INFORMATICS JOURNALS

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: www.informaticsjournals.com/index.php/jmmf

Influence of Casting Die Diameter Size on Microstructure and Mechanical Fractrography of Al-7Si Alloy with Flyash and Graphite Composites

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Abstract

MMCs exhibit increased modulus, strength, and fatigue strength. In MMCs, reinforcements can either be discontinuous or continuous or a combination of both. Owing to lower aspect ratio, and random orientation of the reinforcements, discontinuously reinforced composites exhibit comparatively higher isotropic properties than composites that are continuously reinforced. In the current research an attempt has been made to carry out experiments on Al-7Si and Fly ash and Graphite hybrid composites which were fabricated in steps of 3 wt.% of Flyash with 3 wt.% of Graphite and 3 wt.% of Flyash with 5 wt.% of Graphite for 25mm and 75mm diameter dies. Microstructural characterization of the specimens prepared following SEM, XRD, and EDS. Mechanical properties like hardness, yield strength, and ultimate tensile strength were evaluated as per ASTM standards. The composites prepared in 25 mm cast iron die were exhibited superior mechanical properties as compared to the composites prepared in the 75 mm diameter cast iron die. Further, with the addition of fly ash and graphite particles mechanical properties of Al-7Si alloy were improved.

Keywords: *Al-7Si Alloy, Graphite, Fly Ash, Microstructure, Tensile Strength, Hardness*

1.0 Introduction

A composite material is a macroscopic combination of two or more distinct materials with non-identical physical or chemical properties, when intermixed results in a new product with distinct characteristic much better than any one of its constituent materials with recognizable interface between them resulting in improvised properties [1].

MMCs exhibit increased modulus, strength, and fatigue strength. In MMCs, reinforcements can either be discontinuous or continuous or a combination of both. Owing to lower aspect ratio, and random orientation of the reinforcements, discontinuously reinforced composites exhibit comparatively higher isotropic properties than composites that are continuously reinforced.

Among MMCs, AMCs are most commonly studied, and used on large scale in aerospace, and automotive industries. Aluminum because of their good physical

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and mechanical properties is a potential material used as matrix in composites for several applications in vast area of Engineering. Because of its light weight, and corrosion resistance, they are widely utilized even in engineering structures, and components [2]. Stir casting method involving mixing of the dispersed phase into liquid matrix metal with constant stirring. It is accepted to be the most economical and simplest method so far in liquid state processing.

Several researches have been conducted experiments on different aluminium alloys and ceramic reinforcements, some of which are discussed below.

K.V. Mahendra et al. [3] in his investigation used Al-4.5% Cu alloy as matrix, and Flyash, and silicon carbide (SiC) as reinforcements. He showed that, increase in Flyash, and SiC content witnessed decrease in density, increase in compression, tensile, and impact strength; increase in resistances to dry wear & slurry erosive wear, and increased corrosion.

Auradi et al. [4] processed B_4C particulates reinforced Al6061 aluminum matrix composites by stir casting method and showed that addition of B_4C particulates to Al alloy matrix led to improvements in hardness, and tensile strength of base matrix.

Madeva Nagaral et al. [5] studied the mechanical behaviour of Al6061/Al_2O_3/Graphite reinforced hybrid Aluminum metal matrix composites, and showed that addition of Al_2O_3 particles increased hardness, and tensile strength of Al6061 alloy while addition of Graphite content decreased Micro-Vickers hardness of Al6061-6 wt.% Al_2O_3

Based on the literature survey a very less work has been done on Al7-Si as a base matrix. Most of the work has been done on standard materials like Al6061, Al7075, Al2024 and other alloys but not much on Al-7Si and Fly ash and Graphite as reinforcements.

In the current research an attempt has been made to carry out experiments on Al-7Si and fly ash and Graphite hybrid composites which were fabricated in steps of 3 wt.% of flyash with 3 wt.% of Graphite and 3 wt.% of flyash with 5 wt.% of Graphite for 25 mm and 75mm diameter dies. Microstructural characterization of the specimens prepared following SEM and EDS. Mechanical properties like hardness, yield strength, and ultimate tensile strength were evaluated as per ASTM standards.

2.0 Experimental Details

2.1 Al-7Si Matrix Material

In the current experiment, Al-7Si alloy was selected as base matrix metal owing to its outstanding castability, fluidity, weldability, and ability to counteract corrosion, to prepare composites with improved mechanical and tribological properties.

The Table 4 shows Al-7Si alloy chemical composition selected as matrix phase in the current study:

2.2 Reinforcing Materials

(a) Flyash

Flyash, a finely divided mineral residue resultant from the combustion of pulverized coal in electric generating plants, was selected as the reinforcing material owing to its low density

(2.1 g/cc), advantageous physical & mechanical properties, and cheap availability. Mostly Particles of Flyash are spherical shaped and are referred to as cenospheres with particle size ranging between 5 µm to 15 µm. Flyash with an empirical formula as given in Table 2 based on dominant key elements present.

