BENEFICIATION OF IMPURE ZIRCON SAND FOR USE AS A HIGH QUALITY FACING MATERIAL IN FOUNDRY OPERATIONS

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ABSTRACT

Imported chromite sand had been used as facing material for high Mn-Steel castings in Delta Steel Company (D.S.C.) Foundry. These castings are very valuable high wear resistant products employed in various industries. In search for local alternative for the chromite sand, some zircon sand earlier imported for use in the Steel Melting Shop was tried and the result proved satisfactory. The trial was extended to unbeneficiated zircon sand from Vectics and Nigerian Mining Corporation, Jos. The latter trial revealed profused mould-metal reactions. The work reported here was aimed at examining the characteristics of locally available zircon and seeking means of adapting it as facing sand for high Mn-Steel casting without enormous capital investment on any beneficiation process. It is shown that unbeneficiated local zircon with grain size restriction between –0.25mm and +0.1mm has been found to produce castings with close dimensional toleranc,e and good surface finish and contain a minimum zirconia content of 60% - a result quite comparable with that obtainable using either chromite sand or imported zircon sand.

1.0 INTRODUCTION

The importance of high manganese casting products such as jaw crushers, flywheels, hammer heads etc. in the process industry cannot be overemphasized. The quality and the economics of casting these products depend on the properties of the sand used as mould facing material. The use of chromite and zircon sand for this application has been variously reported in literature [1]. The properties of the sand usually include high refractoriness as well as its neutrality at casting temperature. Chromite sand ($FeCr_2O_4$) and Zircon sand ($ZrSiO_4$) all have high melting points. Zircon is structurally tetragonal with a specific gravity of 4.7 $gmcm_3$ and melting points in the range of 2340 – 2550 °C depending on the purity. The problem with the use of zircon in the Foundry seems to be associated with its thermal behaviour especially in the presence of harmful impurities especially at elevated temperature. At about 1500 °C zircon sand thermally decomposes according to the following equilibrium reaction:

$$ZrSiO_4 \rightleftharpoons ZrO_2 + SiO_3 \qquad (1)$$

However, this dissociation is usually obscured by recombination reaction on cooling [2]. Zircon sand (zirconium silicate) has been found to be purity sensitive when used as facing sand for high manganese steel casting. It is reported [3] that below 1750 °C zircon sand is neutral but in the presence of impurities, especially free silica, it behaves like an acid refractory.

Initially an imported chromite sand was used in the Delta Steel Foundry as a facing material for high manganese steel casting. Since it was known that zircon sand was available locally and could possibly be an alternative to the chromite sand, it was considered necessary to assess the performance of high quality zircon sand earlier imported into DSC Warehouse for an entirely different application elsewhere in the plant which proved very encouraging. The trial was then extended to impure zircon sand obtained from two local sources namely the Nigerian Mining Corporation, and Vertices Nigeria Limited both in Jos, Nigeria. It may be of interest to note that hitherto there has been an apparent inertia on the part of the owners of the zircon sand dumps in Nigeria to process them for use, either due to the enormous capital investment and operational costs or lack of confidence in the existing markets in the country, or both.

Recent reports have shown increased interest in the use of inexpensive methods such as sand - size grading for improving the quality of foundry castings. In this connection, Oyetunji et al [4] investigated with promising results the effect of grain size analysis of foundry sand on the mechanical properties of cast steel. More recently, in another work, it was reported [5] that fine – size grain sand was found to improve overall properties of grey cast iron.

The object of this work was therefore to examine how the physical and chemical characteristics of the local zircon sand affect its performance and then seek means of adapting it for high manganese steel castings without intensive capital investment.

2.0 METHODOLOGY

2.1 Moulding Characteristics of as Received Local Zircon

Samples of imported and local zircon were subjected to series of physical and chemical test. Having characterized the local and imported zircon, a standard laboratory rammer was used to prepare cylindrical zircon samples of different composition. The rammed samples were subjected to series of tests in order to obtain the optimum of zircon sand, binder, fillers and moisture.

