EXPLORING THE POTENTIAL OF MILL SCALE AS REINFORCEMENT IN METAL MATRIX COMPOSITES (MMC)

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ABSTRACT

Enormous 'waste' is generated from the operation of steel industries. The environmental and material conservation consideration has compelled the search for effective utilization of these 'waste'. About 16,695 tonnes of mill scale is expected from the operation of Nigeria Steel Industry annually. Mill scale, whose major constituent is FeO, is known to possess properties characteristic of various metallic and non-metallic oxides utilized as reinforcement materials in Metal Matrix Composites (MMC) production. MMCs are new engineering materials in which reinforcement materials are incorporated into the metal matrix to improve its properties. The present work explores the possibility of using mill scale as reinforcement material in Al-Si matrix. Stir-casting method of composite preparation was chosen because of its simplicity, inexpensiveness and wide usage for the production of Metal Matrix Composite of particulate brand. The introduction of mill scale into Aluminium matrix resulted in marginal improvement in the strength parameters for composites with more than 10wt.% reinforcement. The maximum UTS attained is 160.53 MPa, which is barely an increase of 3% above the unreinforced specimen. Increase in hardness for composites with more than 5wt.% reinforcement was equally observed.

Keywords: Metal Matrix Composite, Mill Scale, Reinforcement materials.

INTRODUCTION

Enormous 'waste' is generated from the operation of steel industries. The environmental consideration has necessitated extensive research into reduction of the proportion of 'waste' that is eventually sent to the waste heap. In Germany and France, only 6% and 14% respectively, of the initial 'waste' is eventually dumped (Roth, 1992). The proportion is condiderably higher in Nigeria. While effective utilisation of other metallurgical byproducts such as slags, flue gases, scraps, mettalised fines have been identified, mill scales presently find uses only in sintering plants, pellet plants and in steel making plants as reducing agents (Abubakre, 1997). In Nigeria, non-traditional use of mill scale as conditioner of moulding sand has been explored. Considering the enormous volume of mill scale expected from the operation of Nigeria Steel Industry, the need to explore innovative and efficient use of mill scale for economic and enviromental benefit is apt.

Metal Matrix Composites (MMC) are new engineering materials with great potential. It consist of reinforcement materials incorporated into the conventional metallic material for improved stiffness-to-weight ratio, lightweight, wear resistance and thermal stability parameters among others.The reinforcement materials are often characterised by high refractoriness, hardness and wear resistance (Khan and Abubakre, 1996) Metallic oxides that possess above listed properties have been variously utilized as reinforcement materials. Such include Al_2O_3, ZrO_2, SiO_2, TiO_2 and others (Abdel-Azeem *et.al*,1995; Maity *et.al*,1995; Rizkalla and Abdulwaheed, 1996). Since mill scale, whose major constituent is FeO, is equally known to possess the properties characteristic of these other oxides, the present work explores the possibility of using mill scale as reinforcement material in Al-Si matrix. Stir-casting method of composite preparation was chosen because of its simplicity, inexpensiveness and wide usage for the production of Metal Matrix Composite of particulate brand (Lindroos and Talvitie,1995)

Mill Scale

Mill scales are obtained from descaling operation at the roughing and finishing stands of the Steel Rolling Mill. Fine particles of iron oxide are also formed during the cooling of the rolled products when water cooling is employed. The mill scale carried in the industrial waste water is recovered in the process of treatment which involves the use of scale pit, sedimentary and flocculation tanks. The quantity of mill scale won in the process is reflected in the Table 1.

Although the Al/Mill Scale composite has not been widely investigated, the existence of various rolling mills within the country, which produce considerable amount of mill scale, prompted the investigation of its influence as a reinforcement in Al matrix. The mill scale used was obtained from the Jos Steel Rolling Company. The typical composition of raw mill scale as obtained is given in Table 2.

Table 1: Scales from Nigerian Steel Industry

Steel Industry	Quantity Generated At Full Capacity Utilization (Tonnes)
Delta Steel Company (DSC)	10,080.00
Jos Steel Rolling Company (JSRC)	2,205.00
Oshogbo Steel Rolling Company (OSRC)	2,205.00
Katsina Steel Rolling Company (KSRC)	2,205.00
TOTAL	**16,695.00**

Source: Abubakre (2001)

Table 2: Chemical Composition of Mill Scale

Composition	Fe total	FeO	Fe_nO_m	S	P	Zn	C	Oil
Percentage (%)	68.38	48.56	25.38	0.08	0.02	0.02	1.54	4.58

Source: Ostapenko and Miasnikor (1988).

