Comparison of Mechanical Properties of Zn-27Al Alloy Using Various Casting Techniques

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Abstract. Zinc-aluminium alloys are cost effective substitute for wide range of applications in the industrial purpose mainly as bearing materials. Zn-27 Al is the material selected due to its good mechanical and tribological properties. Casting is one of the methods which can be used to fabricate the alloys. Sand casting and stir casting are used to develop Zn-27 Al alloy. Both mechanical and wear properties were studied. Hardness, tensile strength and impact strength is highest for the stir casted alloy when compared to sand casted Zn-27 Al. The composition of the prepared alloys justifies the better properties of stir casted alloy and the compositions are analysed by Energy Dispersive X-Ray (EDX) analysis.

1. Introduction

The commercial usage of Zinc based cast alloys, commonly referred to as “ZA” alloys, and is now increasing day by day. The common fabricating methods of ZA alloys are sand casting, permanent mould, shell mould, stir casting and high-pressure die casting. These ZA alloys possess better mechanical properties when compared with the conventional zinc die casting alloys and those of cast iron, copper alloys and aluminium. In addition, they have excellent wear resistance, bearing properties and machinability. Advantage of cast properties is low melting energy consumption because of low melting temperatures and hence increased mould stability and die life.

In 1990, Jim Birch found out the possibilities of different casting methods to fabricate the zinc-aluminium alloys like sand casting, gravity die casting and pressure die casting. Zinc-aluminium alloys possess better mechanical properties than aluminium alloys, plastics, copper alloys, cast iron and steel fabrications [1]. The ZA-27 is a high-strength alloy but ZA-12 and ZA-8 alloys are moderate to high strength materials. All the above mentioned alloys can be fabricated using sand cast, pressure die cast and permanent molding [2]. The studies were conducted on the effect of rare earth elements on the Zn-12Al alloy fabricated using sand casting. The rare earth metal used for this purpose is mischmetal. And the impact toughness of the alloy is directly proportional to the mischmetal addition due to the grain size refinement [3]. Manganese also can be added into the Zn-Al alloy. Researchers were conducted on the microstructure and mechanical properties of manganese added Zn-8Al alloy and finally the formation of complex intermetallic compound (MnAl$_6$) [4]. The 2% addition of copper content obtains the highest wear resistance and tensile strength for the monotectoid-based zinc-
aluminium alloys but the hardness is directly proportional to the percentage addition of copper [5]. The garnet reinforced zinc-aluminium alloys shows reduced wear rate than the unreinforced alloys and it exhibits abrasion wear at low loads and delamination wear at high loads [6]. Both fatigue strength and fatigue life increases for the binary zinc-aluminium alloys as the percentage of aluminium increases. But copper addition upto 2% can enhance the fatigue strength of binary zinc-aluminium alloys [7]. The heat treated Zn-27Al has better tribological properties when compared to the as-casted alloys and it is due to the breaking of dendritic structure [8]. Also, studies reveals that the zinc-aluminium alloys without addition of copper and silicon exhibits lower mechanical properties [9]. The wear and electrochemical behaviour of hypereutectic Zn-Al alloys and role of grain microstructure and macrostructure was also studied for the different ranges of Zn-Al alloys (Zn-1Al, Zn-2Al, Zn-3Al and Zn-4Al) [10].

Hence, the present study focus on the mechanical properties (hardness, tensile strength, yield stress and impact strength) of the Zn-27Al alloy fabricated using both stir casting and sand casting techniques.

2. Experimental Procedure

The following section deals with the material selection, fabrication of the alloys, microstructure, mechanical tests and wear tests.

2.1 Selection of materials

Zinc-aluminium alloys possess wide range of applications in the industrial area due to its good mechanical properties such as hardness and tensile strength. Zn-8Al, Zn-12Al, Zn-27Al are the most commonly used binary Zn-Al alloys. The material selected for the present research work is Zn-27Al due to its better mechanical and wear properties.

2.2 Selection of fabrication techniques

Fusion method, electro-deposition method, reduction method and powder metallurgy are the most common methods used for the fabrication of alloys. Fusion method is selected for developing Zn-27Al binary alloy. Sand casting is the conventional method usually uses two piece moulds. Stir casting is an advanced method which uses mechanical stirrer for the uniform distribution of elements.

2.3 Fabrication of alloys

Pure zinc and aluminium are used for developing Zn-27Al using both sand casting and stir casting process.

2.3.1 Sand casting

Figure 1 represents the schematic diagram of sand casting technique. The metals are melted in a furnace at 650 °C. The moulds are prepared using silica sand. Cylindrical die of size Ø 30 mm × 120 mm and impact testing die of size 15 mm × 15 mm × 140 mm are made. The molten metal is allowed to fill the mould and then the alloys are removed after cooling.
Figure 1. Sand casting process

Figure 2. Hardness testing specimen by sand casting process

Figure 3. Tensile testing specimen by sand casting process
Figures 2, 3 and 4 shows the hardness, tensile and impact testing specimens fabricated using sand casting process.

2.3.2 Stir casting

In the stir casting process, the molten metals are distributed by mechanical stirring, and then the molten matrix is poured into the mould. Mechanical stirring is the key element of the stir casting process.

