Impact of Chromium Addition on the Mechanical Properties of A356 Alloy

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ABSTRACT

A significant problem in the modern day automotive and aerospace industries is to manufacture more fuel-efficient components to reduce energy usage. A356 is a material that could meet the demand for an automotive industry in the manufacturing of machine components because of their high strength-to-weight ratio, high toughness and good cast ability. However the existing properties of A356 alloy can be improved by blending it with additive elements in order to meet the modern requirements of various industries. Chromium is selected for the alloying process because of its increased resistance to oxidation at high temperature and higher wear resistance. The project deals with the fabrication of A356 alloy blended with Chromium particles and the determination of impact strength, hardness, and tensile strength of the fabricated alloy. The compositions of 0.15 wt. % Cr, 0.17 wt. % Cr and 0.20 wt. % Cr with A356 are taken for conducting the experiment. The stir casting method is the most suitable method for mixing the chromium particles into the metal matrix. It is a liquid-phase fabrication method that uses mechanical agitation approach to produce the required alloy. Impact testing and hardness testing are to be conducted on the specimen by using Charpy method and Rockwell hardness tester respectively. The tensile strength of the alloy can be analyzed with the help of a universal testing machine (UTM). The results are compared with the existing properties of A356 to analyze the improvements in mechanical properties.

Keywords: A356 alloy, Stir casting, Chromium

1 Introduction

Aluminium is one of the most abundantly available metals on earth having many unique properties which enables its usage in various industrial sectors. Addition of alloying elements could enhance its natural properties. Today plenty of aluminium alloys are available on the market out of which aluminium 356 (A356) alloy is one of the most important alloy. A356 alloy has a density that is around one third that of steel, which is lower than that of most common metals. High toughness, strong corrosion resistance, high toughness, and good castability are additional characteristics. Because of all these properties it has been greatly used as a sustainable replacement for cast iron in modern automobile and aviation industries. Car body frames, aircraft wings, wheels, suspension parts, bumpers are some of the potential applications of this alloy. However, as the modern industries are advancing at a rapid rate the requirements are also high. Therefore, the existing properties of aluminium Silicon alloy can be improved by the addition of Chromium particles.

Chromium is one of the most important alloying elements and is the seventh most abundant element on earth. It is selected because of its increased resistance to oxidation at high temperature and promotes the formation of ferritic microstructure [2]. There are three main types of chromium: metallic chromium (Cr 0), hexavalent chromium (Cr VI), and trivalent chromium (Cr III). The most stable forms of chromium that are now accessible are thought to be Cr (III) and Cr (VI). Its carbide strengthens the edge-holding characteristic and limits the dislocation motion, especially at high temperatures, as strong carbide formers

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[1]. Another important property that leads to the selection of chromium is its wear resistance. It improves cutting performance of alloys due to the formation of wear resistant carbides.

The mixing process is carried out with the help of Stir casting technique. It is the liquid-phase composite fabrication process in which ceramic particles or the alloying elements are mixed with metal using the mechanical agitation approach. Majority of Aluminium alloys are fabricated with this technique as they are relatively cheaper, flexible and economical than other methods. This technique can also be utilized to produce alloys of large volume and size. Stir casting experimental setup consist of a graphite crucible, furnace, stirrer, motor, feeder and the mold. The base metal is melted in the graphite crucible and the alloying elements are added to it with the help of feeder after preheating. The process requires strong agitation for proper mixing of the matrix mixture hence the stirrer is used which is usually coupled with a motor. The prepared alloy is obtained by employing the use of a mould after solidification process. The aluminium melt surface is exposed to the air throughout the casting process, which tends to continuously oxidise the melt. The wettability of the aluminium decreases as a result of ongoing oxidation, and the reinforcement particles do not combine. An inert environment must be produced in order to entirely stop the oxidation.

Addition of wetting agents such as TiK_2F_6, borax and magnesium are commonly used for this purpose. Use of protective elements like Argon gas is required to shield the direct contact between air and metal matrix to avoid possible oxidation and other reactions. Hexachloroethane is used as the degassing agent in the fabrication of the alloy. Other than oxidation, obtaining homogenous dispersion of particles in the melt is a challenge in the stir casting process. In order to homogenize the metal matrix, the casting parameters are crucial. The primary variables are the speed and duration of the stirring process, as well as the size, location, and angle of the impeller blades [6]. Therefore, while creating an aluminium alloy, choosing the right characteristics is crucial.

