Innovative Systems Design and Engineering www.iiste.org
ISSN 2222-1727 (Paper) ISSN 2222-2871 (Online)

Characterization study on the variation of weight percentage of Alumina Aluminum in-situ Particulate reinforced composite material

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Abstract

IN-SITU Al_2O_3 SiC C having 20 wt%, 25 wt%, 30 wt% and 35wt% of powdered particulate were fabricated by liquid metallurgy (stir cast) method. The composite specimens were machined as per test standards. The specimens were tested to know the common casting defects using image analyzer. Some of the mechanical properties have been evaluated and compared with Al6061 alloy. Significant improvement in uniform distribution of particulates is noticeable as the wt % of the flake particles increases. The microstructures of the composites were studied to know the dispersion of the powdered particles in the matrix. It has been observed that addition of flake particles significantly improves particulate distribution.

Keywords: flake particles, Al - Al2O3SiC C matrix composite, image analyzer, particulate distribution properties.

INTRODUCTION

Metal Matrix Composites are being increasingly used in aerospace and automobile industriesowing to their enhanced properties such as elastic modulus, hardness, tensile strength at roomand elevated temperatures, wear resistance combined with significant weight savings over unreinforced alloys [1-4]. Aluminum is the commonly used metallic matrix. These alloys are preferred matrix materials for the production of MMCs. The reinforcements being used are fibers, whiskers and particulates [5]. The advantages of the particulate-reinforced composites over others are their formability with cost advantage [6].

The various MMCs & their applications are mentioned in Table 1 as shown below.
The strengthening of particulate MMC may be due to different mechanisms.

- Orowan strengthening
- Grain and sub-structure strengthening
- Quench strengthening
- Work hardening.

Hence the particulate having Al2O3 SiC C in powder form with 30 µm is selected for reinforcement in whisker form. Low strength alloys (eg. Pure Aluminum) are greatly strengthened by ceramic phased e.g. SiC particulates. For high strength alloys (e.g. 2xxx or 7xxx alloys), there is an effect of the reinforcement on the age hardening. In some alloys (e.g. 7xxx series), it is difficult to reach the same strength in the composite as in the monolithic alloy, for 2xxx and 7xxx based composites, the strength of the composite may be 100 MPa higher than the starting matrix alloy.

Here the technique used is grain and sub-structure strengthening. Further, they are inherent with heat and wear resistant properties [7, 8]. For MMCs SiC, $Al_2O_3$and C are widely used particulate reinforcements. The ceramic particulate reinforced composites exhibit improved abrasion resistance [9]. They find applications as cylinder blocks,pistons, piston insert rings, brake disks and calipers [10]. The strength of these composites is proportional to the percentage volume and fineness of the reinforced particles [11]. These ceramic particulate reinforced Al-alloy composites led to a new generation tailorable engineering materials with improved specific properties [12, 13]. The structure and the properties of thesecomposites are controlled by the type and size of the reinforcement and also the nature of bonding [14-16]. From the contributions of several researchers, some of the techniques for the development of these composites are stir casting [17], powder metallurgy [18], spray atomizationand co-deposition [19], plasma spraying [20] and squeeze-casting [21]. The above processes are most important of which, liquid metallurgy technique has been explored much in these days and hence the present paper summarizes the studies conducted by several investigators under sections characterization and particulate distribution.

Density is the physical property that reflects the characteristics of composites. In a composite, the proportions of the matrix and reinforcement are expressed either as the weight fraction (*w*), which is relevant to fabrication, or the volume fraction (*v*), which is commonly used in property calculations. By relating weight and volume fractions via density (ρ), the following expression is obtained (m stands for matrix, c for the composite and r for reinforcement material):

$$\rho_c= \rho_r v_r+\rho_m v_m$$

The above expression can be generalized and its general form is known as law of mixture and is given below

$$X_c = X_m V_m+ X_p V_p$$

Experimentally, the density of a composite is obtained by displacement techniques [22] using a physical balance with density measuring kit as per ASTM: D 792-66 test method. Further, the density can also be calculated from porosity and apparent density values (sample mass and dimensions) [11].The results of the several investigations [23-24] regarding the density of the Al_2O_3 SiC C particle reinforced Al and other aluminum alloys can be summarized as follows: the reinforcements Al_2O_3SiCC enhance the density of the base alloy when they are added to the base alloy to form the composite. Moreover, the theoretical density values match with the measured density values of these composites. Further the density of Al_20_3-SiCC particle composites is greater than that of Al_20_3-SiC C whisker reinforced composites for the same amount of volume fraction. From the above the increase in density can be reasoned to the fact that the ceramic particles possess higher density.

