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THE EFFECT OF PARTICLE SIZE ON THE PROPERTIES OF Al-Si/SiO₂ PARTICULATE COMPOSITE

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ABSTRACT

Metal-Matrix Composites (MMC) are relatively new class of engineering materials that possess high stiffness-to-weight ratio, significant weight reduction, wear resistance and thermal stability when compared with unreinforced matrix alloy. Extensive research work has been done on Alumina reinforcement in metal matrix. However, very little information is available in the literature on Al-Si/ SiO_2 particulate composites. Stir casting method of producing composites is particularly attractive to the developing nations venturing into MMPC development because of the reduced sophistication, possibility of using conventional foundry equipment and relatively low cost of the process. In this work, Stir-casting method was used to synthesize Al-Si/SiO_2 Particulate Composites using silica reinforcements of different particle size. A 17% increase in strength was attained in composite reinforced with 10wt.% coarse silica particles when compared with unreinforced alloy. The use of fine SiO_2 particles equally improves the strength of the Al-Si/SiO_2 composite. Higher degree of strengthening was achieved with the use of fine particles than with the use of coarse reinforcement particles.

INTRODUCTION

Composite Materials are volumetrically formed special combination of two or more components, dissimilar in form and properties, exhibiting clear boundaries between components, using the advantages of each component [1]. Metal-Matrix Composites (MMC), as a relatively new class of engineering materials, have received attention over the past decades as one of the substitutes for iron and steel. They have great potentials as new engineering materials in aerospace, automotive, nuclear and defence industries. These materials posses high stiffness-to-weight ratio, significant weight reduction, wear resistance and thermal stability when compared with unreinforced matrix alloy [2]. Particle-reinforced MMC is one class of composites that is easy and cheap to manufacture. One of the prospective methods of producing Metal-Matrix Particulate Composites (MMPC) has long been identified as the stir-casting technique [3]. In the class of Aluminium-ceramic particles MMPC, extensive work has been done on Alumina reinforcement. However, Al-Si/SiO_2 Particulate Composites have not received wide attention among researchers into new brand of composites. Although Rizkalla and Abdulwaheed [4] did attempt to produce this brand of composites, the chosen method of production was the powder metallurgy route and the study of the mechanical properties of the obtained composite showed that the split tensile strength decreases with increasing SiO_2

Metal-Matrix Composites are attracting the attention of manufacturers and users because of their exceptional mechanical properties and growing availability due to continued research to develop better and cheaper composite materials [5]. The stir casting method of producing composites is particularly attractive to the developing nations venturing into MMPC development because of the reduced sophistication, possibility of using conventional foundry equipment and relatively low cost of the process. Metal-Matrix Particulate Composites (MMPC) are used in producing such automobile parts as ring grooves of reinforced pistons, connecting rods for gasoline engines, shock absorber cylinders, and diesel engine piston and cylinder liners. They are equally useful in the production of the joints for aerospace structures, rotary compressor vanes, vane and pressure sides of oil pressure vane pumps. Bicycle frames, golf materials, tips of screwdrivers, bearing materials, bolts and others have also been successfully produced from MMPC. [6].

In this work, the stir-casting method was used to synthesize Al-Si/SiO$_2$ Particulate Composites using reinforcements of different particulate sizes. The properties of the produced composites vis-à-vis the percentage reinforcement was established and the effect of particulate size on the strength of the particulate composites was also presented.

1.0 TYPES OF PARTICULATE COMPOSITES

Particulate Composites have the reinforcing phase with insignificant dimensions in all directions. The reinforcing particles may be round, square, or even triangular. But the dimensions of its sides are almost equal. Particle reinforced composites could be classified into two categories as follows:

i) Dispersion - Strengthened Composite Materials: - They have a matrix of metal or alloys, in which very small particles ranging from 0.01 □m to 0.1 □m and amounting to 1 - 15 % by volume are uniformly dispersed. The matrix here bears the main load, whereas the dispersed particles obstruct the motion of dislocation in the matrix.

ii) Particle Strengthened Composite Materials: - The particle size exceeds 1 □m and the volume fraction of the particle exceeds 25%. The load here is distributed between the matrix and the particles that begin to produce a strengthening effect when the matrix strain is limited by a mechanical constraint due to particle influence. The size of the particles in the two cases above is nearly isometric [1].

2.0 STRENGTHENING MECHANISM

Constituents of composites have been identified with specific functions. While the reinforcement in the matrix carries the load, the matrix serves to transfer and distribute the load to the reinforcements. The interface transmits the shear stress. Analysis of Al/Al$_2$O$_3$ composite shows that a strong bond exists between the two phases which allows for good load transfer between the two phases. Thus, as the content of the reinforcement particle increases, the strength of the composite increases [7].