2 Materials Used

2.1 A356 Alloy

Base materials are the primary or underlying material on which additives are applied in order to obtain materials of desired properties. It is usually an inexpensive and more abundantly available compared to other materials. Aluminium is one of the most important base materials that is commonly used in the alloy fabrication process. A variety of aluminium grades are available in the market but A356 alloy is the most commonly used alloy in different industrial applications. Due to its ease of fabrication the alloy is extensively used in automotive transmission cases, aircraft fittings and pump impellers. The physical properties of A356 are listed in table 1. The mechanical properties of A356 alloy were greatly improved by the use of additives as reported by K Logesh [3] as they caused grain refinement. A356 is selected as the base material for the fabrication process because of its good cast ability, high fluidity, low density and availability. The physical properties of the alloy are listed in table 1.

Table 1: *Physical properties of A356*

Property	**Values**
Melting point, °C	750
Boiling point, °C	2425
Density, kg/cm^3	2.67
Crystal structure	FCC

2.2 Chromium Powder

Additives are pure metal constituents added to a melt to change or enhance certain characteristics of the base material. The inclusion of additives can change many properties ranging from strength to color to thermal conductivity. Use of additives can result in the fabrication of parts much easier and often improve the lifespan of cast products. Cobalt, Nickel Scandium Chromium and Zirconium are some important additives used in alloy fabrication. Out of this Chromium is selected as the additive material to improve the properties of A356 alloy. As reported by R Ahmed [4] presence of small quantities of chromium developed a protective coating over the aluminium due to the formation of intermetallic phases in the matrix material. The selection criteria were based on the high solubility of chromium in aluminium matrix and due to the enhancement of corrosion resistance property of aluminium alloy. The physical properties of Chromium are mentioned in table 2. Significant improvements in mechanical properties of aluminium alloy were also reported by B Joseph [5] with the addition of small traces of chromium powder.

Table 2: *Physical properties of chromium*

Property	**Value**
Melting point, °c	1857
Boiling point, °c	2672
Density, kg/cm^3	7.18
Crystal structure	BCC

3 Methodology

Stir Casting is a liquid state metallurgical process in which reinforcing components are incorporated into the molten matrix before the mixture solidifies. Here, proper wetting between the reinforcements and the molten aluminium or aluminium alloy is crucial; this is accomplished using the simplest and most often used approach, also known as the vortex technique or stir-casting technique [7]. The vortex technique was utilized to minimize gravitational segregation in the crucible by adding pre-treated ceramic particles to the vortex of molten aluminium alloy created by the revolving impeller.

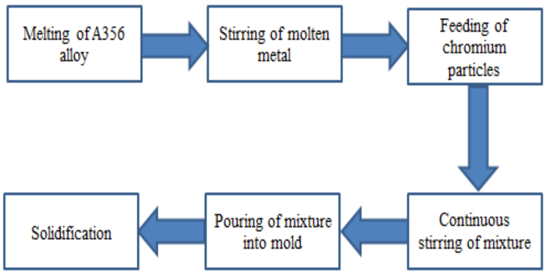

Figure 1: *Steps in stir casting*

The whole process involved in the fabrication is illustrated with the help of figure1. Stir casting technique is to be utilized for the fabrication. The process is primarily used to provide uniform reinforcing material distribution, establish wet ability between the two primary substances, and reduce porosity in the matrix of the cast metal. The experimental apparatus is illustrated in figure 2.

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Figure 2: *The experimental apparatus*

An electric resistance furnace is to be used for the melting process. A graphite crucible, a stirrer rod, a feeder unit, a temperature controller, and a mould for pouring molten matrix material make up the device. The ingredients are heated and melted in the furnace. A feeder unit is used to introduce the reinforcing material into the melt, and the mechanical stirrer is used to generate the vortex that causes the material to mix properly. The stirring rod and the impeller blade make up a stirrer. Typically, graphite is used to make the mechanical stirrer rod. The shape and number of blades of the impeller blade might vary. This stirrer is attached to motors with variable speeds, and the motor's regulator controls the stirrer's rotational speed.
The base metal that is A356 is melted in the furnace at a temperature of 800 °C. The furnace must be firstly preheated to remove the presence of moisture content and other impurities if present. At the same time the filler material that is Chromium is preheated in the feeder to remove the presence of moisture content if present. After attaining the desired temperature Chromium particles are added to the base matrix and are stirred properly for uniform distribution. The matrix requires strong stirring and it is attained by using a mechanical stirrer which is usually made with graphite material. Addition of protective elements like Argon gas is required to shield the direct contact between air and metal matrix to avoid possible oxidation and other reactions. Finally the molten mixture is poured onto a permanent mould and is allowed to solidify. By doing so alloy variations with different composition of Chromium can be prepared.

3.1 Mould

The mould used for the casting is shown in figure 3. After the melting of metal matrix it is then poured onto a permanent mould for the solidification process. Mould having a dimension of 240×200×30 mm is selected for the purpose. The pouring temperature is maintained at 750 ⁰C. Mould was preheated for 15 to 20 min and then both the faces of the mould were clamped together and were held together tightly.