(b) Graphite

Graphite, a crystalline form of carbon, was selected because of its unique metallic and non-metallic properties. It is high heat resistant material with very

Table 1: Composition of Al-7Si alloy

Element	Si	Cu	Mg	Mn	Fe	Zn	Ni	Ti	Al
Wt. %	7.20	0.02	0.29	0.01	0.18	0.01	0.02	0.11	Balance

Table 2: Chemical composition of Flyash

Element	Si	AL	Ca	Na	Fe	Mg	K	Ti
Wt. %	1.0	0.45	0.51	0.047	0.039	0.020	0.013	0.011

Table 3: Typical Properties of Graphite

Elastic Modulus (GPa)	Density (g/cc)	Poisson's Ratio	Hardness (HB500)
8-15	2.16	0.14	1.7 Mohs' scale

low specific gravity, and is extremely soft and grayish black with lustrous black sheen. The Graphite particles used in the study have average size of 1–25 μm.

The resistance furnace used for the melting and mixing of Al-7Si alloy is Bottom Pouring Remote Controlled Stir Casting type and the same is shown in the Figure 1. A control box consisting of indicating lamps, on/off switch, contractor, and digital temperature is provided adjacent of the furnace along with a thermocouple sensor.

2.3 Preparation of Composites

Though there are several time tested approaches to create composites, standard stir casting method was chosen to produce Al-7Si, Fly-ash, and Graphite hybrid composite because of low cost & simple processing method. A pre-weighed billet of Al-7Si was selected and cut into pieces (Fig.1) which were then weighed as per requirement for the casting to be added to the crucible.

The cast iron dies were cleaned with oil and rubbed with sand paper to remove any rust followed by cleaning again with brush/soft cloth. The dies were preheated to 300^{o}C prior to pouring of melt mixture to avoid cracking on the surface due to rapid cooling & unsatisfactory filling of the moulds, and to remove the moisture content absorbed by atmosphere. Preheating imparts good surface finish.

Required amount of pre-weighed Al-7Si was introduced in the Graphite crucible, and with the aid of resistance furnace heated to 730^{o}C. Hexachloroethane (C_2C_{16}) in the form of degassing tablet was then added to the melt during casting to get rid of entrapped air in the melt thereby preventing porosity, blow holes, and casting defects. Graphite and Flyash particulates in different weight percentages were added to Al-7Si matrix at 730^{o}C temperature with constant vigorous stirring for 5 minutes. Magnesium was added in small amount to increase wettability.

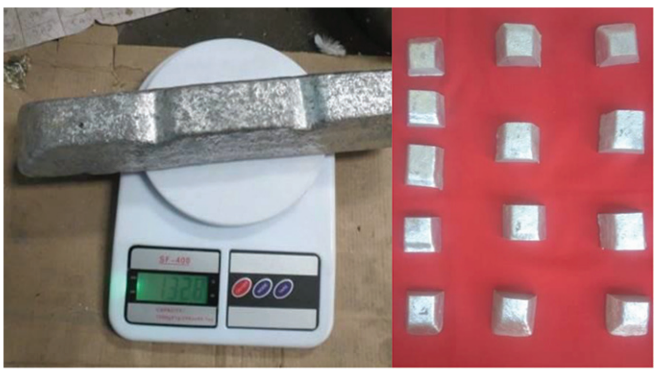


Figure 1: Measuring billet, and billet cut pieces

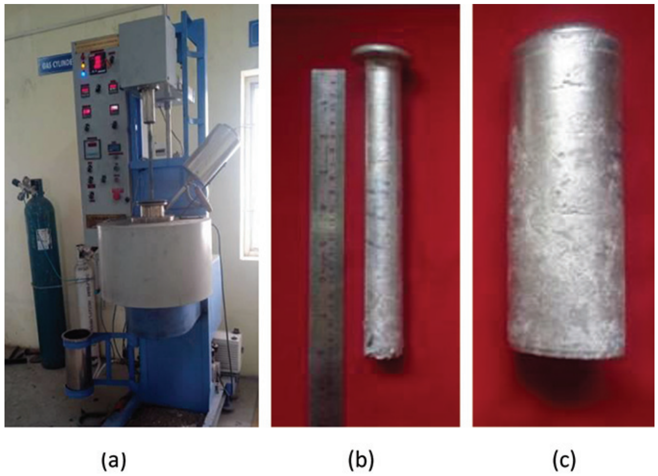


Figure 2: (a) Bottom pouring type stir casting machine (b) 25 mm diameter and length 200 mm length castings (c) 75 mm diameter and length 200 mm length castings

