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Microstructures and Mechanical Properties Studies of the Directional Solidified Developed Ex-Situ Al-4.5% Cu-SiC_p Metal-Matrix Composites

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Abstract: In the present investigation, silicon carbide reinforced Al-Cu alloy based metal matrix composite was fabricated by the Directionally Solidified (DS) stir casting technique and the effect of this novel technique on composite property was compared with conventional method. In this study, studied the comparison between conventional cast and DS developed specimen and also investigate the influence of Cu and ceramic particles in the Al-matrix. The DS developed samples were found porosity and shrinkage defect free due to very good interface bonding of uniformly dispersed sub-micron size SiC particles with the Al-Cu matrix. X-ray diffraction was also performed to know the presence of the inter metallic phases of reinforced material. The microstructures of the MMC revealed the homogeneous dispersion of SiC particles throughout the aluminium matrix having clear and good interfacial bonding is obtained. The hardness and tensile strength value of the composite show the enhancement of the synthesized composite compared to conventionally develop composite. This practical oriented research investigation and test results of the tensile and hardness of Al-Cu-SiCp MMC will provide useful trace for the industry to use this newly developed composite as per their requirement.

Key words: Al-4.5 Cu-SiC composite, DS, XRD, hardness, requirement, enhancement

INTRODUCTION

Aluminum alloys poses high specific strength (good strength to weight ratio), good elastic modulus, good corrosion resistance with high electrical and thermal conductivity, excellent combination of mechanical property (ductile to brittle), good machinabilty as well as forming capability (Costa *et al*., 2015; Ferreira *et al*., 2009; Sjolander and Seifeddine, 2010; Engin *et al*., 2016; Mohamed and Samuel, 2012; Samuel *et al*., 2014; Cadirli, 2013; Quaresma *et al*., 2000; Rocha *et al*., 2003; Gunduz and Cadirili, 2002; Carvalho *et al*., 2013; Kaya *et al*., 2008). Alluminum alloys systems are broadly classified in 2 categories. In one group comprises with pure aluminium, Al-Mg and Al-Mn binary alloy which can improved in mechanical property by strain hardening and annealing and other group consist of those non-ferrous alloy system which are respond to precipitation and age hardening (Cadirli, 2013). During solidification in the Al alloy micro segregation and dendritic structures are common features observed and due to its great influenced in the mechanical property of the Al alloy it draw attention of the engineers (Karakose and Keskin, 2011). In the directional solidification process several uncertainty in development of dendritic growth in solid-liquid interface which has been tried to prediction by many metallurgist, mathematician and physicist, since, last few decades (Grugel, 1995). Different grade of Al-Cu-Si alloys like that ANSI 319.1 and 333.1 are usually used in automotive and aerospace industry in fabrication of cylinders, piston and engine blocks etc components. These alloys can sustain in elevated temperature and good castabilty are the meliorate features of these alloys. Al_2Cu intermetallic phase is precipate in Al rich Al-4.5Cu binary alloy which makes alloy as good corrosion resistance as well as improvement of remarkable mechanical properties (Sjolander and Seifeddine, 2010; Mohamed and Samuel, 2012; Samuel *et al*., 2014; Cadirli, 2013). In Al-Cu alloys due to well distribution of Al_2Cu in Al-rich phase it attain the capability of good corrosion resistance (Lin *et al*., 1999; Tewari and Shah, 1996; Cadirli *et al*., 1999, 2000; Osorio *et al*., 2000). A literal flow near the solidification interface is beneficial for develop the columnar grains and the development of micro segregation can also controlled with flow manage in the melt (Osorio *et al*., 2007). Expanding requests on such kind properties have attract regard for the current scientist which requirement for close microstructure control with tight composition and taken after by heat treatment.

The literature basically concentrates on both hypothetical and exploratory investigations of the micro structural development of binary aluminum-based

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alloys. In this present, research attempt to developed stir cast Al-4.5Cu-SiC Composite followed by Directional Solidification (DS) method.

MATERIALS AND METHODS

Experimental procedure: The directional solidified experiment was performed with binary Al-4.5 wt.% Cu alloy mixed with 2, 4 and 6% of SiC particulates. The chemical composition of obtain Al-obstructs that are utilized to develop the matrix alloys are illustrated in Table 1. The chemical composition investigation done under an optical emission spectrometer (ARL 3460, Switzerland). In this Aluminium based MMC's, eutectic solution of Al-Cu system, i.e., pure aluminium alloy with 4.5% Cu is used as a matrix material the 25±6 μm mesh size of SiC particle used as reinforcement in the melt.

