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INFLUENCE OF VIBRATIONS DURING DIRECTIONAL SOLIDIFICATION ON MICROSTRUCTURE, HARDNESS AND STRENGTH OF Al-Si-GRAPHITE FG COMPOSITE

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ABSTRACT

The present work aims to synthesize functionally Graded (FG) composites through directional solidification (DS) in combination with lateral vibrations. Directional solidification is one of the effective processing techniques to synthesize FG composite. Due to the advancements in developing new class of materials, DS has become one of the important processing techniques in order to attain the gradation in properties. To achieve the better gradation of properties in Al-Si alloy, Chill was placed at the bottom of the mold which is subjected to lateral vibrations. FG composites produced showed that better hardness was obtained towards the region where primary Silicon (Si) is precipitated. In contrast diametrical compression strength results revealed that the Si rich region is brittle in nature when compared to the other end of the cast which is ductile in nature. Microstructural study also revealed that gradation in properties has taken place from bottom to top portion due to precipitation of Si.

KEYWORDS

Functionally graded composite, vibrations, Al-18wt%Si, Diametrical compression test.

1. INTRODUCTION

FG materials are one of the novel concept in realization of innovative materials with local controlled properties in the cast that cannot be achieved by conventional homogeneous materials. This multifunctional behavior has created wide scope in automotive, aerospace, bio-medical, electronics [1-3]. Controlling the microstructure and properties is one of the challenges faced in today's foundry industry. With the researchers interest in developing new processing techniques to synthesize FG composites which include centrifuge casting, magnetic separation, centrifugal casting, powder metallurgy, stir casting [4-7]. It was revealed that FG composites can be synthesized through DS process by providing external chills [8]. By providing external chills, it was found that solidification begins at chill/melt interface. A group of researchers investigated that the ability of the material to extract heat from the melt during freezing depends on chill size and chill material, Research on previous studies showed that mechanical vibrations promotes changes in microstructure which influences changes in mechanical properties [9]. When lateral vibrations are maintained at high frequencies, pores were produced in the structure. Therefore, in the present work, frequency of 100Hz is maintained to attain a graded distribution of Si particles in the top portion of the cast. It has been observed that not much work has been done to synthesize functionally graded composites through DS in combination with vibrations. In the present work novel technique was developed to synthesize functionally graded composite. The obtained samples were investigated for microstructure, hardness and diametrical compression strength.

2. EXPERIMENTAL PROCEDURE

2.1 Alloy used

To fabricate Functionally graded composite commercial Al-18wt%Si alloy was used with a reinforcement of 2wt% Graphite. The reason for adding graphite to the melt is to improve the hardness of the cast [10]. The composition of alloy matrix and reinforecement is shown in Table.

Table 1: Composition of Al-Si alloy with Graphite reinforcement (wt%)

Composition	Si	Mg	Fe	Graphite	Al
Al-Si	18	0.1	0.1	2.0	Balance

Thermal properties of the chill material is presented in Table

Table 2: Thermal properties of the chill material

Chill Material	Thermal Conductivity (W/mk)	Density (g/cc)	Specific Heat (J/gk)
Cast-iron	55	7.61	0.4

The volumetric heat capacity (VHC) which takes in to account the chill size and properties determines the efficiency of solidification [11]. Therefore, VHC of the chill used in the present work is calculated using the following equation

$$(VHC) = \rho * C_p * V \ (J/k) \qquad (1)$$

Where, ρ= Density of the chill, Cp = Specific heat, V= Chill volume,

Chill Volume=8.5*8.5*4 =289 cc

VHC = 1649.47 (J/k).