The melted mixture obtained was then poured into mould of cast iron and allowed to rest for few minutes to solidify. Following solidification & ambient cooling, castings were removed from the mould, and sample preparation done as per ASTM standards. Hybrid composite samples of dimensions 25 and 75mm diameter of 200 mm length obtained from moulds were then subjected to mechanical tests as per ASTM standards. The top, middle, and the bottom portion of the castings were taken for microstructural characterization to analyze second phase particulates distribution in the matrix. Evaluation of mechanical properties was done using BHN for hardness test and UTM for UTS, YS, and Percentage of Elongation to assess extent of improvement of matrix behaviour after reinforcement. Towards the end of this work, the improved properties were correlated at microstructural levels. Fig.2 (a) is showing the stir casting set up, Fig. 2 (b-c) are indicating casting of Al-7Si alloy and its composites prepared by using 25 mm diameter and 75 mm diameter cast iron dies.

2.4 Testing of Composites

Basically, investigating the microstructure of a material is termed as metallography, in which a tiny piece of metal or alloy is usually considered for inspection [6, 7]. Metallographic observer examines the size, shape, and distribution of the particulates within the composites.

In present work, portions of composite casting were sliced in several pieces selected from different regions & subjected to polishing with abrasive particles with size of less than 3 microns at very low speed on polishing machine. Polishing removed scratches from surface of composites materials rendering the surface smooth. Films made up of SiC & Al_2O_3 abrasives were used for polishing. Superiority of both abrasive films and polishing cloth play key role in obtaining fine microstructure. The polished material was etched using Kellar's reagent (HCl+ HF+ HNO_3+ H_2O) as an etchant for optical enhancement of microstructural features like phase features, and grain size. After ensuring the polished surface to be free of dirt, grease & oil, Kellar's reagent was applied on to the polished surface in gentle rotating movements using cotton swabs dipped in etchant. The etched surface was then washed with alcohol & dried. The etched surface of the dried specimen was then analyzed for their characteristics under scanning electron microscope (SEM), and energy dispersive spectroscope (EDS).

Hardness test is a measure of material's hardness on a microscopic scale. The Brinell hardness tester as per ASTM-E10 is used in the present work to determine hardness. In current work, evaluation of hardness of base alloy Al-7Si, and Al-7Si-FA-Gr hybrid composites were done using 5mm ball indenter with load application of 250 N & 30 seconds dwell time at different locations for each sample, and average recorded.

Figure 3: Tensile test specimen

Tensile testing involves subjecting the sample to controlled tension until failure. Being a test process that is destructive, tensile testing provides information on material's UTS, YS, and ductility. Tension test is conducted to locate the breaking point when the specimen is subjected to high amount of tensile load. The procedure also helps in finding the factor of safety (FOS) of the material & in measuring the maximum load a material can withstand prior to its failure. With this test, engineers can understand weather the material is suitable for application [8]. A lot of information is gathered by conducting this test, like its strength, elasticity, plasticity, Young's modulus just by generating the tensile curves obtained during the tests [9] & [10]. Preparation of testing specimen was done as per American Standard Testing Materials ASTM-E8-M88 standard as shown in Fig.3.

3. Results and Discussion

Experimental investigations conducted to study the influence of Graphite (Gr), and Flyash (FA) in Al-7Si base alloy. Mechanical properties of the hybrid composites along with microstructural characteristics are discussed below.

3.1 Microstructural studies

Fig.4 (a-d) are showing the SEM micrographs of as cast Al-7Si alloy casted in 25 mm diameter die (Fig.4a), as cast Al-7Si alloy casted in 75 mm diameter die (Fig.4b), Al-7Si alloy with 3 wt.% of flyash and 5 wt.% of graphite reinforced composites casted in 25 mm diameter die (Fig. 4c) and Al-7Si alloy with 3 wt.% of flyash and 5 wt.% of graphite reinforced composites casted in 75 mm diameter die (Fig.4d). From the SEM, it is clear that 25 mm diameter showing a fine microstructure with small sized grains and less alloy segregation compared to 75 mm diameter casting. Fig.4 (c-d) are showing flyash and graphite particles.

Fig.4 (a-d) are showing the EDS spectrums of as cast Al-7Si alloy casted in 25 mm diameter die (Fig.4a), as cast Al-7Si alloy casted in 75 mm diameter die (Fig.4b), Al-7Si alloy with 3 wt.% of flyash and 5 wt.% of graphite reinforced composites casted in 25 mm diameter die (Fig.4c) and Al-7Si alloy with 3 wt.% of flyash and 5 wt.% of graphite reinforced composites casted in 75 mm diameter die (Fig.4d).