The Al-Cu alloys were melted at the temperature around 650°C in the graphite crucible by using induction furnace. During melting Silicon Carbide (SiC) particles are used as *ex-situ* filler reinforcements where as scrap magnesium is added as a wetting reagent which initiate as binder in between reinforcement and matrix. Before pour the SiC powder in to the melt, it kept for preheating at 850°C for 3 h. Silicon Carbide (SiC) in particles were poured into the molten alloys with the help of a cone-shaped funnel with feed rate 1.2-1.6 g/sec. During the powder feeding the whole mixture was mixed continuously by a mechanical stirrer coupled with a motor at a rotational speed around 350 rpm. The various process parameters associated to the stirring casting process enscapsulated in Table 2.

Figure 1 shows the stir casting setup used in the development of MMCs. The vertical ascendant unidirectionally solidified casting set up is shown in Fig. 2. The experimental set up for casting is designed in such a way that mould is heated under the eutectic temperature of the alloys in a insulated chamber with bottom opening to the ambient. During the pouring of the melt to the mould the cold water-jet is applied to the bottom of the mould which promoting to vertical ascendant unidirectional solidification. A split cylindrical stainless steel mold was used which have internal diameter of 30 mm, height 170 mm and thickness of 10 mm. Insulating alumina paste is used in the internal surface of the mold to minimize radial losses of the heat. Figure 1c illustrate the cylindrical shape specimen developed in this mould by directionally solidified casting.

Table 1: Elemental composition of Al-Cu alloy

Element	Wt. (%)
Cu	1.5~3.5
Mg	0.30
Si	9.6~12
Iron	0.90
Zn	1
Mn	0.50
Ni	0.50
Sn	0.20
Al	Bal

Table 2: Process parameter

Parameters	Values
Spindle speed (rpm)	350
Stirring time (sec)	600
Stirring temperature (°C)	775
Preheating temperature of SiC (°C)	850
Preheating time (min)	90
Preheat temperature of mold (°C)	300
Powder feed rate (g/sec)	1.2-1.6

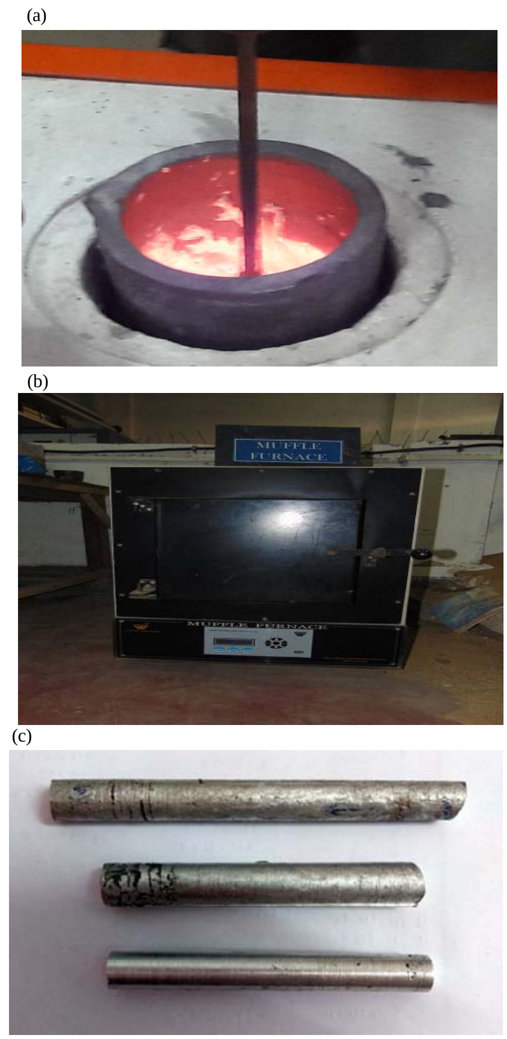

Fig. 1: a) Stir Casting Setup; b) muffle furnace and c) As cast specimen

Each directionally solidified casting was then sectioned longitudinally and transversely at different position from the bottom 5, 10, 15 and 20 mm. To studied the variation of primary and secondary arm spacing in different position.