Further, the casting performance of the local zircon was assessed first by studying the effects of certain additives such as coal dusts and molasses, crushed manganese oxide (MgO) based bricks and binders in the form of bentonite and Portland cement in moderating the negative effect of silica content and then the influence of grain size restriction.

2.2 Field Trials

Two types of sand were prepared for field trials based on their promising sintering and moulding characteristics. Zircon – MgO mixture and zircon sand with grain size between 0.25mm and 0.1mm. Both of which sintered above 1400 °C, were used for field trials after initial trials with as-received zircon sand.

A number of crusher jaws were cast using the two types of sand as facing material in the mould cavity. After casting, the products were shaken out, visually inspected and observed mould-metal reacting product was sent for chemical analysis.

3.0 RESULTS AND DISCUSSION

3.1 Behaviour of As-Received Zircon Sand

Table 1 shows the result of the physico - chemical properties of the as received zircon sand compared with the imported zircon sand. The zirconia content of as-received zircon ranged from as low as 40% in some batches to as high as 55% in some isolated cases. Stoichiometric ratio of zirconia to silica in imported zircon sand was about 2:1; however, this was not the case for the local zircon. From the Table 1 it was found that the ratio of zirconia to silica was 1:1 which signifies high proportion of free silica, an undesirable substance in foundry casting operations.

3.2 Undesirable Effects of Free Silica on Mould Performance

The effect of high content of free acidic material such as silica in zircon sand was studied [2, 3] and it was found that it leads to the formation of low melting fluxes under basic casting conditions. This in itself causes mould-metal reaction at the interface to form low melting,low viscosity slag which dissolves small particles thereby increasing the volume of faced products. The implication of this is that at casting temperatures of 1450 °C, the siliceous material fuses at random sites, creating some soft spots through which the liquid metal penetrates under metallostatic pressure. This process inhibits free flow of displaced gases from the mould cavity leading to the formation of blow holes and deposit of burnt sand over the cast surfaces and the attendant problem of costly fettling and machining.

Further, there is the possible characteristic volumetric expansion of silica (6) in the mould sand occasioned by α -ß quartz phase transformation phenomenon at elevated temperatures mainly producing stresses which cause the surface to successively bulge, crack, peel or spill. This results in liquid metal penetrating behind the original surface to cause rough surfaces.

3.3 Effect of Additives on Moulds for High Mn Castings

The addition of coal dusts and molasses to mould materials was aimed at countering the expansion stresses by creating a cushioning effect within the system as well as providing a reducing atmosphere at the metal-mould interface showed unsatisfactory results. Rather that achieve the desired effect it appeared the MgO-Silica reaction at the mould – metal interface produce a low melting point slag of FeO-MnO-SiO_2 complex [7]. It is believed that such slags cause severe adherence of fused silica on the surface of casting as was confirmed by the results of chemical analysis of the fused products shown in Table 2.were not only produced but caused severe deposit of fused materials on the surface of casting. This was confirmed by the results of chemical analysis of the fused products shown in Table 2.

A feasible simple mechanism for the above reaction was accordingly postulated as follows:

- The water vapor of the green sand and the air in the mould cavity oxidize the manganese steel at the interface producing iron oxide, siliceous oxide other metal oxides. The oxide fluxes combine with the free siliceous material in the mould to form a relatively low-melting point silicate which wets other silica grains rapidly. At the same time the liquid metal which does not wet silica but does adhere to the silicates, penetrates the sand and is oxidized.
- The above was confirmed via analysis of fused material on cast products, (Table 2). The reaction products were found to contain 10-15% Mn0 and 6 -12% Fe_20_3. The additives (coal and molasses) could not prevent Mn and Fe transfer into the test facing material.

Reaction product analysis also indicated the presence of $ZrSi0_4$, and $MgSi0_4$.