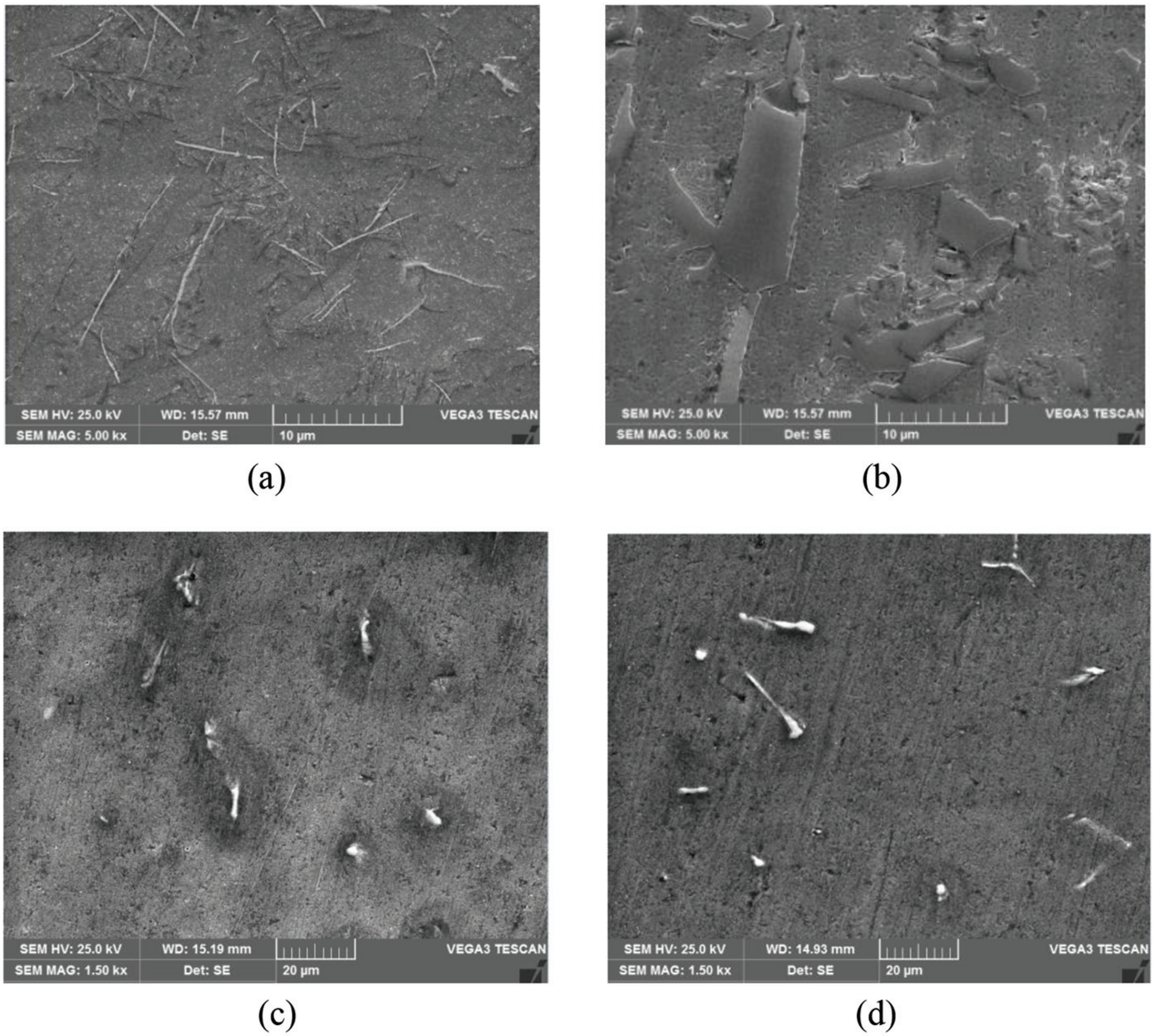


Figure 4: SEM micrographs of (a) Al-7Si alloy 25 mm dia (b) Al-7Si alloy 75 mm dia (c) Al-7Si alloy with 3 wt. Flyash and 5 wt.% graphite 25 mm dia (d) Al-7Si alloy with 3 wt. Flyash and 5 wt.% graphite 75 mm diameter die casted composites

The EDS of Al-7Si base alloy's 25 and 75 mm diameter specimen confirms the presence of aluminum as the highest element followed by silicon along with magnesium & other alloying elements. The EDS of Al-7Si-3FA-5Gr hybrid 25 and 75 mm diameter specimens shows the presence of Silicon (Si), Magnesium (Mg), Iron (Fe), and Graphite in the form of Carbon (C), and other alloying elements within the hybrid alloy. The scanned surface area is also represented in the graphs showing FA & Gr particulates [11].

