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Microstructure and Mechanical properties of A356 alloy Castings made in Sand and Granulated Blast Furnace Slag Moulds

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Abstract

Investigations were focused on structure property evaluation of castings made through Granulated blast furnace (GBF) slag and silica sand moulds. Sodium Silicate-CO_2 process was used for making the necessary moulds. Three types of moulds were made with slag, silica sand individually and combination of these two. A356 alloy castings were performed on these newly developed slag moulds. Results reveal that the castings were performed successfully in all the moulds. Cast products with good surface finish, no surface defects and without porosity were produced by slag moulds. Faster heat transfer in slag moulds enabled the obtained castings with enhanced metallurgical and mechanical properties. Consistent and uniform hardness on the cross section of the specimen was obtained in all the materials made through sand, slag and mixed moulds. Improved hardness, compression, tensile and impact properties were observed in all the materials made through GBF slag moulds. Based on these present investigations can conclude that GBF Slag moulds can make a way for producing the castings with improved surface finish and enhanced properties while reduced operational costs.

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Keywords: Silica sand; GBF slag; A356 alloy castings; Optical & SEM studies, Mechanical properties.

1. INTRODUCTION

Silica sand is traditionally used in the foundry applications as a moulding material. Due to the depletion of natural materials, there is a need to find suitable alternative material, which will replace the conventional materials. The large scale industrialization has resulted accumulation of huge amount of industrial wastes, endangering the environment in terms of land, air and water pollution. In order to use the industrial waste in huge quantities efforts

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are being made to use the same as a substitute of natural resources. Various efforts have been made to use industrial solid wastes like fly ash, red mud, blast furnace slag etc. in civil and construction works. In view of the large quantity of slag availability, having similar physical and chemical properties with silica sand and non availability of literature on GBF slag usage in foundry industry; present investigations are focused to evaluate the structure property evaluation of castings made through Granulated blast furnace (GBF) slag and silica sand moulds for assuring the GBF slag as an alternative mould material in non ferrous foundries.

2. MATERIALS AND METHODS

In the present investigation two types of materials namely high Silica sand and Granulated Blast Furnace (GBF) slag was chosen. Silica sand is the principle molding sand used in foundry industries. It was procured from Chirala, Andhra Pradesh, India. Blast furnace slag in granulated form procured from Visakhapatnam Steel Plant, Visakhapatnam, India. Preheating of the Silica Sand and granulated blast furnace slag (GBF) particulates were carried out in a muffle furnace at 300^0 C for 3 hours to get rid of the any moisture presence in them. Later on these materials were investigated for their chemical and physical properties [1].

2.1 Melting and Casting practice

Melting and casting practice non ferrous castings was performed on these newly made GBF slag moulds to assess both metallurgical and mechanical properties of slag and sand mould castings. For this study three types of moulds were selected, namely; Type 1: 100% Silica sand; Type 2: 100% GBF slag; and Type 3: mixture of 50% GBF slag + 50% Sand. The moulds were prepared with optimum mould properties by addition of sodium silicate along with CO_2 gassing [2]. These prepared moulds were made ready for castings. A 356 (Al-7.5% Si) alloy has been chosen in non ferrous castings. Al-Si alloy having a wide range of applications in the automotive and aerospace; also provides the most significant part of all shaped castings manufactured. This work is first of its kind; hence, only regular shaped cylindrical castings (18 X 180 mm diameter and length respectively) are aimed to cast. Cope and drag as well as split pattern was used for preparing the mould with mould cavity. A356 alloy Ingots of 500 grams in weight of was taken in a graphite crucible and melted separately in a high temperature melting furnace at 750 ^{O}C. The molten metal was allowed to fill in the mould cavities via sprue, runner and in gates; care was taken to ensure continuous and smooth flow of the liquid metal while filling in the mould cavities. Riser was placed in the mould to ensure complete mould cavity filling. After cooling the castings were withdrawn from mould boxes and same was undergone for further metallographic and mechanical properties evaluation. Figure 1 shows the finished A356 alloy cylindrical castings before and after machining.