Further, the increased volume fraction of these particles contribute in increasing the density of the composites, also they have stated that the theoretical and measured density values of these composites match to each other. Additionally, the above discussions can be reasoned to the fact that the ceramic particles possess higher density.
The reinforcement of aluminium alloys with ceramic particle leads to new generation of engineering materials with improved mechanical properties to weight ratio [1-3]. Aluminium alloys are still the subjects of intense studies, as their low density gives additional advantages in several applications. These alloys have started to replace cast iron and bronze, to manufacture wear resistance parts [4]. Previous studies have shown that mechanical properties of Al-matrix composites would be enhanced with particle reinforcement [5-7]. Development of composite materials can bring combined advantages of the constituent materials [8-10]. MMC`s reinforced with particles tend to offer enhancement of properties processed by conventional routes [11, 12]. Al_2O_3 SiC C is particulate used as reinforcement in Aluminium alloy composites in the present work. But SiC is the most commonly used particle used as reinforcement in Aluminum alloy composites[10, 11]. By adding ceramic particles as reinforcement to Aluminium matrix, the properties are enhanced and lead to the development of materials for many lightweight applications [12]. For production of aluminium particulate reinforced composites stir casting method appears to be promising method among various conventional processing methods [16]. Heat treatment process to modify the microstructure of aluminium alloy composites with aluminum alloy matrix is the final production stage of composites [17, 18]. Most of the researchers have investigated aluminium composites using SiC, Al2O3, MgO, Zircon etc,[19] and these composites are commercially available in different structural forms.

In this light an attempt has been made to develop Aluminum particulate alloy composites. An effort has been made in this paper to study the particulate and whisker distribution properties of Aluminum alloy composite by varying the wt% of the particulate.

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MATERIALS AND METHODS

Materials preparation

The Aluminium matrix particulate composite material is manufacturing by the mixing equation as

$$a\frac{\partial^2\varphi}{\partial x^2}+b\frac{\partial^2\varphi}{\partial x\partial y}+c\frac{\partial^2\varphi}{\partial y^2}+d\frac{\partial\varphi}{\partial x}+e\frac{\partial\varphi}{\partial y}+f\varphi+g+h\frac{\partial\varphi}{\partial t}=0$$

where φ is function and a,b,c,d,e,f,g and h are the constants of the differential function.

Pure Al is the matrix material and Al_2O_3 SiC C is used as reinforcement material in the preparation of composites. The properties of matrix material is shown in Tables 2 and Table 3.

A stir casting setup was used consisting of resistance furnace with a mechanical stirrer unit. Approximately 190 grams of pure Al ingots were cut in to pieces to accommodate into the graphite crucible. The temperature of the furnace was raised slowly above liquideous temperature of the melt and then slowly reduced below the liquideous temperature of the matrix material. Preheating of the particles at 450^0 C was done in a muffle furnace, placed near the casting set up, in order to remove the moisture and gases from the surface of the particles [20]. The stirrer was raised, positioned and then lowered into crucible. The speed range was 300-350 rpm. The preheated particles in weighed quantities were added slowly into the melt. After adding the particles, stirring was continued for 10 minutes for better wetting dispersion. The pouring temperature was maintained at 710^0C. Then melt was poured into a preheated metal molds (dies) as shown in Figure 1and Figure 2.

RESULTS AND DISCUSSIONS

Micrograph studies: The specimen thus cast was studied under an image analyzer. It is very clearly seen that an uniform distribution of flakes was happened to the specimen. The aspect ratio and the quantity of flakes were studied and tabulated as shown in the table 4, Table 5, Table 6 and Table 7.

