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Non Destructive Evaluation of A356 alloy Castings made in Sand and Granulated Blast Furnace Slag Moulds

I.Narasimha Murthy and J Babu Rao*

Dept of Metallurgical Engg, Andhra University, Visakhapatnam – 530003, India
**Corresponding author Email: baburaojinugu@yahoo.com*
**Phone Number: +91 9848431073*

Abstract

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. In view of the large quantity of blast furnace slag availability, having similar physical and chemical properties with silica sand present investigations are focused to evaluate the suitability of GBF slag as an alternative mould material in foundries. In the present investigation three types of moulds were made with slag, silica sand individually and combination of these two. Sodium Silicate-CO_2 process was used for making the necessary moulds. Two types of commonly used automobile parts like Gear wheel and Connecting rod was selected for casting the same. A356 (Al-7.5% Si) alloy castings were performed on these newly developed slag and sand moulds. The cast products were investigated for its quality evaluation by non destructive methods; in this investigation Visual inspection, Liquid penetrant, Ultrasonic and Radiographic tests was used. Results reveal that the castings were performed successfully in GBF slag and sand moulds. The cast products show good surface finish with dimensional accuracy. NDE results evident that both sand and slag mould cast products had a sound castings with neither surface, subsurface defects nor internal defects.

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Keywords: Silica Sand; GBF Slag; Visual inspection; Liquid Penetrant testing; Ultrasonic and Radiography testing.

1. INTRODUCTION

Huge quantities of silica sand are conventionally used in the foundry applications as a moulding material for production of ferrous and non-ferrous castings. Due to the exhaustion 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 are being made to use the same as a substitute of natural resources. Various efforts have been made to use industrial wastes like fly ash, blast furnace

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slag, red mud, Ferro Chrome (Fe-Cr) slag etc. in civil and construction works. Blast furnace Slag is an industrial solid waste generate from the steel plants. Globally, BF slag is producing around 11million tons per annum and likely to be increased by 10%. Since by the large amount of availability and having similar physical and chemical properties with silica sand; investigations are carryout to find out the suitability of this BF slag as alternative mould materials in foundry industry. Till now very limited literature is available in this area. Cast A356 aluminum alloys are widely used in automotive industry due to their excellent castability, corrosion resistance and their high strength to weight ratio. But these cast products suffer heavily from various casting defects which exist on both surface and subsurface of the components. The origin of these defects are due to the various sources such as type of the mould material used, design of the mould, shape of the component and also other process parameters like melting, pouring, and solidification. Hence, these to be addressed while using blast furnace slag as an alternative mould material for silica sand to enable to produce sound castings.

The detection of material's defects by using several physical probing techniques is known as non-destructive testing (NDT). Non-destructive inspection is a powerful tool will be used for either rejection or acceptance of a material, improving product quality, reducing costs and maintaining quality levels [1, 2]. Six main NDT methods generally used for this purpose; namely visual inspection, liquid penetrant testing, magnetic particle testing, electromagnetic or eddy current testing, radiography and ultrasonic testing [3-5]. Casting defects can be broadly classified into three major groups: (i) void-type defects such as porosity, micro porosity and gas holes, (ii) inclusions such as sand, slag and dense inclusions and (iii) crack type defects like shrinkage (micro and spongy), hot tears and cracks [6, 7]. In the present investigation three types of moulds were made with BF slag, silica sand individually and combination of these two. Sodium Silicate-CO_2 process was used for making the necessary moulds. Two types of commonly used automobile parts of Gear wheel and Connecting rod was selected for casting the same. A356 (Al-7.5% Si) alloy castings were performed on these newly developed slag and sand moulds. The cast products were investigated for its quality evaluation by non destructive methods; for this Visual inspection, Liquid penetrant, Ultrasonic and Radiographic tests were carried out. This research results will be useful to the small scale and large scale/captive foundries by providing an alternative mould material for sand to replacement either fully or partially.

2. MATERIAL 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 moulding 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. Investigations on their chemical, physical and moulding properties were reported in earlier works [8].

2.1 Melting and Casting practice

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. Hence, melting and casting practice of A 356 (Al-7.5%Si) alloy castings was performed on these newly made GBF slag moulds. 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 best possible mould properties were obtained by optimum addition of sodium silicate along with a sufficient CO_2 gassing [9]. Present investigation two types of patterns namely toothed gear wheel and connecting rod were chosen and aimed to cast the same. 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 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 quality inspection like macro and non destructive evaluation. Figure 1 shows the A356 alloy castings before machining.

(a) (b) (c)

Figure 1: A356 Aluminum alloy castings before machining casted in: (a) 100% Sand mould (b) 100% GBF Slag mould (c) Mixture of 50%GBF Slag + 50% Sand mould

2.2 Castings Non Destructive Evaluation

A356 alloy castings after machined were inspected for its size, shape and defects presence by both the methods like visual and non destructive evaluation (NDE). Four types of testings methods of Visual Inspection, Liquid Penetrant test, Ultrasonic test and Radiography tests were carried out on these castings. All the NDE tests were performed according to international specifications.