Mc Daniels [8] loaded aluminium alloy with 15 – 40 % SiC particle and observed a general increase in both the yield and ultimate tensile strength. The increase in strength was attributed to smaller interparticle spacing in the highly loaded composite. Before any strengthening effect could be achieved however, the fraction of loaded reinforcement must exceed a certain minimum value ($F_{\min}$) given by Dieter [9] as:

$$F_{\min} = \frac{\sigma_{mu} - \sigma_{m}}{\sigma_{fu} + \sigma_{mu} + \sigma_{m}} ---(1)$$

where

□ $_{mu}$ - Ultimate tensile strength (UTS) for metal

□ $_{fu}$ - UTS for the fibre reinforcement

□ $_{m}$ - flow stress in the matrix

Although this expression was obtained specifically for fibre - reinforced composite, it could be infered that particulate reinforced composites equally have minimum reinforcement fraction below which no substantial reinforcement could be attained.

Reinforcement particles act in two ways to retard the motion of dislocations. The particle may either be cut by dislocations or the particles resist cutting and the dislocations are forced to bypass them. A critical parameter of the dispersion of particles is the interparticle spacing [9].

A simple expression for interparticle spacing as expressed by Corti et al. [10] is

$$\lambda = \frac{4(1-f)r}{3f} ----(2)$$

Similarly, Maity et. al. [11] presented expression for evaluating □ as follows:

where f- volume fraction, r – radius of the particles and Dr – diameter of the particles .

When the particles are small and or soft, dislocations cut and deform the particles.

$$\lambda = \left[\frac{\pi}{2} - \frac{2}{\pi}\right] D_r ---(3)$$

When the particles are small and or soft, dislocations cut and deform the particles.

3.0 EXPERIMENTAL PROCEDURE

The stir casting method was used to introduce four samples of silica weighing 1%, 3%, 5%, 8% and 10% into the molten metal. The Silica of 99.95% purity were initially preheated at 1000^{0}C for 1 hour. The preheated silica was introduced into molten aluminium alloy using the specially constructed funnel. 250 grammes of Aluminium Silicon alloy was previously melted in a resistance furnace and superheated to a temperature of 760 ^{0}C. A speed of 1000 rpm and a four-blade impeller fixed into the mixer was used for introducing the reinforcement particles into the molten metal. Immersion pyrometer (Migert type) capable of measuring up to 1400 ^{0}C was used after the stirring to ensure correct pouring temperature. The prepared composite was poured into the prepared green sand mould immediately. Two types of Silica were used in this procedure. Relatively fine particles (SiO_{2f}) with an average particle diameter d_{50} = 107□m and relatively coarse particles (SiO_{2c}) with an average particle diameter d_{50} = 198□m were used. The relative distribution of the grains of both SiO_{2f} and SiO_{2c} as obtained from the sieve test carried out is reflected in Figure 1.

3.1 CASTING OF TEST SPECIMEN

A wooden British Directorate of Technical Development (DTD) test bar pattern with a cylindrical portion having a diameter of 25mm and a sprue of 30mm maximum diameter 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. Specimen were cast for each melt with varying degrees of reinforcement to provide samples for tensile tests.

3.2 TENSILE TESTS

Tensile test was performed under uniaxial tensile loading on a standard specimen (ASTM standard A 370-74G25.) machined from DTD cast specimen. The tensile test was carried out on a Hounsefield Tensometer equipped with data acquisition system, which supplies the stress-strain curve during testing at room temperature. Mechanical properties such as Yield Strength, Ultimate Tensile Strength (UTS), percentage elongation (□) and percentage reduction in area (□) as well as a plot of the stress-strain curve were derived from test results. Each reading of the measurement shown in subsequent figures represents an average value from two test samples produced from the same test bar.

4.0 RESULT AND DISCUSSION

The results of tensile tests carried out on the composite reinforced with coarse silica are presented in figure 2. The general trend observed in the tensile test carried out on the samples with varying proportions of reinforcement showed that both the ultimate tensile strength (UTS) and yield strength tend to increase with increase in the reinforcement fraction. For the composite reinforced with SiO_{2c} the maximum strength of 182.37 MPa was recorded for Al-Si/10 wt. % SiO_{2c}. This represents a twenty percent increase in strength compared with unreinforced composite. The corresponding Yield Strength for this composite is 145.10 MPa as against 128.38 MPa for the untreated alloy (Fig.2).

