12th GLOBAL CONGRESS ON MANUFACTURING AND MANAGEMENT, GCMM 2014

The Effect of Heat Treatment and Aging Process on Microstructure and Mechanical Properties of A356 Aluminium Alloy Sections in Casting

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Abstract

Aluminium A356 alloy is widely used at automobile and aircraft industries in the form of cast component with varying section size. This study investigates how the microstructure and mechanical properties of different section size vary before and after heat treatment and aging processes. Aluminium ingot is melted using a furnace and poured into the mold having mold cavities of varying dimensions. Cast components are heat treated as per ASTM standard B917-01 at a temperature of 537°C for 12 hours followed by a temperature of 155º for 5 hours. In order to investigate the effect of heat treatment and aging processes microstructure and mechanical properties such as impact strength, hardness, and tensile strength were analysed as-cast condition and after heat treatment and aging process.

Keywords: Aluminium A356 alloy, microstructure, impact strength, hardness, tensile strength, metal casting, heat treatment, and aging.

1. Introduction

Cast A356 aluminum alloy is widely used in automotive and aircraft industries because of their excellent properties like high strength to weight ratio, low density, high corrosion rates etc. This increased use of A356 aluminum alloy leads to a need for deeper understanding of their mechanical properties and the impacts of
processing factors [1-2, 4]. The mechanical properties can determine by controlling the microstructures of the alloys. For designing any part we should have a thorough understanding of solidifications at different cross sections of the cast part and its influence on the mechanical properties [5-6, 3]. Most applications of A356 alloy dependent on mechanical properties, so the performance of this alloy has been the subject of many micro-mechanical investigations. Mechanical properties were improved with grain refinement. Since the mechanical properties are mainly dependent on their microstructure, a lot of efforts have been done for refining microstructure of casting to improve the mechanical properties of aluminum alloy A356. Refinement can achieve by using power ultrasound and electromagnetic stirring and equal channel angular pressing, or accumulative roll bonding. As-cast A356 alloys are made up of coarse primary $\alpha$-Al dendrites and acicular-shaped eutectic silicon, which lowers the mechanical properties and limits its industry application. Heat treatment and aging are important to homogenize $\alpha$-Al dendrites in aluminum alloys so we can achieve better mechanical properties. Cooling rate of mold is measured by introducing a thermocouple inside the mold [7-8]. Heat treatment and aging processes are the most important processes determining casting microstructure and mechanical properties [1-2, 11-12]. As-cast A356 alloys are made up of coarse primary $\alpha$-Al dendrites and acicular-shaped eutectic silicon, which lowers the mechanical properties and limits its industry application. The mechanical properties can determine by controlling the microstructures of the alloys [9-10]. Heat treatment and aging are important processes to homogenize $\alpha$-Al dendrites in aluminum alloys [11].

2. Experimental method

Experimental apparatus consisting of four green sand molds with mold cavities of 20 mm, 40 mm, 60 mm, 80 mm diameters (section sizes). A356 aluminum alloy is melted using muffle furnace and poured to the molds. Thermocouple tip is placed 1 mm apart from mold cavity in order to avoid damage of contact tip and temperature is monitored till there is a decrease in temperature after an initial increment. Temperature is measured using a K type thermocouple. Temperature-Time graph were plotted for all experiments and cooling rate for each sections were measured. Cast specimens were heat treated to ASTM standard B917-01 at a temperature of 537°C for 12 hours and followed by an aging of 5 hours.

3. Testing

In order to investigate the effect of heat treatment and aging process on microstructure and mechanical properties, impact strength, hardness and tensile strength were measured for as-cast condition, heat treated and aged condition. Specimens were prepared for microstructural analysis by polishing on disc polisher followed etching with diluted hydrofluoric acid. Microstructural analysis was performed by an inverted metallurgical microscope and the microstructures were compared. Average grain size is measured using Metal Vision software. Cast specimens were machined to ASTM standard E23-12C, 10 mm*10 mm*75 mm for Izod test and 10 mm*10 mm*55 mm for Charpy test. Using an impact testing machine model IT30 both impact tests Izod test and Charpy test were performed for as cast condition and heat treated and aged condition. Cast specimens were machined to ASTM standard E8M with a gauge length of 45 mm and gauge diameter of 9 mm for tensile test. Tensile test were performed on universal tensile testing equipment and ultimate tensile stress value for as-cast condition and after heat treated and aged condition were compared. Hardness test were performed with Vickers hardness tester by applying a load of 100 kgf for 20 second both as cast condition and after heat treated condition. All tests were repeated 5 times in both as-cast and aged and heat treated condition.

4. Results and discussion

4.1. Effect of section size on cooling rate

Fig. 1 shows cooling curves of cast specimens of varying section size. Time taken to decrease in temperature for 20 mm, 40 mm, 60 mm, 80 mm, sections were 15 minutes, 22 minutes, 27 minutes, 31 minutes respectively. Cooling rates are measured from the graph and found to be 4°C/minute, 3°C/minute, 2°C/minute and 1°C/minute for
20 mm, 40 mm, 60 mm, and 80 mm sections respectively. From the graph it is found that increasing the section size lead to reduction of cooling rate or increase in solidification time.