2.2.1 Visual Inspection

Visual inspection was carried out on all the A356 alloy cast products. This was done with naked eye to evaluate the surface finish and defects presence. The test was performed as per the ISO: 10049 standards for aluminium alloy castings.

2.2.2 Liquid Penetrant Test (LPT)

Liquid penetrant test has the capability to detect surface defects with higher clarity than Visual inspection and makes defects easier to see. Hence, Liquid penetrant test was performed on all the A356 alloy castings. The test was performed according to ASTM E 1417 standards.

2.2.3 Ultrasonic Test (U.T)

Ultrasonic testing was carried out on all the A356 alloy cast products made in sand, slag and combination of these two moulds. In this technique reflection and transmission of high-frequency sound waves (ultrasonic waves) was used for sub-surface and internal defect's detection in cast products. As per the available literature of Ultrasonic test (U.T) of Al alloys the wave frequency in the range from 5 to 10 MHz was used. The cast products surface roughness (Ra) value was maintained in the range between 50 µm and 100 µm. The test was carried out according to ASTM B548-76 standards. Ultrasonic testing machine Einstein-II DGS (make: Mon sonic, Gujarat, India) was used for present investigation.

2.2.4 Radiography testing

X-ray Radiography technique was carried out on all the A356 alloy castings. The same was performed by using prototype machine named ROLI-2 camera (radioactive source: 20 C_i. Ir^{192}). The test was carried out according to ASTM 1B11 standards.

3 RESULTS AND DISCUSSION

3.1 Visual Inspection

Figure 2 & 3 shows the A356 alloy gear wheel and connecting rod cast products made by sand, slag and combination of these two moulds. The visual inspection was done under sufficient light by using magnifying glass. All the components surfaces, inner & outer ring, teeth of the gear wheel and the flange of the connecting rod was examined thoroughly for possible presence of any surface defects, size and shape distortions etc. Results reveal that no such defects were observed in any of the cast products; it was also true even after machining of the components. The cast products dimensional accuracy was measured and same was compared with the respective wooden patterns. It was found that the dimensional stability was decent and accurate after giving machining allowance. It was true for both the products. Hence, it can be conclude that slag mould cast products shows on par with sand castings.

(a) (b) (c)

Figure 2: Visually inspected A356 alloy Gear wheel castings made in: (a) 100% Sand mould (b)100% GBF Slag mould (c) Mixture of 50% GBF Slag+50% Sand mould.

(a) (b) (c)

Figure 3: Visually inspected A356 alloy Connecting rod castings made in: (a) 100% Sand mould (b)100% GBF Slag mould (c) Mixture of 50% GBF Slag+50% Sand mould

3.2 Liquid Penetrate Test (LPT)

Liquid penetrant testing (LPT) generally used in both ferrous and nonferrous castings to detect surface discontinuity, tiny cracks, pores or other surface glitches that are hard to detect by the human eye. The principle of this method is capillary action, which is the ability of a liquid or dye to travel to or be drawn onto a surface opening. In this method, a colored dye solution is applied to the surface of the casting. The dye, which is suspended in penetrating oil, will find its way into the surface defects. When a developer is applied, the defects are clearly indicated [10]. Figure 4 and 5 shows the A356 alloy gear wheel and connecting rod cast products made by sand, slag and combination of these two moulds. The same was also depicts the samples under liquid penetrate testing. Existence of defects on the sample was indicated by the red patches on the specimen surfaces. Interestingly sand castings show few numbers of red patches followed by mixed mould castings. 100% GBF slag mould cast products shows very less number of red patches. Entire component was thoroughly checked and found that no cracks. It was true for both gear wheel and connecting rod samples.

(a) (b) (c)

Figure 4: Liquid penetrant inspection of A356 aluminum alloy Gear wheel castings made in (a) 100% Sand mould (b)100% GBF Slag mould (c) Mixture of 50% GBF Slag+50% Sand mould.

(a) (b) (c)

Figure 5: Liquid penetrant inspection of A356 aluminum alloy Connecting rod castings made in (a) 100% Sand mould (b)100% GBF Slag mould (c) Mixture of 50% GBF Slag+50% Sand mould.

3.3 Ultrasonic testing (U.T)

The ultrasonic testing (U.T) technique uses ultrasonic waves for sub-surface and internal defect's detection and sizing in both ferrous and non-ferrous castings. The method uses reflection and transmission of high-frequency sound waves. The high frequency acoustic energy travels through the casting until it hits the opposite surface or an interface or defect. The interface or defect reflects portions of the energy, which are collected in a receiving unit and displayed for the analyst to view. The pattern of the energy deflection can indicate the location and size of internal defects [11]. The results of the Ultrasonic testing of A356 alloy cast products made in sand, slag and combination of these two moulds were shown in figures 5 and 6 for Gear wheel and Connecting rod samples respectively.