The result of tensile tests carried out on the composites reinforced with fine silica is presented in figure 3. The results showed that a maximum tensile strength of 193.58 MPa was attained in composite reinforced with 8 wt. % reinforcement. In both cases the ductility of the prepared composites reduces with increase in proportion of the reinforcement materials.

Although a higher percentage of incorporation was attained by Rizkalla and Abdul Waheed [4] for Al-Si/SiO_2, the production route employed was powder metallurgy. This production method is also responsible for the conflicting result of the present work when compared with Rizkalla work. (Figure 4) [4].

The decrease in strength with increased percentage of reinforcement observed by Rizkalla was partly attributed to increased volume of porosity, which characterized his production technique and thermal mismatch between the matrix and the reinforcement. The measured porosity for the composites is as presented in Table I.

Table I: The Variation in Porosity with increasing SiO_2 content. [4].

Volume Percentage of Reinforcement (%)	Sintered Density(g/cm3)	Porosity (%)
0	2.690	1.20
5	2.610	3.25
10	2.570	4.64
15	2.560	4.93
20	2.515	6.51

Stir cast composites are hardly known to suffer from porosity if the right pouring temperature and appropriate mould moisture were chosen. From the graph, the fine grain size gives a higher strength to the composite than the coarse-grained particles for the various proportion of reinforcement except for 10 wt. % fraction. Here, the relative brittleness of the composite could have been responsible for the failure of the sample before attaining full strength.

One of the controlling factors that determine the effect of the reinforcement on the strength is the compatibility of the interface. Interfaces from the viewpoint of crystal structures can be categorized as coherent, semi-coherent or non-coherent. A coherent interface is formed when crystal lattices of the two component phases are in complete registry at the boundary and the crystal planes are continuous across the interface .The atomic planes that terminate at the boundary can be viewed as forming edge dislocation. These dislocations are also known as misfit dislocations. When these dislocations are closely spaced, the interface can be viewed as virtually incoherent. [12].

Fine-grained reinforcement improves strength better than equal weight of coarse grained reinforcement because more dislocation locking points are produced by the former. However this effect is not observed when other factors such as chemical strengthening and work hardening are well pronounced in composite formation [9, 11 & 13].

5.0 CONCLUSION

Considerable success was recorded in the synthesis of Al-Si/SiO_2 composites using both coarse and fine silica particles. The highest UTS value of 182.37Mpa was achieved in Al-Si/ SiO_2 with the use of 10wt.% coarse silica particle reinforcement. This represents a 17% increase in strength compared with unreinforced alloy. The ductility of Al-Si/ SiO_2 composite decreases with increased proportion of reinforcement particles. However, the general ductile behaviour of Al-Si/ SiO_2 composite is quite better than that of Al-Si/ Al_2O_3 composite [14]. The use of fine SiO_2 particles improves the strength of the Al-Si/SiO_2 composite for wide range of reinforcement proportion with maximum strength of 193.58Mpa attained for composites with 8% fine silica reinforcement. A higher degree of reinforcement incorporation was achieved with the use of fine particles than in the use of coarse reinforcement particles. Generally, fine silica reinforced composites possess better strength than the coarse silica reinforced Al-Si alloy.

REFERENCES

1. Zagainov G.I. and Lozino-Lozinski(1996) *Composite Materials in Aerospace Design* Chapman and Hall, London p.670.

2. Varma V.K., Kamat S.V.,Jain M.K., Bhanu Prasad V.V. and Mahajan Y.R (1993) *Effect of homogenization treatment on fatigue behavior of 2124Al/20 vol % SiC_p composite* Journal of Material Science 28. pp.477 – 481
3. Hanumanth G.S. and Irons G.A. (1993) *Particle Incorporation by Melt Stirring for the production of MMC* JMS 28 pp2459 – 2465
4. Rizkalla H.L and Abdulwaheed A (1996)."*Some Mechanical Properties of Metal-NonMetal ($Al-SiO_2$) Particulate Composites*" Journal of Material Processing Technology 56 pp398-403.
5. Lindroos V.K and Talvitie M.J (1995) *Recent advances in Metal Matrix Composites* JMPT 53 pp.273 – 284.
6. Bracke P., Schurmans H. and Verhoest J. (1984) *Inorganic fibres and Composite Materials* Pergamon Press, Oxford. 173pp.
7. Kelly A. and Nicholson R.B. (1971) *Strengthening Methods in Crystals* Applied Science Publisher, London pp 331 – 403
8. McDanels D.L. (1985) *Analysis of Stress – Strain, fracture and ductility behaviour of Al-Matrix Composites containing Discontinous SiC reinforcement.* 16A p Metall. Trans.1105
9. Dieter G.E. (1986) *Mechanical Metallurgy* 3rd Edition., McGraw - Hill, New York. 223pp.
10. Corti C.W, Cotterill P and Fitzpatrick G. (1974) *Int. Met. Rev.*, Vol. 19 pp.77-88.
11. Maity, P.C., Chakraborty, P.N. and Panigrahi, S.C.(1995), *Processing of Al/Al_2O_3 (TiO_2) in-situ particle Composite* Journal of Material Processing Technology (JMPT) 53 pp 857-870
12. Jack R. Vinson and Tsu-Wei Chou (1975) *Composite Materials and their use in Structures* Applied Science Publishers, London. P. 438
13. Sendeckyj G.P (1974) *Mechanics of Composite Materials* Academic Press, New York.
14. Abubakre O.K.(2001) "Development Of Aluminium Based Metal Matrix Particulate Composites (MMPC) Reinforced With Alumina. Silica And Mill Scale" Ph.D Thesis. F.U.T., Minna. (Unpublished)