Aluminium / Refractory Oxide Composite

Particulate brand of MMCs are the least expensive and the least sophisticated to produce. Stir-Casting method of manufacturing MMC is particularly attractive to the developing nations because of the reduced sophistication, possibility of using conventional foundry equipment and low cost of process. There is greater incentives in composites based on light metals such as Aluminium and Magnesium where considerable improvement in mechanical properties are obtained. The light metal matrix of the composites contribute such properties as toughness, formability, electrical and thermal conductivities while the oxide reinforcing phase improves the strength, stiffness, hardness and wear resistance. Extensive work has been done on the use of Al_2O_3, as reinforcement material.(Maity *et al*,1995; Aghajanian *et al*, 1993; Abubakre,1997). Some reseachers have equally worked on the ZrO_2 $SiO_2$and TiO_2 (Abdel-Azeem *et al*, 1995; Maity *et al*,1995; Rizkalla and Abdulwaheed, 1996).. However, no appreciable work on the use of FeO which is the major constituent of mill scale is available in the literature. The similarity between properties of FeO and other oxide is an indicator of the possibility of using it (FeO) in the capacity of reinforcing phase. The various impurities that characterised mill scale could be eliminated via roasting at elevated temparature. The expected area of application of Al/Mill Scale composite includes all sphere of application of Al/ Al_2O_3 composites where such properties as light weight, wear resistance, noise damping, wear resistance at high temperature are desired.

EXPERIMENTAL PROCEDURE

Melting

250 grammes of Aluminium Silicon alloy was melted in a resistance furnace. The heating of the furnace continued for about 60 minutes to obtain molten aluminium superheated to a temperature of 760 ^{0}C. The temperature was measured using immersion pyrometer (Migert type) capable of measuring up to 1400 ^{0}C. The alloy used was a primary alloy whose composition is given in Table 3. The mechanical properties of the sand cast alloy is as follows:

$\sigma_{0.2}$ = 85MPa; σ_u = 155MPa; δ = 5%; HRB = 40

Reinforcement Incorporation

Four samples of mill scale weighing 1%, 5%, 8% and 10% of the melted metal were initially preheated at 1000^{0}C for 1 hour to burn off the volatile component and increase the FeO content. Sieve test carried out on the mill scale to determine the grain distribution of the sample used is reflected in Table 4.

A speed of 1000 rpm was chosen and a four-blade impeller was fixed into the mixer. The mixer was switched on and gently lowered into the molten metal. The position of the stirrer was adjusted inside the crucible until a vortex was formed. The reinforcement particles inside the injection funnel were then gradually and smoothly introduced into the molten metal.

The stirring continued for about five to ten minutes after the completion of particle introduction.

Table 3: Chemical Composition of Aluminium Alloy.

Elements	Al	Si	Cu	Mg	Fe	Mn	Na	Zn	Pb	Sn	Ti	B
%age Composition	85.76	11.5	0.64	0.212	0.911	0.123	0.015	0.619	0.167	0.033	0.017	0.007

Table 4: Grain Size Distribution of Iron Oxide Particles.

Grain Size(μm)	>420	>300	>212	>150	>75	>63	<63
Mass Distribution (19.54g)	0.00	0.00	0.05	6.42	10.10	1.55	1.42
Percentage Distribution (%)	0.00	0.00	0.25	32.86	51.69	7.93	7.27

The stirrer was raised at the end of mixing. Digital thermocouple was used after the stirring to ensure that correct pouring temperature of 760 ^{0}C was attained. The prepared composite was poured into the prepared mould immediately.

Casting of Test Specimen

The pattern employed for the casting was a wooden British Directorate of Technical Development (DTD) test bar with a cylindrical portion having a diameter of 25mm The funnel – shaped riser which served as the sprue has a maximum diameter of 30mm. This pattern was used to prepare sand mould for casting the composite. After the temperature of the prepared composite was recorded, the molten composite was then poured into the sand mould. Specimens were cast for each melt with varying degree of reinforcement to provide samples for tensile test, hardness test.

Mechanical Testing

Tensile Test.

Tensile test was performed under uniaxial tensile loading on a standard specimen machined from DTD cast specimen to obtain a standard geometry shown in Figure 1. The tensile test was carried out on Hounsefield Tensiometer equipped with data acquisition system, which supplies the stress – strain curve during testing at room temperature environment.

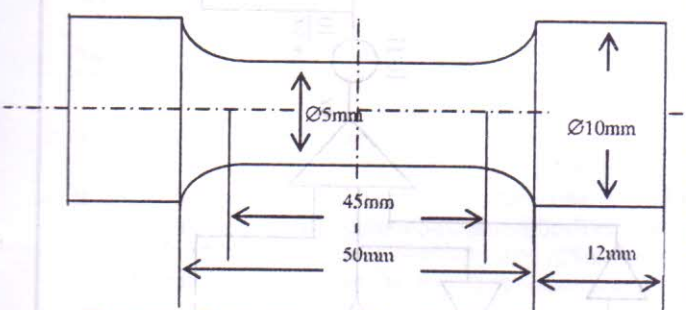

Figure 1: Geometry for Tensile Test Specimen.

Mechanical properties such as yield strength, ultimate tensile strength (UTS), percentage elongation(δ) and percentage reduction in area(ψ) as well as a plot of stress-strain curve were derived from data acquisition and data treatment. Each reading of the measurement shown in subsequent figures represents an average value taken from two test samples produced from the same test bar.