Figure 1: A 356 alloy finished cylindrical castings before and after machining

2.2: Metallographic evaluation

Optical metallographic observations were made on the castings made through sand, slag and mixed moulds. 16 X 16 mm cylindrical samples were cut from the cast ingots. Standard polishing practice was followed to prepare the samples for observation. The microstructures of the specimen were investigated by optical microscopy (Model: Olympus, C – 5060 - G x 4- Japan). Keller's reagent (chemical composition: HF = 1.0 cc, HCl = 1.5 cc, HNO_3 = 2.5 cc and H_2O = 95 cc) was used as etching reagent.

2.3: Mechanical properties evaluation

2.3.1: Hardness studies

Rockwell hardness tests were carried out on these cast samples to have comparative strength properties of the slag and sand castings. Standard testing procedure was followed by applying the minor load of 10 kgf; and major load of 100 kgf with HRB scale. Hardness was measured at four different regions on the cross section of the specimen and averaged. An average of eight readings was considered to report the respective hardness value.

2.3.2: Tensile testing

Tensile specimens were casted directly from respective slag, sand and combination of sand and slag moulds. Melting and casting procedure to make these tensile specimens was followed the same procedure as discussed in section 2.1. Figure 2 show the standard tensile test specimen and its experimental set up respectively. Tensile strength of materials under investigation was determined by using computer controlled servo hydraulic universal testing machine (model: Fuel Instruments and Engineers (FIE –UTE 100 with 1000 tons capacity). The test was conducted at a constant cross head speed of 0.5 mm/min. The testing procedure was followed as per ASTM E-8 standards. Online plotting of load versus extension has done continuously though a data acquisition system. Figure 3 shows the tensile specimens before and after testing for A356 alloy specimens made through sand, slag and mixture of slag and sand castings respectively.

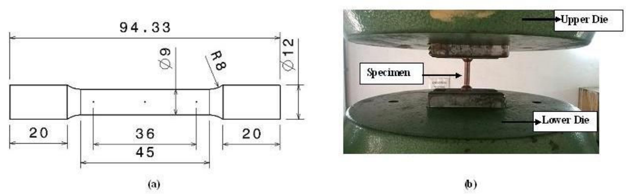


Figure 2: (a) Standard tensile specimen (b) Closer view of the tensile testing.

Figure 3: A 356 alloy Tensile specimens: (a) before testing (b) after testing.

2.3.3: Compression testing

Standard cylindrical specimens with aspect ratio (H/D=1.0) of 16 mm length and 16 mm diameter were machined from the cylindrical finger castings of respective materials. Sample edges were chamfered to minimize the folding. Concentric grooves of 0.5 mm depth were made on both the end surfaces of the sample. These samples were compressed by placing between the flat platens at a constant cross head speed of 0.5 mm/min in dry condition, using a computer controlled servo hydraulic 1000T universal testing machine (Model: FIE-UTE). Cold work die steel dies (flat flattens) were machined to produce smooth finish to yield low friction. Figure 4 shows the cylindrical samples of A356 alloy before and after deformation respectively. Online plotting of load versus displacement has done continuously through a data acquisition system.

Figure 4: Cylindrical samples with aspect ratio = 1.0 showing bulge profiles before and after deformation under compression

2.3.4: Charpy Impact testing

Charpy impact tests were carried out on these cast samples to have comparative impact properties of the slag and sand castings. The V-notched impact test standard specimens with dimensions of 10 X 10 X 55 mm were made according to ASTM-A370. The test was conducted at room temperature and was repeated for three times of each material. An average of three readings was considered to report the respective impact value. The Charpy impact test machine (Model: R17 DT 63M4: Micro technology, Chennai, India) was chosen for above test. Figure 5 shows the A356 alloy Charpy impact specimens before after testing.