Microstructure analysis: The microstructures of Al-Cu-SiC_P composites are shows in Fig. 3a-d. The microstructure of cast Al-Cu alloy matrix reveals the

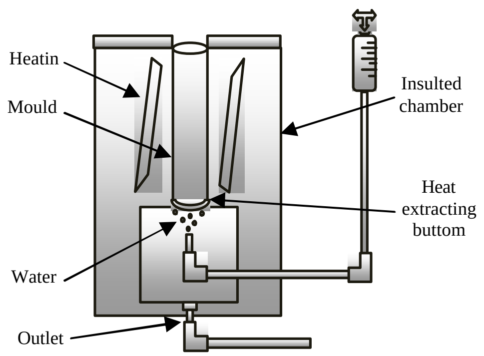

Fig. 2: Experimental setup used in directional solidified castin

formation of α-aluminium dendrite network structure which is formed due to the cooling of the composite during solidification. In Fig. 3a, microstructure it is clearly reveal the equally distribution of the SiCp in the Al-4.5 Cu alloy matrix and there is no confirmation of porosity and pits like cating defect in the casted specimen surface. In Fig. 3c and d have shown the dendritic structure formation in microstructure during directionally solidification. This dendrite structure formed due to consideration of proper process parameters to employ for the castings of Al based composite. During solidification Al-4.5Cu-SiC composites, the reinforcement particles SiC_P are discarded in the direction of solidification head and refined α-Al grains developed in the matrix. The α-Al grains refinement occurs due to presence of SiC_p particles in the matrix which act as nucleation site of equiaxed grain. The SiC_P depletion zone formed columnar grain in the matrix. The uniform distribution of SiC_P particles is a prerequisite to enhance the mechanical properties of the matrix alloy which is successfully achieved Fig. 3a clearly reveal it. Further, the SiC particles are well bonded with the aluminum matrix which makes composite a isotropic material.

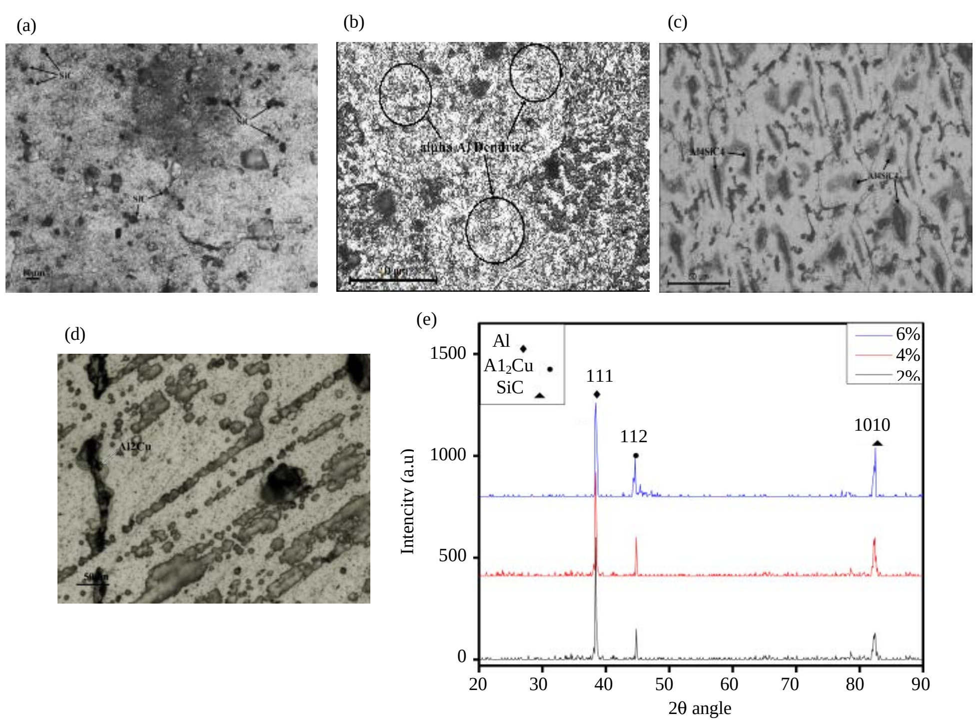

Fig. 3: a) Uniform SiC distribution in the Al-4.5 Cu-2SiC; b) Dendritic structure in DS developed Al matrix; c) Presence of Al_2Cu in Al- 4.5% Cu-SiC composites; d) Presence of ternary carbide Al_4SiC_4 in Al-4.5% Cu-SiC composites and e) XRD profile

RESULTS AND DISCUSSION

XRD analysis: The as cast Al-Cu-SiC composites have been characterized by XRD in order to identify the present phase. From the Fig. 3e, confirmed that Al and Cu formed the spheroidal Al_2Cu phases which have good quality to improve the mechanical property of the alloy. The XRD results in Fig. 3a depict the presence of SiC particles in alone form not in compound form in the matrix. It can be also observed from the XRD plot that the peak intensity of SiC phase increases with an increase in wt.% of SiC in the matrix. From the XRD it was confirmed that there is no formation of Al_4C_3 This was affirmed from the XRD pattern that there is no degradation of the SiC after composite was formed.