2.2 Methodology

DS technique in combination with lateral vibrations was used to fabricate Al-Si-Graphite reinforced functionally graded composite. Graphite size was maintained at 5-10µm. Main issue associated with Graphite in synthesizing FG composite is the poor wettability of graphite particles with Al-Si alloy matrix, which results in inadequate interface bonding between the melt and graphite. Due to this issue the graphite cannot be directly added to the melt [12]. Graphite must be preheated at 400^{0}C for 1 hour before adding it to the melt [13]. The base alloy is heated at 750^{0}C in a resistance furnace, the necessary melt treatment is carried out by degassing and to improve the wettability 1wt% Mg was added. The preheated graphite mixture is reinforced to the melt and stirred for about 10 minutes. Figure 1 shows the DS experimental set up combined with lateral vibrations which consists of insulation mold placed on cast-iron chill. The volume of insulation mold is 85mm*85mm*120mm. A through hole of 25mm in diameter is made longitudinally. The insulation mold and cast-iron chill is placed in the vibration set up and packed with insulation material. The vibrator tray is attached to one end of the spring and the other end is connected to the connecting rod. As it is constrained to move in lateral direction, therefore vibrations is produced. The vibration is set at a frequency of 100 Hz and 1mm amplitude. The melt comprising of Al-Si matrix with graphite reinforcement is poured in to the mold and allowed to solidify. The obtained castings are of 25mm in diameter and 120 mm long, which is cut cross sectionally at top and bottom region. For the obtained two portion scanning electron microscopy (SEM) studied were carried out to analyze the distribution of primary Si In order to verify the gradation, hardness test was carried out on the brinell hardness tester (model: BV-120) in accordance with ASTM E8 standards where a 5mm dia ball indenter is pressed on the obtained portion with a load of 15.625 kgf and average of 5 readings were taken at different locations. Diameterical compression test was carried to determine the strength on these two portions to observe the behavior. Samples for Diametrical compression test were prepared according to the ASTM standards and tests were carried out on electronic tensometer (Model: PC2000) [14]. The Hertz solution predicts that the maximum principal stress occurring at the center of the disc and is tensile in nature [15]. Assuming that the maximum principal stress is responsible for the failure of the specimen, the tensile strength obtained is given by equation.

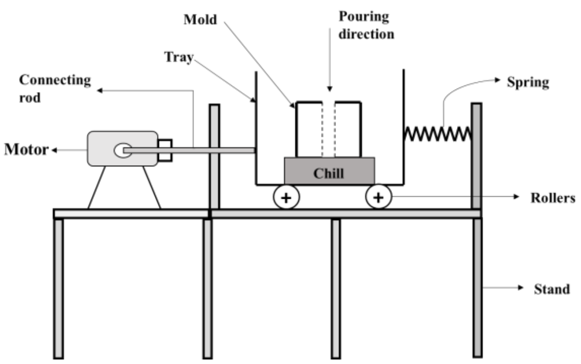

Figure 1: Lateral vibration experimental set up

$$\sigma_t = \frac{2P}{\pi * D_c * t} \quad (2)$$

Where σ_t = Tensile strength in N/mm^2, P = Load applied in N, D_c= Diameter of the specimen in mm,
t = thickness of the specimen in mm.

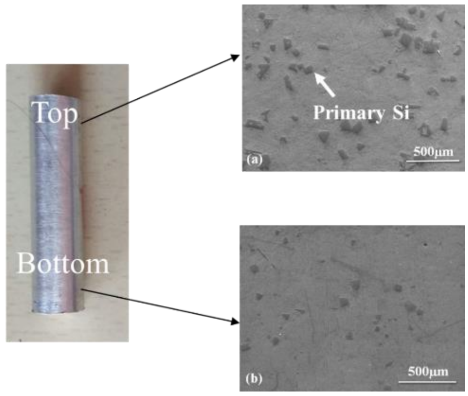

Figure 2: SEM micrographs of FG Composite a)top portion b)bottom region

3. RESULTS AND DISCUSSIONS

FG composites are those materials whose structure, composition and morphology vary smoothly from one end of the specimen to the other end. In the present work the gradation is observed from bottom to top region. It can be seen that primary Si are migrated towards the top region due to the lateral vibrations resulting in primary Si rich zone at the top portion. Microstructure study, hardness and diametrical compression test have been presented in the following subsections.

