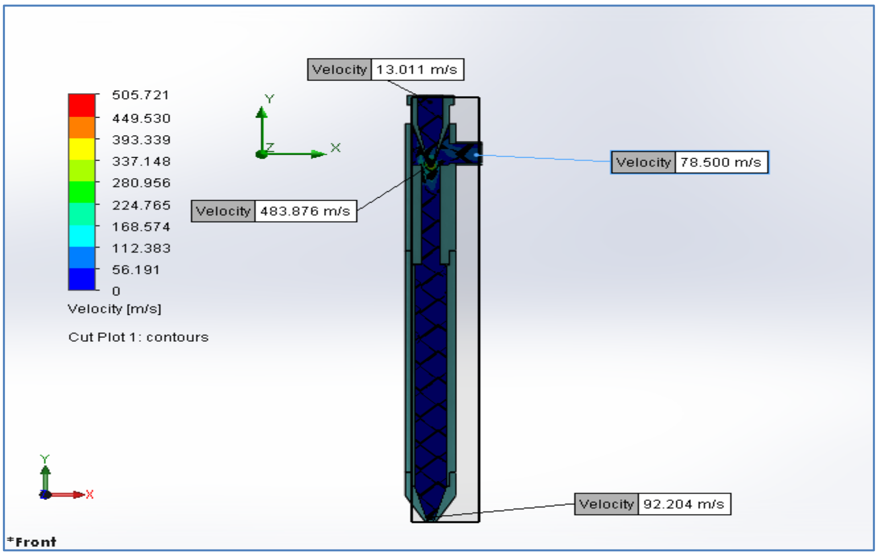

Fig-5: Complete assembly and nozzle diameter of 4.2 (CA ND4.2)

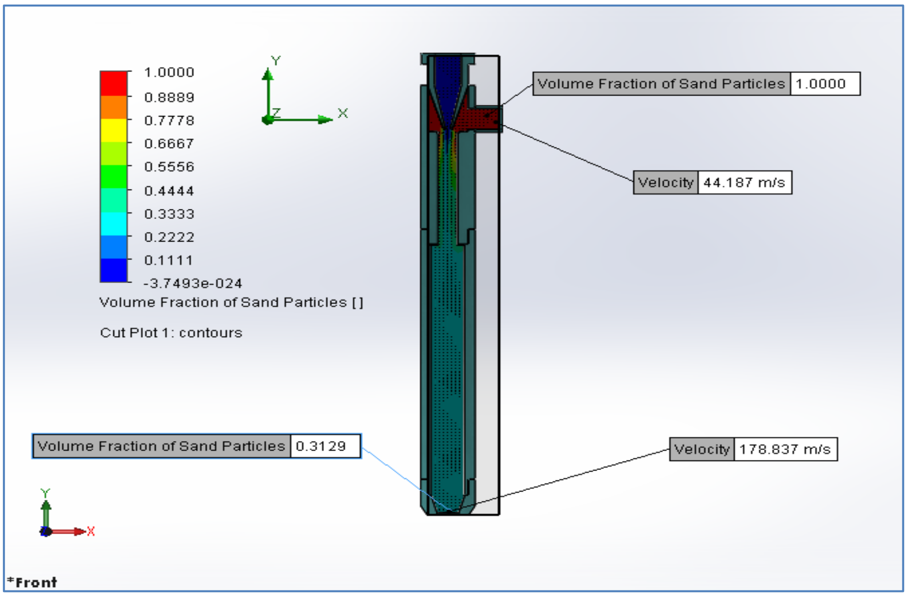

Fig-6: Complete assembly with nozzle diameter 15(CA ND15)

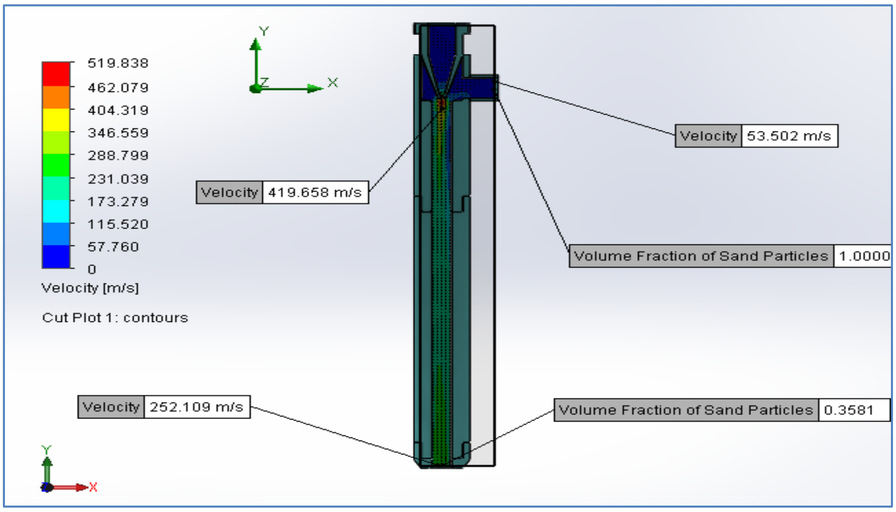

Fig-7: Complete Assembly with Extension and Venturi Same Diameter, Nozzle Diameter 15 (CA-SE ND15)