3.2 Hardness measurements

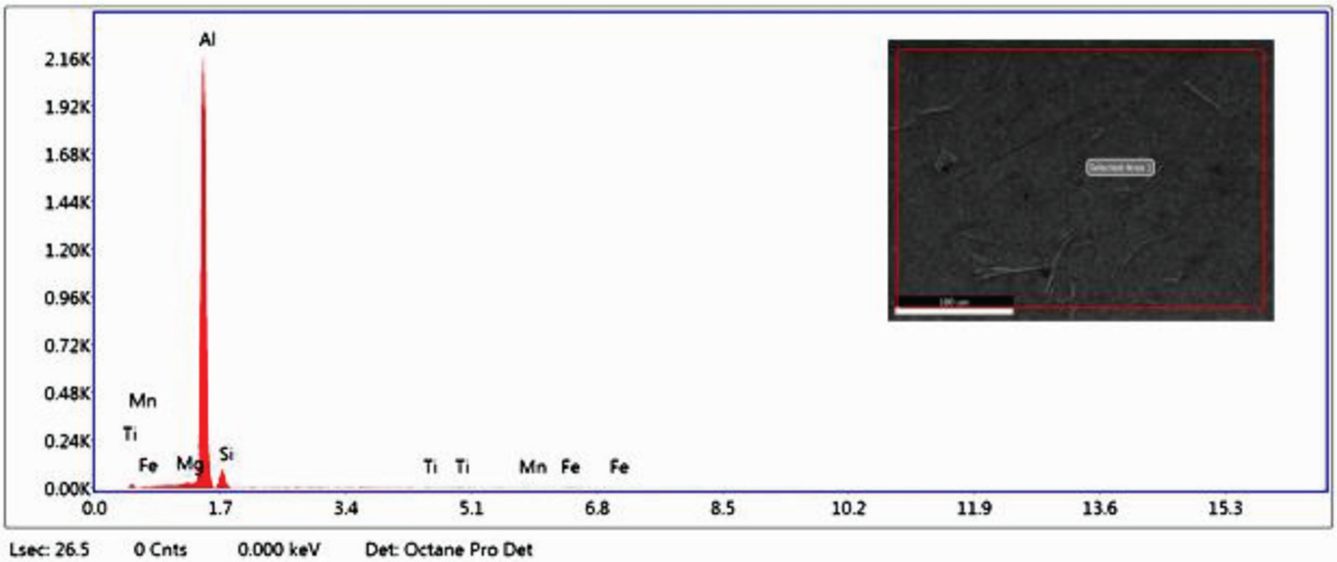
Hardness is the material's ability to resist permanent indentation or deformation when subjected to load through indenter. Test was conducted by subjecting the flat surface of the specimen to a load for a certain fixed time through indenter followed by the analysis of the impression developed over the specimen.

Fig.6 is representing the comparison of hardness of Al-7Si alloy and its composites prepared in 25 mm and 75 mm diameter dies. Al-7Si alloy and its flyash and graphite reinforced composites are exhibiting higher hardness in 25 mm diameter die casted samples as compared to the 75 mm diameter die casted samples. This is mainly due to the reduction in the area of die which helps to cool cast samples rapidly. Rapid cooling of samples in 25 mm diameter casted samples resulting in finer grains as compared to the 75 mm diameter die casted castings. The hardness Al-7Si alloy is 54.82 BHN which is prepared in 25 mm diameter die, further it is 50.92 BHN in 75 m diameter die casted specimens.