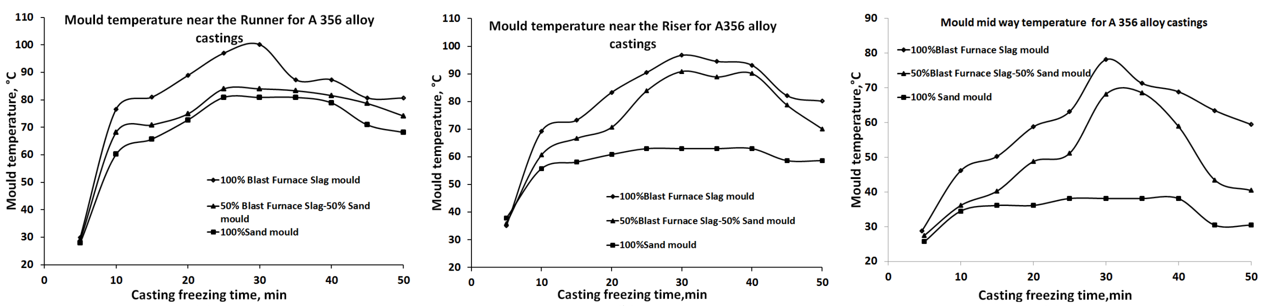
Figure 5: Charpy impact specimens: (a) before testing (b) after testing

3 RESULTS AND DISCUSSION

3.1 A356 alloy laboratory Castings – Mould heat transfer rates

The cylindrical finger castings after cooling were examined and revealed that very less amount of mould ingredients were stick to the casting surfaces; further slag castings shows cleaned surface finish on par with sand castings. All the castings show good surface finish with no surface defects; it also reveals good dimensional accuracy. Before and after machined cylindrical castings shows no porosity or other surface defects presence in any of the either sand or slag mould castings.

Mould heat transfer rate plays a significant role in obtaining final microstructure and its corresponding mechanical properties of the castings [3-8]. Studies were performed to evaluate the mould heat transfer rates of slag, sand and mixture of these two moulds. The same was measured by observing the mould temperature at three locations namely near the runner, riser and mid-way of the mould cavity with solidification times. This assessment was done separately for sand, slag and mixture of these two moulds. The obtained results were shown in figure 6. These figures reveal that initial solidification period (up to 30 minutes duration) increase in mould temperature was noticed; then slowly lowering the mould temperature. The same trend was observed for all the three moulds. For all the three locations (runner, riser and mould mid way) at any given freezing time GBF slag mould shows more mould temperature, then mixture of sand-slag mould and finally sand moulds. From these results it can conclude that GBF slag moulds facilitate faster heat transfer rates than sand moulds; hence faster solidification rates of the castings.

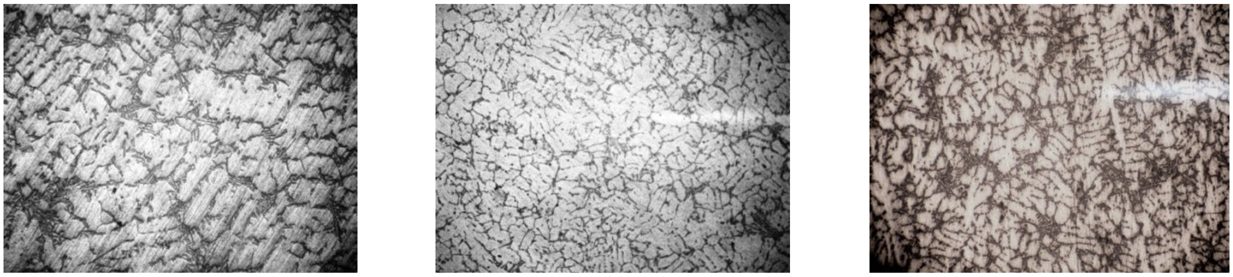


(a) (b) (c)

Figure 6: Variation in mould temperatures at various locations during freezing of A356 alloy castings for Sand, GBF slag and mixture of these two moulds: (a) near the Runner (b) near the Riser, and (c) Midway of the mould.

