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EFFECT OF STRONTIUM ON Al9Si ALLOY WITH COPPER AND NICKEL FOR AUTOMOTIVE PARTS

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Abstract - *In recent years, high fuel efficiency in the automotive industry has been required because of environmental issues. To achieve this, a reduction in exhaust gases, such as carbon dioxide and nitrogen oxide, is required, Automobiles consist of a parts, which have been made using cast iron and steel. It is expected that Fe-based automotive parts will eventually all be replaced with more lightweight metals, e.g., aluminum alloys. The specific weight of Fe is approximately 7.8 g/cm3, which is more than 2.8 times higher than that for Al. Recently, the number of automotive parts made of Al alloy has increased. The objective of the present work is to prepare an alloy by adding silicon, copper, nickel and strontium in to Al9Si alloy by stir casting method. The effect of weight percentages of Sr on the mechanical and microstructure properties is also studied by varying weight percentage of strontium from 0.01% to 0.03% and 7%Cu and 1%Ni. Stir casting is usually carried out. The mechanical characteristics such as hardness, tensile strength and wear test are determined and microstructural evaluation is done. The study revealed that hardness, tensile strength increases with the addition of copper, nickel and strontium and wear rate decreases. Microstructural evaluation revealed that the plate like structure of silicon particle of Al9Si alloy transformed in to fibrous form with increased addition of strontium. The Sr modification can improve the ductility, fracture and impact properties*

***Key Words*: Al9Si alloy, Stir Casting, Strontium**

1. INTRODUCTION

All alloys are light in weight, yet some have strengths greater than that of structural steel. The majority of alloys are highly durable, and no colored salts are formed to stain adjacent surfaces or discolors products with which they come in contact, as they have no toxic reaction. Aluminium and most of its alloys have good electrical and thermal conductivities and high reflectivity to both heat and light. Aluminium and most of its alloys can easily be worked into any form and readily accept a wide variety of surface finishes. Light weight is perhaps aluminium's best know characteristic having a density of approx. 2.7 x 103 kilograms per cubic meter at 20'C as compared with 7.9 x 10^3 for iron and 8.9 x 10^3 for copper. Commercially pure aluminium has a tensile strength of about 90 mega Pascals. Its usefulness as a structural material in this form is thus somewhat limited. However, by working the metal, as by cold rolling, its strength con be approximately doubled, Much larger increases in strength con be obtained by alloying aluminium with small percentages of one or more other metals such as manganese, silicon, copper, magnesium or zinc.

Aluminium has a high resistance to corrosion on surfaces exposed to the atmosphere. A thin transparent oxide skin forms immediately and protects the metal from further oxidation. Unless exposed to some substance or condition, which destroys this protective oxide coating, the metal remains protected against corrosion. Aluminium is highly resistant to weathering, even in industrial atmospheres that often corrode other metals. It general direct contact with alkaline substances should be avoided as these attack the oxide skin and ore therefore corrosive to aluminium. Some alloys are less resistant to is also corrosion-resistant to attack by many acids, but general direct contact with alkaline substances should be avoided as these attack the oxide skin and ore therefore corrosive to aluminium. Some alloys are less resistant to corrosion than others, particularly certain high-strength alloys. In accordance with sound design principles, direct contact with certain other metals should be avoided in the presence of an electrolyte, as galvanic corrosion of the aluminium may take place in the vicinity of the contact area. The fact that aluminium is non-toxic was discovered in the early days of the industry. It is this characteristic, which enables the metal to be used in cooking utensils without any harmful effect on the body and today a great deal of aluminium equipment is used by food processing industries. The same characteristic permits aluminium foil wrapping to be used safely in direct contact with food product.