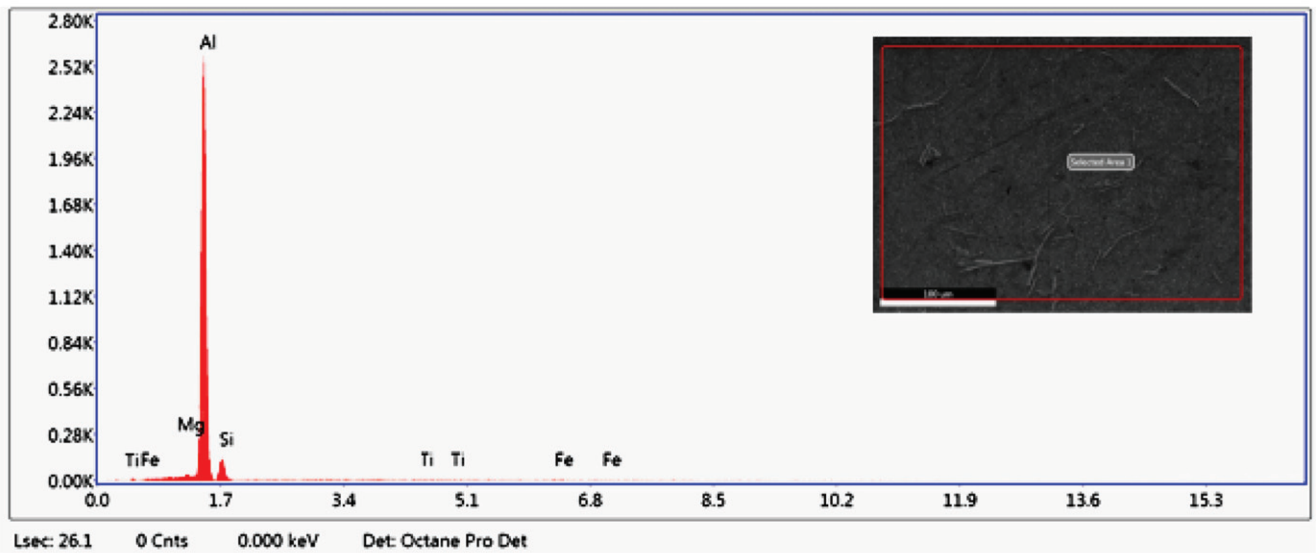
Further, impact of graphite and flyash particles is studied in the Fig.6. Addition of 3 wt.% of flyash and 3 wt.% of graphite has slightly increased the hardness of Al-7Si. As weight percentage of graphite increased from 3 to 5 wt.% there is decrease in hardness of Al-7Si alloy which were prepared in both 25 and 75 mm diameter dies. Higher weight percentage of graphite decreased hardness due to its softness.

3.2 Tensile Properties

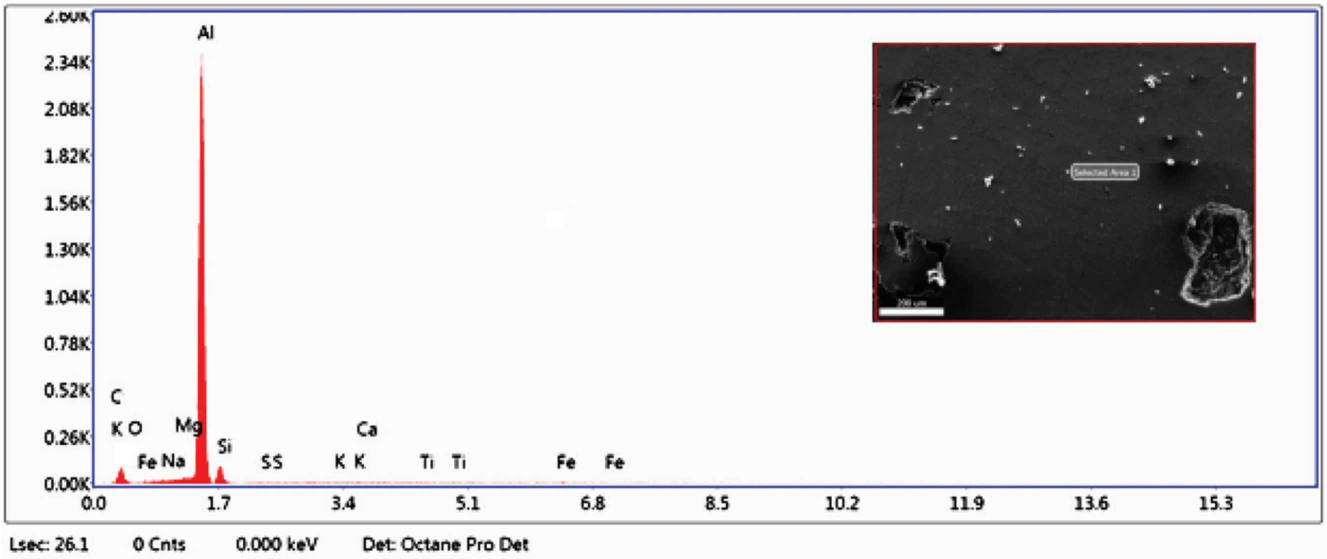
UTS is the maximum stress a material can withstand when loaded in its axial direction. Determining UTS is very easy job, which involves pulling of specimen at constant strain rate until it