In preparing metal matrix composites by this method, there are some factors need to be considered:

1. The difficulty of achieving a uniform distribution of the metals.
2. Wettability between the two main substances.
3. Porosity in the cast metal matrix.
4. Chemical reactions between the materials.
5. Rate of solidification and relative density.
6. Geometry of the mechanical stirrer.
7. Position of stirrer in the melt, melt temperature

Pure aluminium was bought as ingot and pure zinc as thin sheets. Materials were cut into suitable size to be put into the furnace. The stirring speed and stirring time was set at 350 rpm and 10 minutes respectively. The alloy was melted to 650°C in a graphite crucible. Molten metal was poured into dies of tensile specimen (Ø 14 mm × 140 mm) (figure 7), impact test specimen (15mm x 15mm x 140) (figure 8), hardness testing specimen (Ø 30mm x 140) (figure 6). All these specimens were casted out with a solidification tome of 2hrs. Figure 5 represents the stir casting apparatus.
Figure 5. Stir casting equipment

Figure 6. Hardness testing specimen by stir casting process
2.4. Hardness testing

Hardness of the material is found out using the Brinell indentation hardness principle. This test is conducted according to ASTM E10:2015 standards. The model of the machine is AKB 3000. Loading capacity of the machine is 3000 kgf. The diameter of the indenter chosen was 5mm. Casted material were machined to suitable size (25mm x 27mm). Load of 750 kgf was applied for 10 sec. Hardness was taken on 3 different regions of the specimen. Figure 9 represents the Brinell Hardness Testing Machine.
2.5. Tensile testing

The specimen for tensile test were prepared from the casted alloy having gauge dia 9mm and gauge length of 36mm with overall length of 150mm and is shown in the fig. The specimen was made according to the ASTM E8 standards. The specimen were cleaned before the experiment using emery paper of grit size 200. The machine used for the experiment was UTM M30, where maximum load was limited to be 30kN and maximum elongation to 1000mm. Fillet diameter of the specimen was 15.89 mm. The grips in the testing machine were properly serrated before the commencement of the experiment. Figure 10 shows the tensile testing apparatus.
2.6. Impact testing

Charpy pendulum impact tests were carried out on the cast samples to have comparative impact properties of the stir and sand castings. The impact test is done by placing a square shaped V-notched specimen in the machine (placed as cantilever beam). The specimens have V-shaped notch of 45°. The notch is located on tension side of specimen during impact loading. Depth of notch is generally taken as $t/5$ to $t/3$ where ‘$t’$ is thickness of the specimen. The V-notched impact test standard specimens with dimensions of (10mm X 10mm X 55 mm) were made according to ASTM-A370. Model of the machine used was AIT-300-EN. Capacity of the machine was 300 J. The test was conducted at room temperature (25.3 ºC). Schematic diagram of the impact testing apparatus is shown in figure 11.
3. Results and Discussions
This section deals with the comparison of mechanical properties (hardness, tensile and impact) and microstructure of the alloy prepared using both sand casting and stir casting process. Also, the Energy Dispersive X- Ray Analysis (EDX) comparison is discussed in this section.

3.1. Brinell hardness testing
Table 1 depicts the comparison of Brinell hardness of the alloy prepared using both stir casting and sand casting process. Figure 12 depicts the graphical representation of the comparison of the Brinell hardness values.

| Process   | Alloy  | Observed Value | Average |
|-----------|--------|----------------|---------|
|           | HBW 5/750 | 1 | 2 | 3 | value HBW 5/750 |
| Sand casting | Zn-27Al | 114 | 114 | 116 | 115 |
| Stir casting | Zn-27Al | 156 | 143 | 143 | 147 |

Figure. 12. Comparison of Brinell Hardness

From the graph, it is clear that the stir casted alloy possess better hardness property when compared to sand casted alloy. This is because of the better distribution of materials when using stir casting process. The aluminium particles are properly mixed with the zinc matrix because of mechanical stirring process. The better mixing property of stir casted alloy is validated using EDX analysis.

3.2. Tensile testing
The comparison of tensile strength and yield stress is shown using table 2. Figure 13 and figure 14 represents the tensile strength plot and yield strength plot respectively.
Table 2. Comparison of tensile and yield strength

| Process      | Yield strength (N/mm$^2$) | Tensile strength (N/mm$^2$) |
|--------------|---------------------------|-----------------------------|
| Sand casting | 195.8                     | 225.0                       |
| Stir casting | 143.2                     | 194.2                       |

Figure 13. Comparison of Tensile strength

Figure 14. Comparison of Yield strength

3.3. Impact testing

The impact strength in terms of energy (J) of the specimen was found out by Charpy test and the values were recorded of both the castings (Table 3 and Figure 15).
Table 3. Impact strength variation comparison

| Process       | Specimen Temperature (°C) | Thick (mm) | Width (mm) | Length (mm) | Charpy Impact Energy (Joules) |
|---------------|---------------------------|------------|------------|-------------|-------------------------------|
| Sand casting  | 25.3                      | 10.01      | 10.00      | 55          | 1.68                          |
| Stir casting  | 25.3                      | 10.01      | 10.00      | 55          | 2.0                           |

Figure. 15. Comparison of Impact strength

3.4. Microstructure analysis

Figures 16 and 17 represent the microstructure analysis of sand casted specimen and stir casted specimen, respectively. From figure 16, the stir casted alloy specimen has the uniform distribution of zinc-aluminium matrix and the alloy distributions of elements are justified using EDX analysis.
3.5. *EDX analysis*

Figure 18 and 19 shows the EDX analysis of both sand casted and stir casted alloy respectively.
From the figures and tables, it is clear that the percentage of zinc (63.25%) an aluminium (31.20%) is more when the alloys are fabricated using the stir casting process. In sand casted alloys, the percentage quantity of zinc and aluminium is 53.61% and 29.12% respectively. Hence the mixing property or uniform distribution of elements in the stir casted alloy enhances the mechanical properties of alloys.
4. Conclusions

- Zn-27 Al alloy is fabricated using sand casting and stir casting techniques successfully.
- Stir casted Zn-27Al possess better hardness, tensile strength and impact strength when compared with sand casted alloy due to the better distribution of elements in stir casted specimen.
- The proper mixing of the elements in the stir casted alloy is justified using EDX analysis.

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