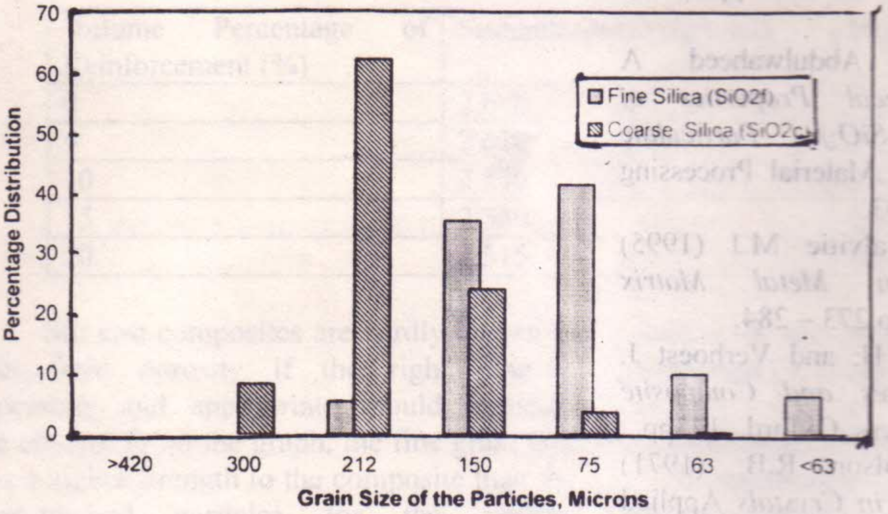

Figure 1: Relative Distribution of Grains of Fine and Coarse Silica Particles

Figure 2: Variation of Tensile Strength and Ductility of Composites reinforced with Coarse Silica Reinforcement.

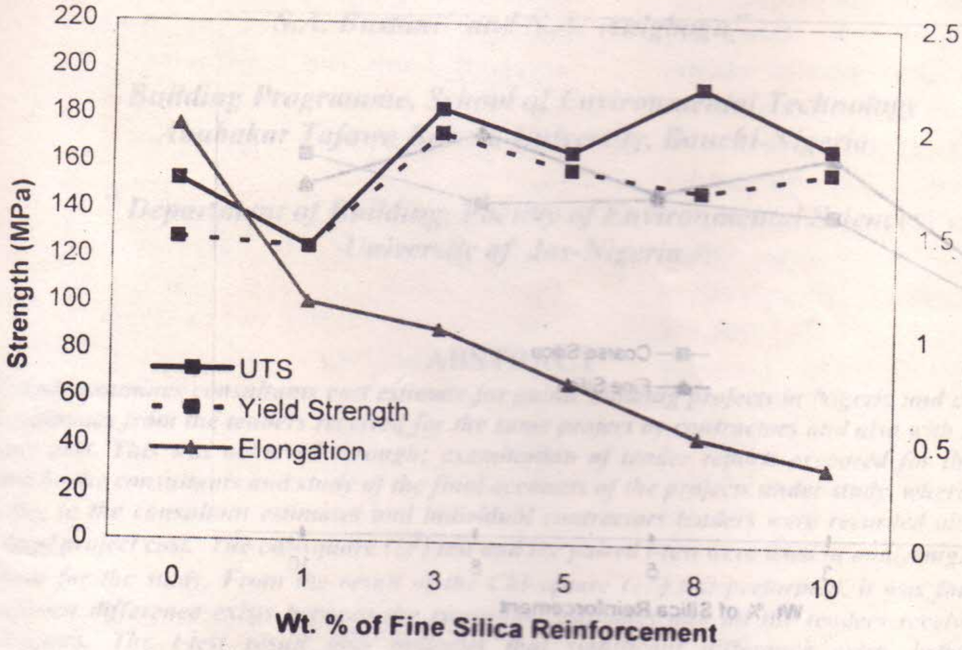

Figure 3: Variation of Tensile Strength and Ductility of Composites with Fine Silica Reinforcement.