Table-1: XRF result for Maiganga Coal

CODE	Sample material	Angle
12	AntiGravel Rough	30
08	AntiGravel Rough	45
06	AntiGravel Rough	60
03	AntiGravel Rough	90
11	AntiGravel Smooth (P1000)	30
09	AntiGravel Smooth (P1000)	45
05	AntiGravel Smooth (P1000)	60
01	AntiGravel Smooth (P1000)	90
10	Galvanized Steel (P1000)	30
07	Galvanized Steel (P1000)	45
04	Galvanized Steel (P1000)	60
02	Galvanized Steel (P1000)	90

III. RESULTS AND DISCUSSION

3.1 Maiganga coal abrasiveness

Table-2: Abrasion Test Result

SiO2(tot)	36.10	46.80	49.20
Al_2O_3	12.50	18.10	17.74
Fe_2O_3	24.19	9.23	8.45
CaO	13.92	15.92	13.74
MgO	0.94	1.62	1.75
SO_3	3.11	3.18	3.67
K_2O	2.11	1.27	1.09
Na_2O	0.13	0.13	0.14
P_2O_5	0.38	0.38	0.41
Mn_2O_3	0.48	0.21	0.19
TiO_2	0.93	1.09	1.09
LOI	0.15	0.20	0.13
TOTAL	94.94	98.14	97.60
SR	0.98	1.71	1.88
AR	0.52	1.96	2.10
LSF	10.58	10.05	8.37
C3S	-336.74	-426.55	-449.87
$CaCO_3$	24.85	28.42	24.51

The Hargrove Grindability Index (HGI) is commonly used to predict abrasion of equipment, however, HGI tests were not conducted on the Maiganga coal samples. Erosion and abrasion are primarily due to the presence of. Abrasive minerals in coal such as quartz and pyrite. Particle size and shape are other factors that affect erosion and abrasion. In the absence of mineralogical data coal technologists have used the Si/Al ratio as an indicator of abrasiveness. This index is- based on the assumption that the higher the ratio the greater is the quartz content. Coals having Si/Al ratios greater than three are considered to be abrasive. This shows that Maiganga coal is considered to be not highly abrasive with Si/Al ratio of 2.8.

3.2 Simulation Result

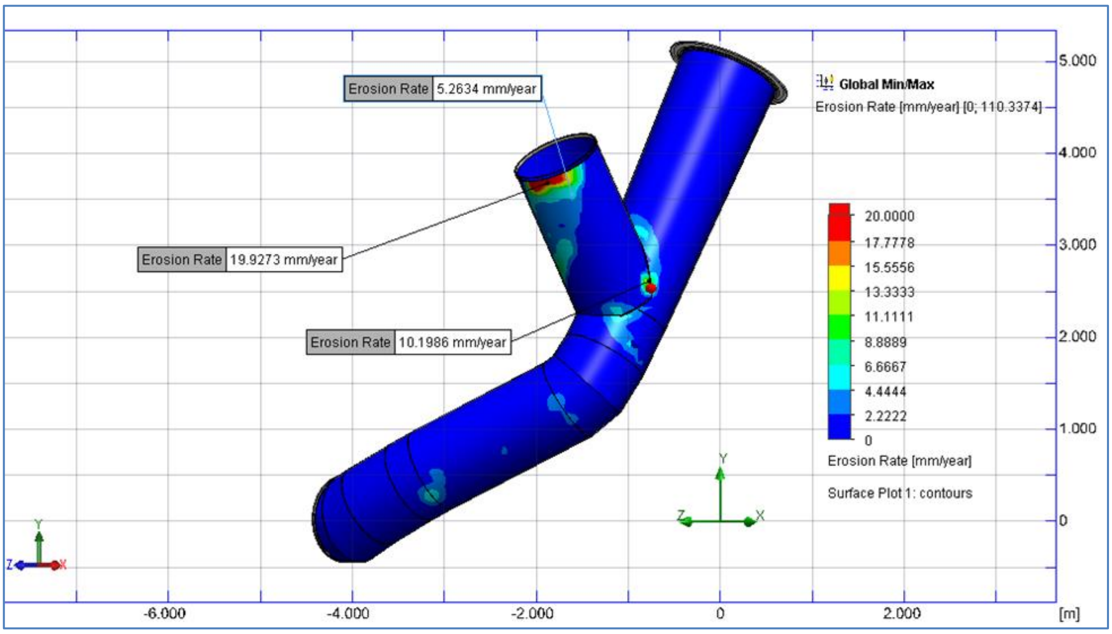

Fig-8: Duct model revealing wear areas of after particle studies

In the simulation, flow rate and the coal velocity were set as criteria for converging and these all converge after 47 iterations as shown in figure 24. The duct flow and particle studies for abrasion simulation result revealed areas with high wear rate and those with no wear at all the areas with high wear rate correspond to regions in the duct where the flow velocity is high greater than 10m/s (figure 3) and the contact angle is minimum due to the shape of the duct. This shows the profile of the duct have tremendous effect on the high wear rate. The areas revealed by the simulation are exact spots that used to wear out completely.