CONCLUSIONS

- Based on the experimental observations made in the present research, the following conclusions have been drawn. Al - Al_2O_3 SiC C particulate composites have been successfully developed with fairly uniform dispersion of the particulate whisker particles.
- The whisker distribution of particulates of Al - Al_2O_3 SiC C composite material increases as the addition of Al_2O_3 SiC C particles weight percentage is increased. This is due to hard Al_2O_3 SiC C particles dispersion in soft aluminium alloy matrix.
- Addition of Al_2O_3 SiC C particles significantly improves ultimate tensile strength of Al6061, when compared with that of unreinforced matrix, the ultimate tensile strength of Al_2O_3 SiC C composite is increased by 36.71%.

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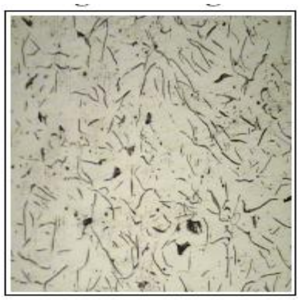
Table 1 MMCs for aerospace applications. (Source: Wei, 1992)

Matrix	Particulate	*Application*
Cu base	C	combustion chamber
	SiC	nozzle (rocket, space shuttle)
	W	NASP[a] heat exchanger
Fe base	W	tubing
Ni base and intermetallics	Al_2O_3	blades, discs
	W	
Ti base and intermetallics	SiC	housings, tubing
	TiB_2	blades, discs
	TiC	shafts, honeycomb
Al base	SiC	housings (pumps, instrumentation), mechanical connectors, satellite, structures
	Al_2O_3	fuselage
	C	structural members
	SiC	wings, blades
Mg base	Al_2O_3	structural members
Directionally solidified eutectics		blades, cable, NASP[a] heat exchanger, superconductors
Cu base	Nb	
Ni base	Carbide	
Ti base	Silicide	

Table 2 showing the densities of matrix and particulate material in gm/cm^3	
Pure Al	**2.7**
Al_2O_3	**3.89**
SiC	**3.21**
C	**1.98**

Table 3 showing the %wt composition of matrix material

Spot	Al	Si	Ca	S	Ti	Fe	Cu
1.	90.837	7.629	0.204	0.00	0.341	0.341	0.995



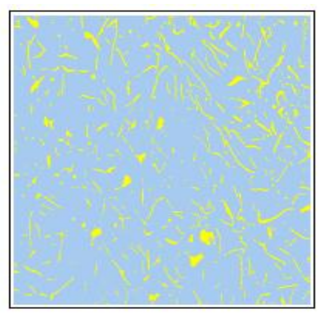


Figure 1and Figure 2. showing the particulate distribution in the Al- Al_2O_3 SiC C composite material under Image Analyzer.

SID:flakes@10x	Frame Area(mm²)	flakes(MeanArea-mm²)
Frame - 1	0.6357	6.904e-005
Frame - 2	0.6357	7.822e-005
Frame - 3	0.6357	6.893e-005
Average	0.6357	7.206e-005

Table 4 showing the frames, area of frames and number of flakes

SID:flakes@10x	flakes
Plane Area(mm²)	0.0488
3.1e-006 - 0.0001 mm²	1690
0.0001 - 0.0002 mm²	189
0.0002 - 0.0004 mm²	94
0.0004 - 0.0005 mm²	25
0.0005 - 0.0006 mm²	20
0.0006 - 0.0007 mm²	10
0.0007 - 0.0008 mm²	5
0.0008 - 0.0010 mm²	1
0.0010 - 0.0011 mm²	4
0.0011 - 0.0012 mm²	0

SID:flakes@10x	Details	flakes
Size Class1	>1.0mm	0
Size Class2	(0.5 - 1.0)mm	0
Size Class3	(0.25 - 0.5)mm	0
Size Class4	(0.12 - 0.25)mm	8
Size Class5	(0.06 - 0.12)mm	98
Size Class6	(0.03 - 0.06)mm	261
Size Class7	(0.015 - 0.03)mm	365
Size Class8	<0.015mm	1306

SID:flakes@10x	flakes
(0.0 - 18.0)°	466
(18.0 - 36.0)°	166
(36.0 - 54.0)°	155
(54.0 - 72.0)°	144
(72.0 - 90.0)°	148
(90.0 - 108.0)°	104
(108.0 - 126.0)°	213
(126.0 - 144.0)°	257
(144.0 - 162.0)°	266
(162.0 - 180.0)°	119

Table 5, Table 6 and Table 7