3.1 Microstructure

Figure 2, shows SEM micrographs obtained at a magnification of 100 x for top and bottom portion of the cast, it can be seen from Figure 2a and Figure 2b that primary Si has precipitated from bottom to top region of the cast leading to gradation in the cast. The segregation primary Si is due to placement of chill at the bottom which promotes DS, when the Al-Si melt reinforced with graphite particles is poured in to the mold [16]. Si which is lighter than Al migrates through the melt during DS. Due to the effect of vibration, it was found that Si particles are segregated in the top portion of the cast because of nonlinear convection in the melt. As a result it is clear that due to the precipitation of Si there will be significant changes in the properties of the cast.

3.2 Hardness

As an outcome from the micrographs, it was investigated that due to rich primary Si near the top portion of the cast, the hardness value obtained was 56 BHN and at the bottom it was 44 BHN. From the Figure 3, it can be seen that there is gradation of properties from bottom to top region. It was found that hardness at the top portion has increased due to segregation of primary Si in the top portion [17].

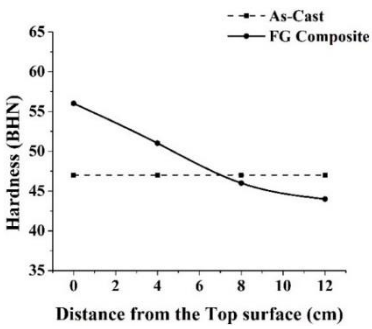

Figure 3: Hardness of Al-Si FG composite along the length of the cast

3.3 Diametrical compression test

In FGMs the properties vary across the length of the castings. Therefore, it becomes very difficult to establish the mechanical properties such as tensile strength of the specimen by conventional method. This section gives an insight in to the diametral compression test from bottom to top of the casting conducted on Al-Si-Graphite reinforced FG composite. From the Figure 4, it is clear that the fracture along the diametral plane was not formed at bottom part of the casting due to its ductile nature and the material was compressed as shown in Figure 4 (b). In top region, which is hypereutectic in nature, the fracture was observed from the centre of disc approximately at an angle of 45 degree to the diametral plane as shown in Figure 4(a). The crack formation shows to an extent brittle tendency of the material and the crack at an angle to diametral plane is indicative of failure on the shear plane. From the Figure 5 it can be seen that the gradation in the properties has taken place from bottom to top region of the cast which correlates the results obtained from microstructure and hardness.

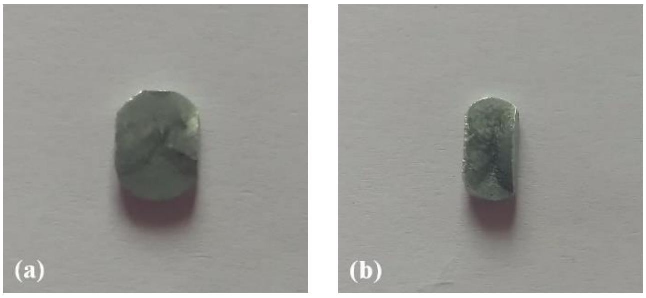

Figure 4: Diametrical compression (a) Top portion (b) Bottom portion

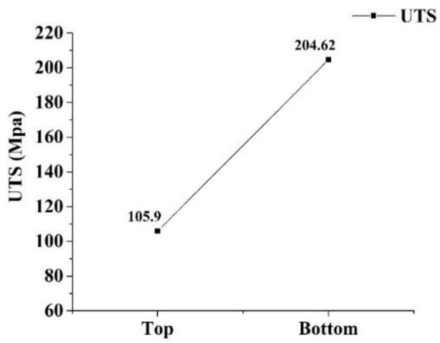

Figure 5: Ultimate tensile strength at top and bottom portion of the cast

4. CONCLUSIONS

In the present study Al-Si-Graphite based FG composite was successfully synthesized with directional solidification technique combined with lateral vibrations, the conclusions drawn from the results are as follows.

1. A novel technique was developed to synthesize FG alloys.
2. From the micrographs obtained, it can be seen that top-portion is primary-Si rich zone whereas bottom portion is primary Si depleted zone leading to gradation in properties.
3. From the hardness results it is seen that gradation has taken place from bottom to top portion ranging from 44 BHN to 56 BHN.
4. Diametrical compression strength test showed enhanced gradation characteristics which correlates the microstructure and hardness values.

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