![Cooling Curves of cast components with varying section size](image)

**Fig. 1.** Cooling Curves of cast components with varying section size

### 4.2. Microstructure evaluation

![Change in microstructure of as-cast specimens with variation in section size](image)

**Fig. 2.** Change in microstructure of as-cast specimens with variation in section size (Magnification 200X)

(a) 20 mm, (b) 40 mm, (c) 60 mm, (d) 80 mm

Fig. 2 shows change in microstructure of as-cast specimens with variation in section size and Fig 3 shows changes in microstructure of heat treated and aged cast specimens. As-cast condition microstructure is found fine for small section size and coarse for large section size this is due to grain refinement of smaller section size caused by fast cooling rate. Microstructure is found much refined and uniform in all section size for heat treated and aged condition. Fig. 4 shows as-cast, heat treated and aged conditions Grain size variation with section size. As-cast condition average grain size was found to be 0.82 microns, 0.94 microns, 1.4 microns, 1.8 microns for 20 mm, 40
mm, 60 mm, 80 mm sections respectively. It shows an increase in average grain size with increasing section size due to reduction in cooling rate. Average grain size for heat treated and aged condition was found to be 0.52 microns, 0.59 microns, 0.56 microns, 0.58 microns for 20 mm, 40 mm, 60 mm, 80 mm sections respectively. At heat treated and aged condition average grain size is much less compared to as-cast condition but it is almost constant with variation in section size.

Fig. 3. Changes in microstructure of heat treated and aged cast specimens with variation in section size (Magnification 200X)

(a) 20 mm, (b) 40 mm, (c) 60 mm, (d) 80 mm

Fig. 4. Variation in Grain size with section size.
4.3. Impact test evaluation

Fig. 5 shows as-cast, heat treated and aged conditions impact strength variation with section size. As-cast condition impact strength in Charpy test is found 67.42 KJ/m², 60.22 KJ/m², 55.43 KJ/m², 48.31 KJ/m² for 20 mm, 40 mm, 60 mm, 80 mm size having sections and Impact strength in Izod test is found 69.61 KJ/m², 62.28 KJ/m², 54.96 KJ/m², 47.63 KJ/m² for the same section respectively. It indicates that as-cast condition impact strength increase with reduction in section size. This is due to grain refinement in smaller section size caused by fast cooling rate. Heat treated and aged condition impact strength in Charpy test is found 114.0 KJ/m², 109.0 KJ/m², 111.57 KJ/m², 116.5 KJ/m² for 20 mm, 40 mm, 60 mm, 80 mm size having sections and Impact strength in Izod test is found 113.5 KJ/m², 109.8 KJ/m², 113.5 KJ/m², 106.12 KJ/m² for the same section respectively. Impact strength at heat treated and aged conditions were improved comparing as cast condition but it is almost constant with variation in section size. This is due to much higher grain refinement in heat treated and aged condition irrespective to section size.

4.4. Tensile test evaluation

Fig. 6 shows as-cast, heat treated and aged conditions Ultimate Tensile Stress of all cast sections. As-cast condition Ultimate Tensile Stress is found 145.4 MPa, 142.9 MPa, 70.4 MPa, 60.1 MPa for 20 mm, 40 mm, 60 mm, 80 mm size sections respectively. It is found that as-cast condition Ultimate Tensile Stress is increased with reduction in cast component section size. This is due to grain refinement in smaller section size caused by fast cooling rate. Heat treated and aged condition Ultimate Tensile Stress is found 263.5 MPa, 269.3 MPa, 265.2 MPa, 258.1 MPa for 20 mm, 40 mm, 60 mm, 80 mm size sections respectively. Ultimate tensile strength at heat treated and aged condition was improved compared to as-cast condition but it is almost constant with variation in section size. This is due to much higher grain refinement in heat treated and aged condition irrespective to section size.
4.5. Hardness test evaluation

Fig. 7 shows as-cast, heat treated and aged conditions hardness of all sections. As-cast condition Micro hardness is found 82.6 HV, 78.3 HV, 75.2 HV, 70.4 HV for 20 mm, 40 mm, 60 mm, and 80 mm size having sections respectively. It indicates that Micro hardness of as-cast components increases as section size decreases. This is due to grain refinement in smaller section size caused by fast cooling rate. Heat treated and aged condition hardness is found 112.6 HV, 122.6 HV, 117.5 HV, 114.2 HV for 20 mm, 40 mm, 60 mm, and 80 mm size having sections respectively. Heat treated and aged condition hardness was improved compared to as-cast condition but it is almost constant with variation in section size. This is due to much higher grain refinement in heat treated and aged condition irrespective to section size.
5. Conclusion

As-cast condition Mechanical properties such as impact strength from 48.31 KJ/m² to 67.42 KJ/m², Ultimate Tensile Stress from 60.1 MPa to 145.4 MPa, Hardness from 70.4 HV to 82.6 HV were increased with decreasing section size from 80 mm to 20 mm due to grain refinement. Heat treated and aged condition mechanical properties such as impact strength, ultimate tensile stress, hardness were further improved but it is almost constant with variation in section size. This is due to further grain refinement in heat treated and aged sections irrespective to section size.

References