3.2 Microstructure evaluation

Figures 7(a-c) illustrate the optical microstructures of A356 alloy castings made in sand, GBF slag and mixture of sand and slag moulds respectively. Slag castings show refined microstructures than sand castings; this might be due to the presence of faster solidification rates in these slag moulds (as shown in figure 6). Microstructure of mixed mould castings shows in between the sand and slag castings. In general, the rate at which a casting cools affects its microstructure, quality and properties. The products of sand casting process generally cool slowly compare to metallic moulds. This slow cooling increases the metal's grain size, creating a coarse microstructure; coarse grain structure weakens the casting [9-13]. The same phenomenon was noticed in the present investigation. Conversely, the products of slag mould process are able to cool more quickly, resulting microstructure with small size grains. The A356 alloy with chemical composition of Al-7.5%Si is a hypoeutectic alloy; microstructure mainly consists of soft & ductile α - aluminum dendrite phase containing magnesium and silicon in solution and hard & brittle eutectic phase (α-Al+Si) in the inter-dendrite region, as shown in figures 7(a-c).

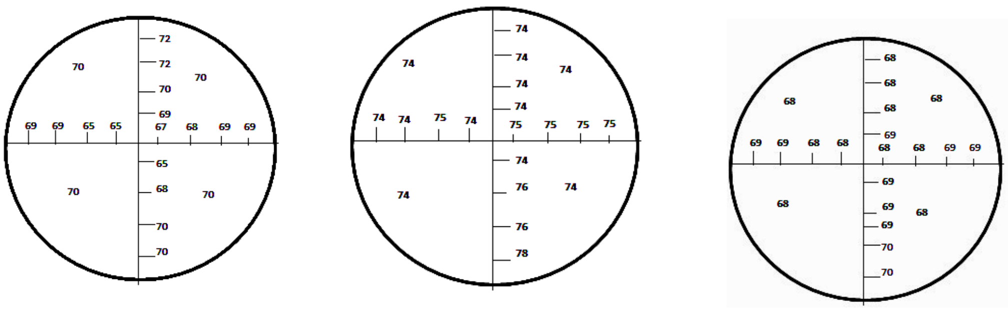


(a) (b) (c)

Figure 7: Microstructure of A356 aluminium in alloy castings at magnification of 100 X: (a) Silica Sand Mould (b) GBF Slag Mould and (c) Mixture of 50% GBF slag and 50% Silica sand mould. Etchant: Keller's reagent.

3.3: Hardness survey

Figure 8 shows the hardness profiles of A356 alloy castings made by sand, GBF slag and mixture of slag and sand moulds respectively. The hardness survey was done across the longitudinal and transverse directions of the samples. Also hardness was measured at four different diagonals of the specimen and averaged. These observed values are similar to the available literature. Further results reveal consistent and uniform hardness was observed in all the castings throughout the cross section of the sample; while sand castings shows lower hardness compared to slag castings. In case of mixed mould castings hardness was in between the slag and sand mould castings.



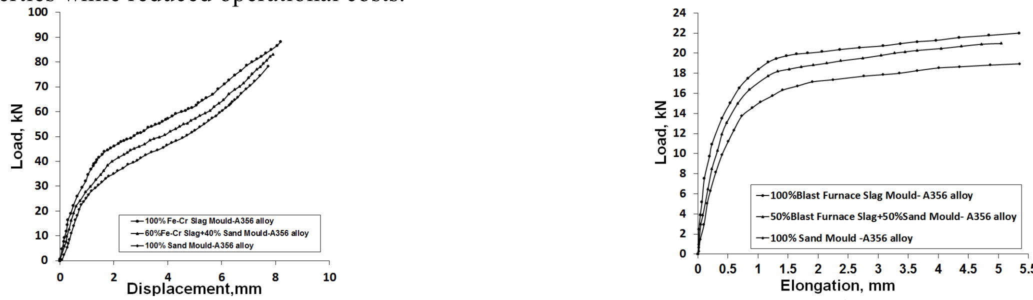
(a) (b) (c)

Figure 8: Hardness profiles of A356 aluminium alloy along the cross section of the sample, cast in various moulds of: (a) 100% Silica Sand (b) 100% GBF Slag and (c) Mixture of 50% GBF slag and 50% Silica sand