Hardness Test:

The specimen for hardness test was obtained by cutting the DTD cast specimen into two equal halves using hacksaw. The flat surface obtained was subsequently smoothened with files. The samples were then polished with emery cloth. The final polishing was done on nylon cloth and micro cloth using one micron alumina polisher. The polished specimen was thereafter subjected to Brinell hardness testing at a uniform interval along the whole length of the specimen (Figure 2).

The test consists of indenting the specimen with a steel ball while the hardness number can be determined from the area of the indent formed and the force of indentation applied. The size of the indenter used is 1mm and the force applied is 49.05 N.

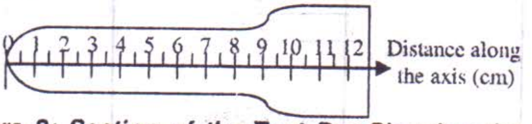

Figure 2: Section of the Test Bar Showing the Points at which Hardness Test was taken.

RESULT AND DISCUSSION

Strength Of Al-Si/ Mill Scale Composites

The result of tensile test carried out on the developed Al-Si/Mill scale composite indicated that both UTS and yield strength increase with increasing reinforcement proportion as depicted in Figure3.

Comparison of the strength properties of the developed composite with unreinforced alloy (0wt.%) shows that it is only the composite with 10 wt.% reinforcement that demonstrated a slight improvement of the strength properties. The UTS and yield strength values for lower proportion of reinforcement falls below the value for the control specimen (0 wt.%). Thus, for reinforcement to have any effect on Al – Si alloy, a minimum of 10 wt.% reinforcement is required. This position was confirmed by Dieter (1984) who concluded that there exists a minimum volume fraction of reinforcement that could give sufficient strengthening to composite. The percentage elongation decreases with increased reinforcement percentage, which showed increased brittle property of the developed composite.

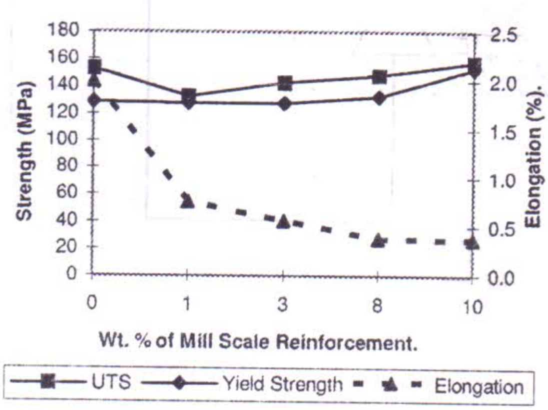

Figure 3: Strength and Ductility of Aluminium/Mill scale Composites.

Hardness of Al-Si/ Mill Scale Composites

The composites reinforced with 1wt.% and 3wt.% mill scale possessed hardness values that are less than those values for the unreinforced specimen (0 wt.%). (Figure 4) This situation was observed throughout the length of the test bar.

For the 5wt.% and 10wt.% mill scale reinforced composites, a general trend of improved hardness was observed in the bottom and the middle portion of the test bar.The 8wt.% mill scale reinforced composite also demonstrated an improved hardness properties at the bottom and the middle portion. Although, at a distance of about 20 – 30 mm from the bottom of the test piece ,a sudden fall in the hardness was observed. This inconsistency observed in the behaviour of the sample loaded with 8wt.% could be attributed to defects in the cast test bar in the form of sub-layer pores and/or cavities.

From the above observation, a minimum of 5wt.% mill scale reinforcement is required to improve the hardness of Al-Si/ mill scale composite.

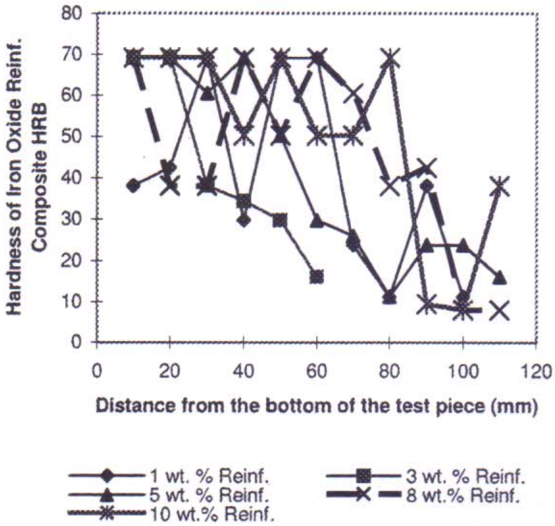

Figure 4: Hardness of Mill Scale Reinforced Composites

CONCLUSIONS

In this work, Mill scale from Steel Rolling shops was successfully incorporated into Al-Si alloy as a reinforcing phase yielding Al-Si/Mill Scale Composite. The resulting composite showed a marginal improvement in strength when loaded with 10wt.% fraction.

Similarly, improvement in hardness was noticed in Al-Si/Mill scale composite loaded with a minimum of 5wt.% reinforcement. The resulting composite, if further researched into, could serve well in wear and thermal resisting aplications. This work produces a viable and economic utilization option for mill scale as a metallurgical byproduct (thus reducing the proportion of the 'waste' sent finally to waste-dump), it equally enrich the scope of engineering materials available for utilization.

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