Based on the simulation result figure 5, there are some areas with wear rate up to 19mm/year and definitely those areas used to be welded twice a year or more.

4.0 Abrasion test

The abrasion test result includes wear rate of each sample determined at different flow angles as shown in the table 13. After construction of the abrasion test equipment Galvanized three set of samples were tested each at different angles for rate of wear. Galvanized steel grounded to 1000 s.f shows near linear rate of wear rate with decrease in flow angle. At 30 degrees it has a wear rate of up to 2.4133E-07 kg/s. For samples coated with rough AntiGravel it has the highest wear rate compared to other samples with up to 3.8800E-07 kg/s the wear rate increase with decrease in angle from 90 to 45 degree and tends to be linear from 45 to 30 degrees. With steel coated with automobile AntiGravel and ground with 1000 s.f sand paper shows good abrasion resistance at all angles 90, 60,45, and 30, the wear rates tend to be constant by decreasing the angle of flow from 90 to 60 afterwards from 60 to 30 the rate of wear increase slowly with the sample at 90 degrees it shows the minimum wear rate of all the samples having 2.8333E-08 kg/s followed by 60 degrees with 2.8667E-08 kg/s then 45 degrees with 6.0333E-08 kg/s.

Table-3: Abrasion Test Result

Sample Code	*Material*	*Abrasion angle*	*Weight, W_1 (g)*	*Weight, W_2 (g)*	*Wear (g) W_1-W_2*	*Rate of Wear (kg/s)*
01	AntiGravel Smooth (P1000)	90	27.5964	27.5879	0.0085	2.8333E-08
05	AntiGravel Smooth (P1000)	60	29.0973	29.0887	0.0086	2.8667E-08
09	AntiGravel Smooth (P1000)	45	25.6599	25.6418	0.0181	6.0333E-08
02	Galvanized Steel (P1000)	90	25.8089	25.7897	0.0192	6.4000E-08
11	AntiGravel Smooth (P1000)	30	27.0494	27.0149	0.0345	1.1500E-07
04	Galvanized Steel (P1000)	60	27.7172	27.6691	0.0481	1.6033E-07
10	Galvanized Steel (P1000)	30	27.4432	27.3708	0.0724	2.4133E-07
03	AntiGravel Rough	90	27.3518	27.2648	0.087	2.9000E-07
07	Galvanized Steel (P1000)	45	26.1092	26.0175	0.0917	3.0567E-07
08	AntiGravel Rough	45	28.3938	28.2921	0.1017	3.3900E-07
06	AntiGravel Rough	60	28.8730	28.7590	0.114	3.8000E-07
12	AntiGravel Rough	30	27.7577	27.6413	0.1164	3.8800E-07

4.1 Surface Roughness

During the test, Surface roughness has been considered, AntiGravel with rough surface finish shows a very poor abrasion resistance more than the material galvanised steel however by grounding the AntiGravel coating to the same surface finish with the duct material to 1000 s.f the rate of wear decrease by 924% at 90 degrees flow angle and decrease by 237% at 30 degrees.

5.0 SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 Summary

The root cause of excessive wear rate has been Identified. Abrasive testing equipment has been constructed with readily available materials in the market. This equipment is easy to handle and operate. Simulation of coal flow has been carried out on Ashaka coal mill riser duct using CFD. XRF has been carried out on Maiganga coal.

5.2 Conclusion

The following conclusions were drawn from this research.

1. The first objective of this work was to check the abrasiveness of Maiganga coal and this has been done the coal has Si/ Al ratio of 2.8 which is less than 3 meaning the coal is not highly abrasive
2. The effect of the duct contour on wear has been checked using CFD and areas with high wear rate were revealed.
3. Abrasion test equipment have been constructed at cost of 50,000 NGN
4. Different types of surface finishing were considered for the wear rate test, coating and surface roughness were considered; galvanized steel coated with automobile AntiGravel wear more than the duct material itself but when the AntiGravel coating was grounded to the same finest to the galvanized still the wear rate drop by 924% proving better wear resistance among the samples tested.
5. The best solution to the high wear rate has been identified. Surface finishing with AntiGravel grounded to 1000 s.f has been selected as the optimum solution considering low cost of implementation and effectiveness.

5.3 Recommendations

1. Coating the internal of the duct with AntiGravel grounded to at least 1000 s.f will eliminate the problem of excessive wear rate of the duct.
2. By incorporating particle flow velocity measuring device for the abrasion particles right before striking the test sample. This will give room for further analysis on the particle behavior at different striking angles

3. Built in timer and auto shut valve of air. This will give a more accurate and precise test time reading.

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