3.4 Influence of Binders

The results of the effect of binders on mould characteristics are shown in Table 3. First, bentonite clay was used in various proportions. Results indicate a drastic drop of sintering point values of the mould with slight increases in bentonite values, dropping as low as 1100 ^{o}C at bentonite value of 10% as in Table 3. To solve this problem, Ca0-based cement binder was tried for the facing sand. This maintained the sintering point significantly, at 1300 ^{o}C minimum. However, this benefit was eroded by poor bond phenomenon at the bentonite backing sand and cement held facing sand, understandably, due to the disparity in the bond type i.e. one being physical and the other being chemical thus making the scheme unsuitable.

3.5 The Effect of MgO additions on Mould Characteristics

It was observed that the addition of crushed Mg0 bricks to local zircon produced some interesting mould characteristics. As may be seen in Table 4, slight increases in Mg0 values significantly raised the sintering point of the mould. However this beneficial effect was swamped by drop in mould permeability values as was manifest in violent boiling during casting operations believed to be due to the inability of the evolving gases to escape freely. The resulting casts were therefore found to have rough surfaces and for the moulds with high Mg0 content, metal splashing and overflow prevailed. Further investigation revealed that the poor permeability phenomenon was occasioned by the inevitable presence of excess Mg0 fines provoking closed packing characteristics. Thus, although the primary objective of adding crushed Mg0 bricks to "stabilize" the zirconia in the as-received zircon was achieved, this benefit was overridden by poor mould permeability and the attendant metal-mould reaction, causing the formation of low melting Mg0 – $Si0_2$ complexes and the resultant poor surface finish of cast. Because of this problem further work on this scheme was discontinued.

3.6 Effect of Grain – Size Restriction

Intense microscopic studies of the samples of the local zircon revealed that the quality of the zircon might be grain-size dependent. For a example it was observed that the bigger grains contained white (silica) and black (ilminite Fe0. Ti02), possibly with tin sand – witched between them. The small grains had brown colour, characteristic of zircon.

Table 5 gives the relationship between the grain – size distribution and the chemical characteristics of the local and imported zircon sand. The result of the sieve and the chemical analysis of various grain sizes of the as – received zircon confirmed the earlier results found by microscopic studies. From Table 6, it can be seen that the various sieve sizes contain various amounts of zircon which increase with decreasing grain size up to 0.1mm size.

However below 0.1mm size there appears to be a decrease in the zircon content showing the likely adverse effect of very fine grains which might impact very negatively on the mould permeability characteristics.

It was further found that zircon of grain sizes between 0.10mm and 0.25mm (beneficiated zircon) had a minimum zirconia content of 60% which gave a sintering point of 1400 °C minimum., as in Table 7, as against 1300 °C for raw as - received zircon shown earlier in Table1. Additionally, within the beneficiated zircon size range i.e.0.1 – 0.25mm, the zirconia to silica ratio was found to be 2:1 which is consistent with the imported zircon (see Table 7). On using the beneficiated grade zircon in an admixture with 3% bentonite as a binder for field trials, it was possible to produce high Mn basic binders did not show much promise. This work has shown that the problem of acidic castings with sufficiently good surface finish comparable with those cast using chromite sand and imported zircon sand [8]. The improved performance of the beneficiated zircon sand based on the grain size restriction can be rationalized in terms of the following:

(a) Obvious decrease in imbedded silica and other impurities with decrease in zircon grains within the range of interest.

(b) Zircon has a natural characteristic grain size below 0.25mm, thus by grinding and screening the ore to obtain zircon grains around this size range, their liberation from entrenched impurities / inclusions is made possible.

4.0 CONCLUSION

Impure local zircon sand was studied and beneficiated in this work for use as a mould facing material in high manganese steel castings.

It was observed that the myriad of problems associated with the use of impure zircon could be attributed to the existence of excess acidic silica forming low melting fluxes that adhere to the cast surface thus making fettling and machining an unproductive venture. It was found that an attempt to modify the chemical reactivity of the zircon sand using additives and reactivity of the as-received zircon sand can be circumvented without much capital outlay by merely restricting the grain size (d), of the local zircon between 0.25mm $\leq d \geq 0.10$mm. The performance of the zircon so beneficiated has compared favourably with the imported chromite and zircon sand. Furhtermore, the processed zircon sand was successfully applied to a commercial scale operation in the Delta Steel Foundry.