Figure 6(a) shows the U.T image of sand mould casted gear wheel specimen. It illustrates multiple peaks with various peak heights. First and last highest peaks were representing the boundary surfaces of the specimen; whereas an intermediate peaks represents the defects inside the sample. Hence, from this result it was evident that the presence of some internal defects in the sand mould cast products. In case of gear wheels made with 100% GBF slag mould and mixed moulds U.T images shows only two echoes i.e. first echo which was originating from the boundary surface of the sample and the last echo which was the return echo from the bottom of the surface. There was no intermediate echoes were observed in both the castings, figure 6 (b& c); hence, no internal defects were observed in these cast products.

Connecting rod (made by sand mould) ultrasonic testing (U.T) image was shown in figure 7(a). It depicts more number of peaks with different amplitude; also these peaks amplitude was increasing with moving the U.T probe from specimen’s smaller cross section to bigger side. This evident that while increasing the cross section of the specimen the possible presence of internal defects also increasing simultaneously. These defects might be sub-surface defects such as pinholes, since the peaks were very small in size. No intermediate peaks were observed in both 100% slag and mixed mould connecting rods U.T images, figure 7 (b &c); hence evident that no internal defects in these specimens. Finally, U.T images of both gear wheel and connecting rod made by slag mould shows sound and internal defects free castings.

(a)

(b)

(c)

Figure 6:.ultrasonic Inspection testing of Gear wheel aluminum alloy A356 castings poured in (a) 100% Sand Mould (b)100%BF Slag Mould (c) Mixture of 50% GBF Slag+50% Sand mould.

(a)

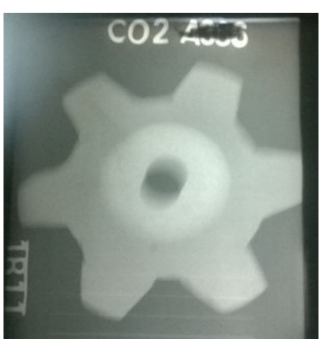
(b)

(c)

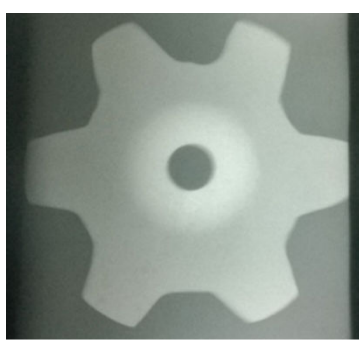
Figure 7:.ultrasonic Inspection of connecting rod aluminum alloy A356 castings poured in (a) 100% Sand Mould (b) 100% GBF Slag mould (c) Mixture of 50% GBF Slag+50% Sand mould.

3.4 Radiography test (R.T)

Radiography is one of the oldest and widely used nondestructive testing method. This is used to detect internal defects such as porosity, shrinkage and inclusions. Radiography testing is a photographic record produced by the passage of electromagnetic radiation such as x-rays or gamma rays through an object onto a film. When film is exposed to these rays an invisible change called a 'latent image' is produced in film emulsion. The areas so exposed become darker when the film is immersed in a developing solution. The recorded images on the film are processed for detecting internal defects in the specimen. Dense material withstands the radiation penetration, so the film is exposed to a lesser degree in those areas, giving the film a lighter appearance. Less dense materials allow more penetration and correlates to darker areas on the film. Any hole, crack or inclusion that is less dense than the casting alloy is revealed as a dark area [12]. Figure 8(a-c) and 9(a-c) shows the radiography test images for two kinds of products namely gear wheel and connecting rod respectively. These castings were made in sand, slag and mixture of these two moulds. All the components were exposed to radiation and shows full and clear images of the components. Interestingly, no defects were observed in any one of the component.



(a)



(b)

(c)

Figure 8: Radiography testing images of A356 alloy Gear wheel made in: (a) 100% Sand mould (b)100% GBF Slag mould (c) Mixture of 50% GBF Slag+50% Sand mould

(a) (b) (c)

Figure 9: Radiography testing images of A356 alloy Connecting rods made in: (a) 100% Sand mould (b)100% GBF Slag mould (c) Mixture of 50% GBF Slag+50% Sand mould

Conclusions

A356 alloy cast products were investigated for its quality evaluation by non destructive methods; in this investigation Visual inspection, Liquid penetrant, Ultrasonic and Radiographic tests was used. Results reveal that the castings were performed successfully in GBF slag and sand moulds. The cast products show good surface finish with dimensional accuracy. All the four NDE results evident that both sand and slag mould cast products had a sound castings with neither surface, subsurface defects nor internal defects. In case of sand castings few surface and sub surface defects were noticed in LPT and UT. Finally, GBF slag mould lead to produce defect free castings; hence this can be used as moulding material to produce real time components with either simple or complex geometries.

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