Micro hardness analysis: The hardness tester is used to perform the micro hardness analysis. The analysis is carried out with load of 0.5 kg as shown in the Fig. 4a with avg. of 30 random point in the matrix. From the bar graph it implies that with the increase in addition of wt.% of reinforcement particle SiC increase the hardness value of the composite alloy. As the reinforcement particles addition is increasing the surface area of the matrix grain sizes are gradually reduced. The presence of these hard particles presence of these hard particles in the ductile matrix gives more resistance to plastic deformation which prompts increment in the hardness of composites. In solutinizing also the large thermal mismatch leads to create dislocation in conjunction of ceramic and matrix which bears the load transferred by the matrix when subjected to loading condition.

Tensile strength analysis: The tensile strength is improves in the fortifications to the reinforcements in various wt.% (2, 4 and 6) which improves the mechanical properties shown in Fig. 4b. The hard ceramic particle existence in the soft ductile matrix reduces the ductility of composites due to the reduction of ductile metal surface area which significantly improve the tensile strength. During the solution treatment of the non ferrous metals, several alloying elements dissolved back into the a matrix during it cooling from the solutionizing temperature and secondary phase precipitation is coming out in the matrix which leads to generating solid solution strengthening. This solution strengthening also creates dislocation density in the matrix which resists the crack initiation in the matrix. The amount of precipitation during solid solution strengthening relied on the number of solute atoms present in the α (Al) matrix. As Cu content increase it prompted in the amount of solute atoms in the aluminium matrix. During natural aging, the high precipitation of the nano-size secondary inter metallic phase increased it prompted to tensile strength of the metal matrix composite.

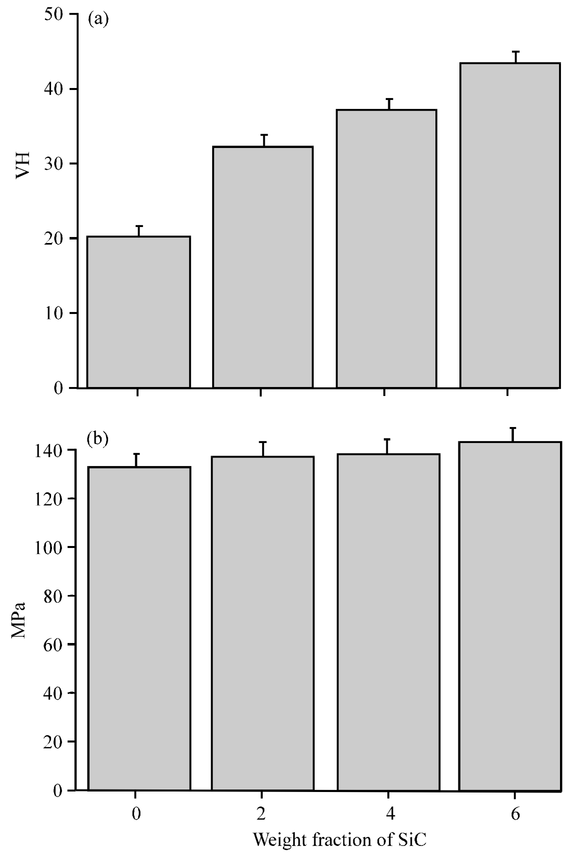

Fig. 4: Bar graph: a) Micro hardness and b) Ultimate Tensile Strength (UTS)

CONCLUSION

Directionally solidified stir casting techniques were successfully implemented in the fabrication of Al-composite containing the ceramic contents up to 6 wt.% .The densities of the composites developed with directionally solidified method are found improved than their base matrix. In directional solidification the sample developed found to be porosity free and less shrinkage defect. Due to force cooling from the bottom heat can extract from only one side which leads to form unidirectional crystal which poses better mechanical property than non directional solidification. The optical micro-structural studies confirm the regular distribution of the SiC_P particles in the matrix system which implies the successful attempt of composite developed. The micro-hardness of the composites noted increased with the weight fraction of the ceramic particle content, i.e., 65-120 HV. Cu addition into the matrix alloy produce significant impact on the formation of the Al_2Cu phase which to increasing the hardness and tensile strength of the alloys due to strengthening mechanism and formation of dislocation density the elongation percentage decreased and significant improvement of tensile 120-125 MPa. From the above studies in overall, it can be concluded that directionally solidified Al-Cu-SiC MMC exhibits superior mechanical properties compare to normal solidified alloy. In this method, single crystal material can be developed for hydro electric turbine blade and with the calculation of primary and secondary arm spacing optimum property can be attained in the material.

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