Figure 3: *Mould*

3.2 Preheater

Figure 4: *Preheater*

Preheater as shown in figure 4 is the device used to heat the mould prior to pouring of metal matrix. It is done to remove the impurities and moisture content, whose presence would cause defects to the final casted alloy. The preheating temperature is maintained as 350 ºC.

4 Parameters Used

4.1 Stirring Speed

Stirring speed is speed at which the stirring action is to be done. It is responsible for dispersion of Chromium particles in liquid metal. The stirring process is done by using a stirrer rod coupled with a motor. The optimum stirring speed is considered between 500- 650 rpm.

4.2 Stirring Time

In the manufacture of A356 alloy, stirring time is an important factor. Less churning results in an uneven dispersion of particles, while too much swirling can cause Chromium to cluster in particular areas. The ideal stirring period is set between 5 to 15 minutes.

4.3 Stirring Temperature

The selection of stirring temperature is very important as it is responsible for the complete melting of metal matrix. The alloy of desired properties can only be obtained once the metals are completely melted. A stirring temperature of 720°C is necessary to perform the casting process.

4.4 Preheating Temperature

A constant pouring rate along with a high pouring temperature should be kept to enhance casting quality and prevent gas entrapment. A greater pouring temperature would result in less porosity in the composite and better-distributed absorption of reinforcing particles.

4.5 Degassing

An oxide layer will form at the top of the melt as the aluminium and begins to react with the oxygen in the air. Although this oxide layer will prevent additional oxidation, breaking through it will be challenging.

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Therefore, mixing reinforcement with metal will be very difficult with such a layer. So it seems prudent to use a degassing agent to prevent this [8]. Hexachloroethane is used as the degassing agent.

5 Result And Discussion

5.1 Tensile Test

The tensile testing of the specimen is to be conducted in Universal Testing Machine. The test is run to gather data on how a given material responds to gradually increasing stress and strain conditions. The device to be utilized is the Linux Universal Testing Machine UTM 100, which has a 1000N capacity. It calculates the amount of strain or elongation that the specimen must undergo to reach its breaking point. Figure 5 comprises of the specimen prepared for conducting the tensile test. As the alloy finds use in numerous industrial areas needing high strength, the amount of load or stress that the material can withstand before failing must be assessed using a tensile test. In order to evaluate the safety of components, it is crucial to determine the tensile strength of a material.

Table 3: *Tensile test results*

Sl.No	Sample	Tensile Strength (MPa)
1.	A356	185
2.	A356+0.15 Wt % Cr	196.33
3.	A356+0.17 Wt % Cr	200.37
4.	A356+0.20 Wt % Cr	238.5

Figure 5: *Tensile test Specimen*

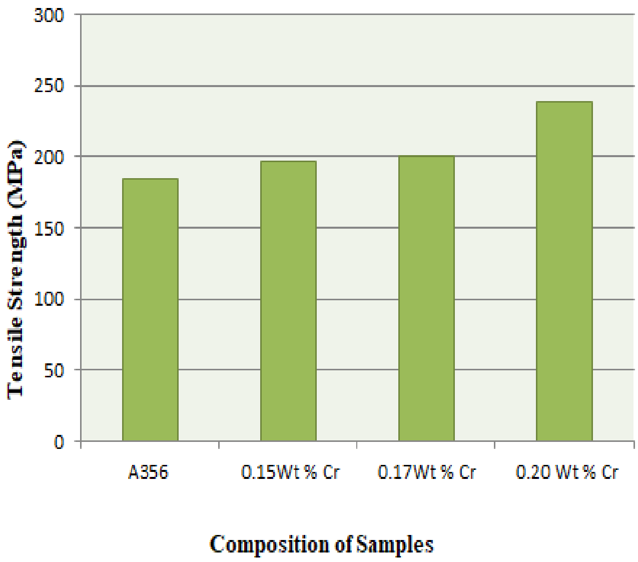

Figure 6: *Tensile test results*

The results in table 3 revealed that the sample with 0.20 Wt % of Cr had maximum tensile strength of 238.5 MPa and the Chromium addition has significantly improved the tensile nature of the samples. Figure 6 reveals the tensile test results.

5.2 Hardness Test

Hardness is the measurement of the resistance of a metal to plastic deformation. A Rockwell hardness tester is required for hardness testing. The test technique entails using a diamond cone or hardened steel ball indenter to make an impression in the test material. The test specimens are shown in figure 7. The indenter is inserted deeply into the specimen by first applying a little load to create a zero reference location and then a big load for a predetermined amount of time. The minor load remains in the sample after the discharge of the major load. The hardness number is derived by the application and removal of the additional significant load, which results in a permanent increase in the depth of penetration. The materials ability to resist surface deformations is directly associated with hardness. Hence it is essential to undertake hardness test on the fabricated samples to evaluate the degree of wear and tear on the surface.