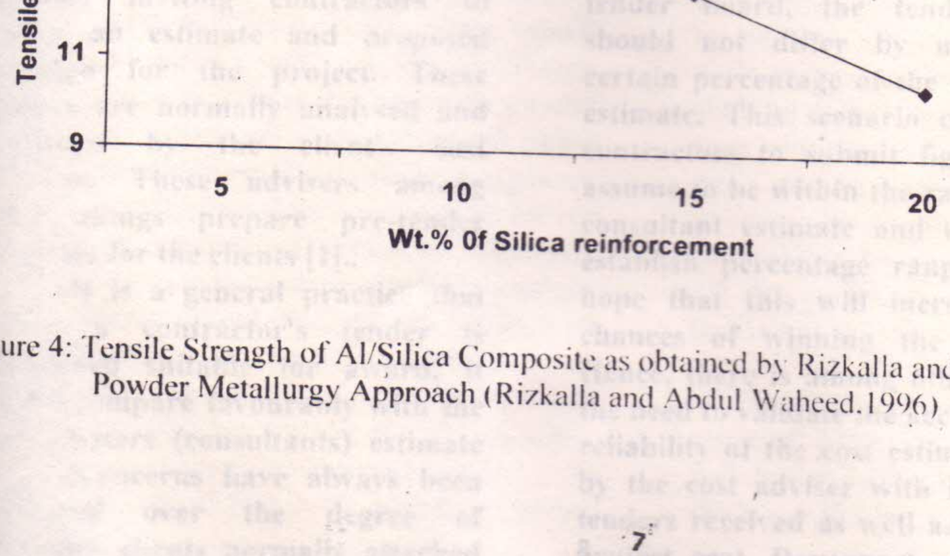

Figure 4: Tensile Strength of Al/Silica Composite as obtained by Rizkalla and Abdul Waheed using Powder Metallurgy Approach (Rizkalla and Abdul Waheed,1996)

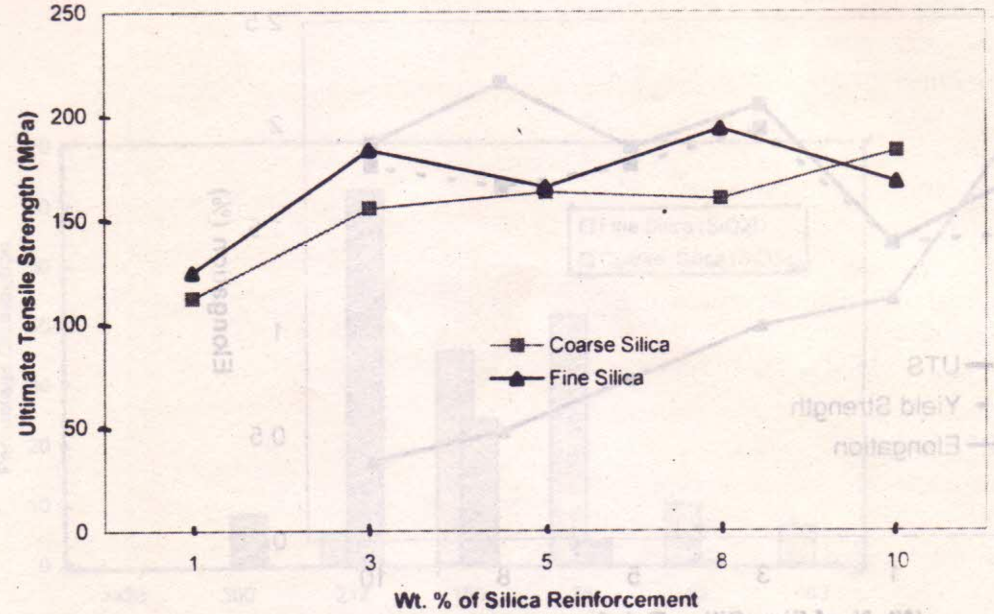

Figure 5: The Comparison of UTS of Fine Silica and Coarse Silica Reinforced Composite.