Table 1: Comparative Analysis of Physico - Chemical Properties of As – Received and Imported Zircon Sand

Physico- Chemical Properties	As Received	Imported Zircon
ZrO_2	35.2%	64%
SiO_2	38.41%	28.4%
Al_2O_3	3.1%	3.2%
Fe_2O_3	2.19%	-
Loss on Ignition	1.0%	1.3%
Sintering Point	1300 °C	1450 °C
Sticking Temperature.	1250-1300 °C	1300– 1400 °C
Particle Size Distribution above 90%	0.160-0.630	0.10-0.25mm
Average Grain Size	0.20mm	0.14mm
ZrO_2: SiO_2 Ratio	1:1	2:1

Table 2: Typical Chemistry of Fused Material on Mn Steel Casting

Component	Concentration (wt %)
MnO_2	13.8
Fe_2O_3	11.9
SiO_2	15.6
MgO	16.95
ZrO_2	21.6
Al_2O_3	8.8

Table 3: The Effect of Binder Type on Sintering Points of Moulds

Binder Type	Composition (%)	Sintering Point (°C)
Zircon	100	1300
Zircon Bentonite	97 3	- 1250
Zircon Bentonite	96 4	1200
Zircon Bentonite	95 5	1150
Zircon Bentonite	90 10	1100 °C
Zircon Bentonite	100	1100 °C

Table 4: The Influence of Mg0 Addition on Mould Characteristics

Components/Test	I	II	III	IV	V	VI	VII	VIII
Zircon	100%	60%	66%	72%	80%	88.5%	95%	96%
Mg0 Based Bricks	-	40%	34%	28%	20%	11.5%	5%	4%
Binder, (Bentonite)	4%	4%	4%	4%	4%	4%	4%	4%
Swelling Binder (starch)	1.2%	1.2%	1.2%	1.2%	0.8%	0.8%	0.8%	0.8%
Water	3%	3%	3.0%	3.0%	2.6%	3.0%	3.5%	.3%
Permeability	185	100	90	100	140	110	104	116
Green Strength (Ncm^{-2})	8.0	8.5	8.0	8.0	6.6	6.4	5.7	7.4
Sintering point (°C)	1250	1450	1450	1400	1350	1350	1300	1300

Table 5: Screen Analysis Showing Grain Size Distribution of Beneficiated Local and Imported Zircon

Sieve Size	Imported Zircon	Beneficiated Local Zircon	As Received Vectices Zircon
Over 0.630mm	0.00%	0.00%	0.00 %
0.63 – 0.400mm	0.15%	0.41%	10.18
0.400 – 0.25mm	13.70%	5.6%	59.97
0.250 –0.10mm	85.70%	88.80%	30.18
Under 0.10mm	0.15%	5.56%	0.80

Table 6: Zircon Content as a Function of Grain Size in the Local Sand

Grain	Zirconia Content (%)
+ 0.5mm	47.3
+ 0.4mm	51.5
+ 0.3mm	58.0
+ 0.2mm	62.2
+ 0.1mm	60.0
+ 0.09mm	48.0

Table 7: Sieve and Chemical Analysis of Beneficiated Local Zircon compared with Imported Zircon Sand

Properties	Beneficiated Local Zircon	Imported Zircon
ZrO_2 (%)	61.7	64
SiO_2 (%)	30.3	28.4
Al_2O_3 (%)	2.87	3.2
Fe_2O_3 (%)	0.95	ND
Lo_1 (%)	1.52	1.3
Sintering point (^0C)	1400	1450
Sticking Temp (^0C)	1300 – 1350	1300 – 1400
+90% Grain Size (mm)	0.10. – 0.25	0.14
Average Grain Size (mm)	0.14	0.14
ZrO_2: SiO_2 Ratio	2:1	2:1

5.0 REFERENCES

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