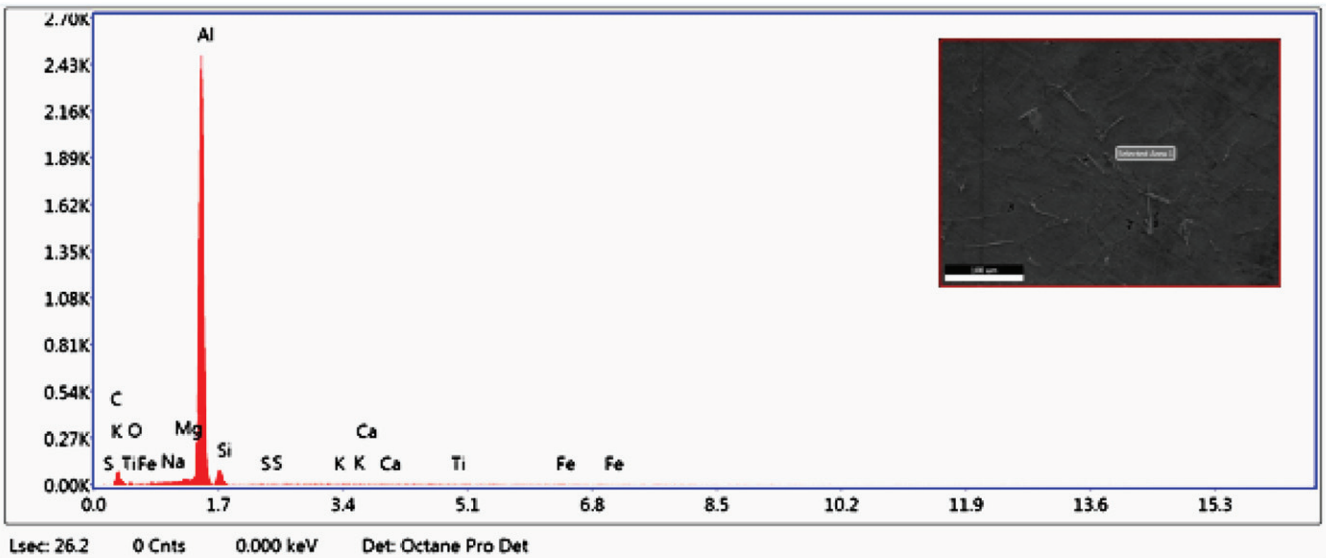
(a) 25 mm Al-7Si base alloy



(b) 75 mm Al-7Si base alloy



(c)



(d)

Figure 5: EDS spectrums of (a) Al-7Si alloy 25 mm dia (b) Al-7Si alloy 75 mm dia (c) Al-7Si alloy with 3 wt. Flyash and 5 wt.% graphite 25 mm dia (d) Al-7Si alloy with 3 wt. Flyash and 5 wt.% graphite 75 mm diameter die casted composites

breaks. Figs.7 and 8 are representing the comparison of ultimate and yiled strength of Al-7Si alloy and its composites prepared in 25 mm and 75 mm diameter dies. Al-7Si alloy and its flyash and graphite reinforced composites are exhibiting higher UTS and YS in 25 mm diameter die casted samples as compared to the 75 mm diameter die casted samples.

UTS and YS of as-cast alloy prepared in 25 mm diameter die are 164.3 MPa and 131.4 MPa respectively. Similarly, the UTS and YS of as-cast Al-7Si prepared in the 75 mm diameter die are 151.3 MPa and 121.1 MPa respectively. The samples prepared in the 25 mm diameter die are exhibited superior strength properties as compared to the samples prepared in the 75 mm diameter die. Strength increased in the smaller diameter die is due to reduced cross sectional area of the die, which helps in the rapid cooling of castings.

Further, addition of flyash and graphite particles

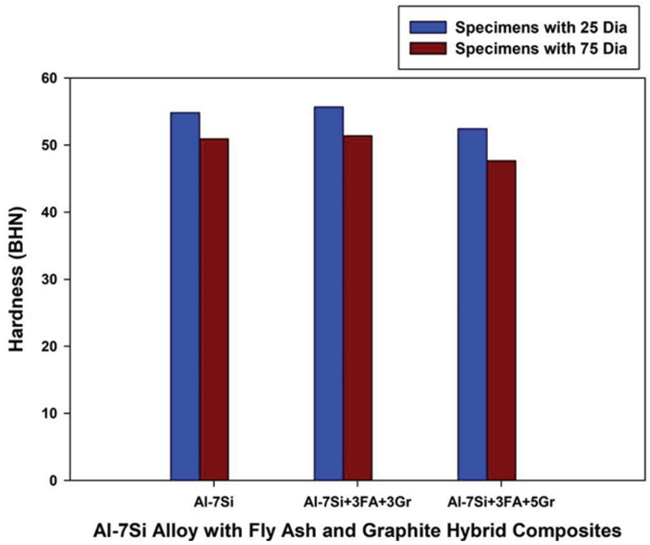


Figure 6: Comparison of hardness of Al-7Si alloy with flyash and graphite composites