Table 4: *Rockwell hardness test results*

Sl.No	Sample	Hardness (RHN)	
		Ball	Cone
1.	A356	37	55
2.	A356+0.15 Wt % Cr	46	61
3.	A356+0.17 Wt % Cr	48	64
4.	A356+0.20 Wt % Cr	52	67

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From table 4 it is inferred that the sample with 0.20 Wt% Cr possessed the highest hardness for both ball and cone intenders having a value of 52 and 67 respectively. Figure 8 shows the Rockwell hardness values of both intenders for each sample.

Figure 7: *Hardness test Specimen*

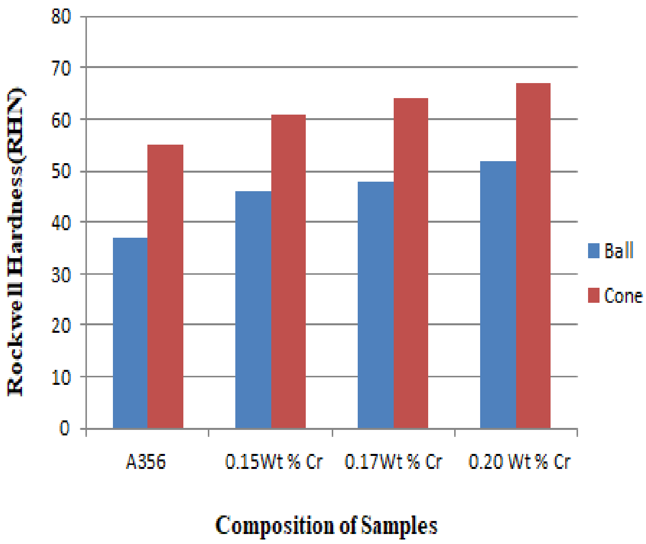

Figure 8: *Hardness test results*

5.3 Impact Test

The impact strength of a material is its ability to resist a suddenly applied load. The Charpy impact test is conducted to analyze the impact strength of each specimen. The test determines the amount of energy absorbed by a material during fracture. Samples of dimensions 55×10×10 mm with a v notch exactly at the center are to be prepared to conduct the impact test as shown in figure 9. The test is done to analyze the toughness of prepared samples as they find extensive application in automotive components and other casted parts requiring high strength.

Table 5: *Impact test results*

Sl. No	Sample	Impact Strength (J)
1.	A356	45
2.	A356+0.15 Wt % Cr	56

3.	A356+0.17 Wt % Cr	52
4.	A356+0.20 Wt % Cr	38

Figure 9: *Impact test Specimen*

The impact strength results are concluded in table 5 and the Charpy impact test revealed that there is a decrement on impact strength of samples on increasing the Chromium content in A356 alloy. This may arise due to the presence of porosity in the castings this is depicted in Figure 10.

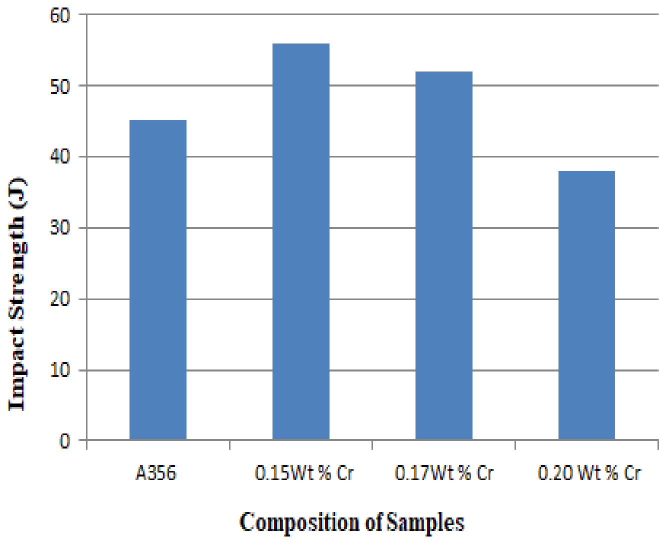

Figure 10: *Impact test results*

6 Conclusions

Samples with varying percentage of Chromium were prepared and the following conclusions were drawn out from the test results

- Highest tensile strength of 238.5 MPa was obtained for sample with 0.20 Wt % Cr.
- Sample with 0.20 Wt% Cr had the highest hardness value of 52 RHN for ball intender and 67 RHN for cone intender.
- Highest impact strength was obtained for sample having 0.15 Wt % Cr and lowest values was recorded for 0.20 Wt % Cr.
- The decrease in impact strength of the samples was caused by the presence of porosity.

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7 Declarations

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