3.4: Compression, Tensile and Impact properties

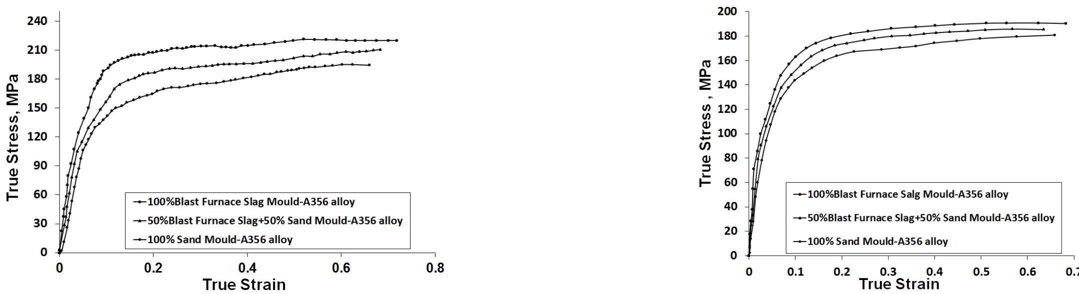
Compression and tensile properties of A356 alloy made through sand, slag and mixture of these two moulds was studied; respective load-displacement and load-elongation curves obtained during testing by online data acquisition system was shown in figure 9 (a & b) respectively. The load requirement increased with increase in deformation for the material under investigation. The slag mould castings show higher loads with slightly improved amount of deformation than the sand moulds; mixed mould castings properties lies in between sand and slag mould castings. In case of impact strength, GBF slag castings shows more or less similar results with silica sand castings. The summary of the obtained mechanical properties for all the materials under investigation was shown in table 1.

Higher strength with more amount of deformation in slag castings might be due to the prevailing of faster mould cooling rates (figure 6); this might be lead to the existence of fine grain structure in slag moulds than sand moulds (figure 7). The same was confirmed from the true stress and true strain results, figure 10 (a & b) for compression and tensile respectively. Grain size has a significant effect on strength of the metals. As the grain size decreases the strength and ductility of metal increase, micro porosity in the casting decreases and the tendency for the casting to crack during solidification decreases. The strength of the materials is expected to increase by the presence of fine grain structure due to the strengthening effects occurred in combination of both grain boundary and strain hardening mechanisms [14]. Based on these present investigations one can conclude that GBF Slag can be used as mould materials; these moulds can make a way for producing the castings with improved surface finish and enhanced properties while reduced operational costs.



(a) (b)

Figure 9: (a) Load- displacement curves under compression testing for aspect ratio (H/D) =1.0and (b) Load- elongation curves under tensile testing.



(a) (b)

Figure 10: True Stress – true strain curves: (a) under compression testing for aspect ratio (H/D) =1.0, (b) Under tensile testing.

Table 1: Mechanical properties of A356 alloy made through sand, slag and combination of these two moulds after compression, tensile and impact testing.

S. No.	Material	Mould Material	Hardness	Tensile Properties				Compression Properties		Impact Strength (joules)
				Y.S (MPa)	UTS (MPa)	break stress (MPa)	% Elongation	UTS (MPa)	break stress (MPa)	
1.	A356 alloy	100% Sand	62 HRB	178	183	183	1.21	195	194	6.0
		100% GBF Slag	75HRB	187	190	188	1.21	220	215	6.2
		50% GBF Slag + 50%Sand	68 HRB	182	185	183	1.20	210	196	6.0

CONCLUSIONS

1. All the castings were performed successfully in GBF slag and sand moulds.
2. Cast products with good surface finish, no surface defects and without porosity were produced by slag moulds.
3. Faster heat transfer in slag moulds enabled the obtained castings with enhanced metallurgical and mechanical properties.
4. Consistent and uniform hardness on the cross section of the specimen was obtained in all the materials made through sand, slag and mixed moulds.

5. Improved hardness, compression, tensile and impact properties were observed in all the materials made through GBF slag moulds.
6. Based on these present investigations one can conclude that GBF Slag can be used as mould materials; these moulds can make a way for producing the castings with improved surface finish and enhanced properties while reduced operational costs.

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