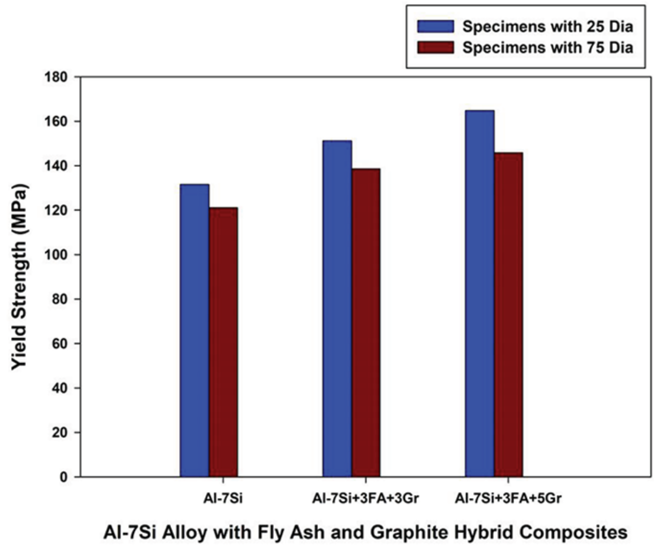


Figure 7: Comparison of UTS of Al-7Si alloy with flyash and graphite composites

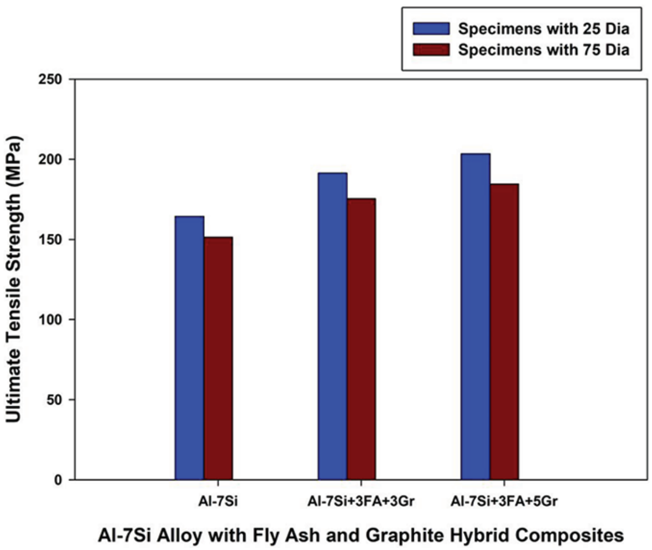


Figure 8: Comparison of YS of Al-7Si alloy with flyash and graphite composites

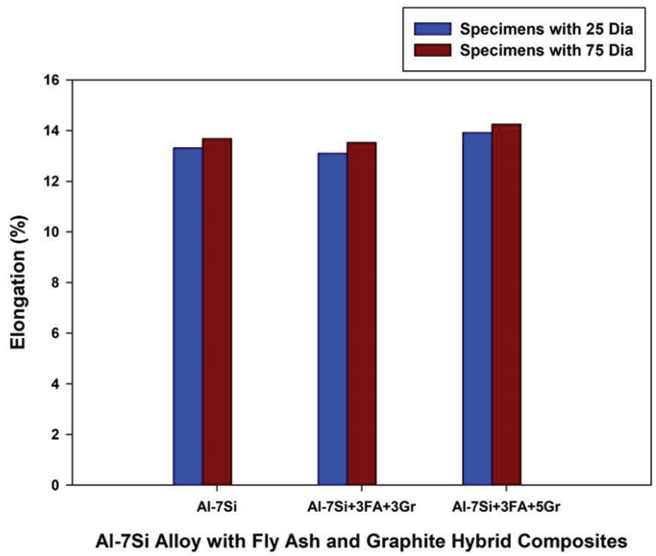


Figure 9: Comparison of elongation of Al-7Si alloy with flyash and graphite composites

improved the UTS and YS of Al-7Si alloy in both 25 and 75 mm diameter castings. These flyash and graphite particles acts as a barrier of regular deformation of Al alloy during axial loading.

Fig.9 is showing the comparison of elongation of Al-7Si and its flyash and graphite particle reinforced composites. Composites prepared in the 25 mm diameter die have shown more ductility as compared to the 75 mm diameter die casted composites. Further, addition of 3 wt.% of flyash and 3 wt.% of graphite particles slightly decreased the ductility of as cast alloy.

4. Conclusions

Al-7Si alloy with varying weight percentages of graphite and flyash particles reinforced composites were prepared by stir casting method by using 25 and 75 mm diameter dies. Microstructural characterization was done by using SEM and EDS, revealed the uniform distribution of particles and presence various elements in the Al-7Si alloy with flyash and graphite composites. Al-7Si and its flyash and graphite composites prepared in 25 mm diameter die exhibited superior properties as compared to the 75 mm diameter die casted samples. Further, as weight percentage of graphite increased from 3 to 5 wt.%, there was slight decrease in the hardness of AL-7Si alloy. Ultimate and yield of Al-7Si alloy were improved with the content of flyash and graphite parties in both 25 and 75 mm diameter die casted samples.

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