Al–Si– Cu-based cast aluminium alloys have high mechanical properties and good castability, so these alloys have been used for automotive parts with complicated shapes, e.g., cylinder blocks, transmission cases, and converter housings. No extensive research has been performed with the addition of two transition elements (Ni and Cu) and one alkaline earth element (Sr) together in a as-cast alloy to maximize mechanical properties of Al9Si alloys. Al9Si alloys have good castability, and these alloys are employed for frames and front panels. Al9Si alloys have good castability, and these alloys are employed for frames and front panels. The silicon particle morphology can be controlled by the addition of strontium containing master alloy to the melt. The addition of Strontium results in a fine and fibrous silicon structure during solidification. The Strontium modification may improve the ductility, fracture, and impact properties. The Sr addition can reduce the rejection rate and improves the casting quality. Approximately 00.03% of Sr will refine platelets into fibrous form

2. LITERATURE REVIEW

Aluminium and its alloys as lightweight structural materials have been in widespread use, and their commercial applications continue to increase. Especially in the automotive industry, Al–Si–Cu alloy is one of the most widely used material because of its moderate properties and relatively low cost. For further expansion of aluminium usage to the area where heavy dynamic loading is required in vehicles, as-cast aluminium alloys with improved properties and their corresponding manufacturing processes become essential. Previous studies have indicated that the transition metal elements as copper (Cu) and nickel (Ni) are found to be effective for improvement of mechanical properties of Al–Si alloy at elevated temperature [1–3].

Studies on Ni-containing aluminium alloys indicated that the Ni presence enabled many complex intermetallic phases to form including Al2Cu, Al3Ni, Al7Cu4Ni, Al9FeNi and Al5Cu2Mg8Si6 in aluminium alloys. The Al3Ni, Al3CuNi and Al7Cu4Ni phases were found having great contribution to the elevated-temperature properties of Al–Si alloy [4–6]. Also, it has been indicated that the eutectic silicon phases affected the mechanical properties of Al-Si alloys significantly.

Since the Si phase is hard and brittle, the coarse Si eutectic reduces mechanical properties of A–Si–Cu alloys [7, 8]. To enhance the strengths of Al–Si alloys, the needle shaped eutectic silicon has to be modified. Alkali element, sodium (Na), alkaline earth element, strontium (Sr), and metalloid, antimony (Sb), were found to affect the nucleation and growth processes of eutectic silicon crystals effectively in Al–Si alloys.

Among the three, Sr is by far the most efficient and effective modifier due to the handling difficulty of sodium and the toxicity of the antimony. Sr was demonstrated to be capable of effectively modifying the morphology of eutectic silicon from acicular (plate or needle-like) to fibrous form despite that Sr addition might coarsened the primary silicon in hypoeutectic Al–Si alloys. The results of mechanical properties showed that Sr modification enhanced tensile properties of both hypereutectic and hypoeutectic properties significantly [9– 17]. Up to date, however, no extensive research has been performed with the addition of two transition elements (Ni and Cu) and one alkaline earth element (Sr) together in as-cast alloy to maximize mechanical properties of Al–Si alloys.

3 ALLOY PREPARATION

The first step in the experimental procedure is casting of required alloys. For casting first, the alloys should be prepared by measuring its weights cleaning etc. The following ingots were used for preparation of the alloys required for experiments

a) Aluminium block
b) Si powder
c) Cu powder
d) Ni powder
e) Sr powder

The following equipment and tools were used for melting the alloy and making castings

a) Electrical induction furnace for melting.
b) Pre heater for heat treatment.
c) Oven for ageing heat treatment.
d) Thermocouple and temperature indicator (0-1200°C)
e) Clay bonded graphite crucibles
f) Graphite plunger.
g) Tongs, skimmers, ladle etc. made of mild steel.

Fig 3.1; Ingot

3.1. PREHEATING OF MOULD AND INGOTS

Ingots are preheated by keeping it upon the induction furnace. Plate mould were preheated to a temperature of 250^0C in the preheating oven. Preheating of stir cast die was carried out using heat extracted from melt of scrap metal. The preheating furnace is shown in figure 3.2

Fig 3.2; Preheating Furnace

3.2 FURNACE

Electrically operated induction furnace was used to melt the alloy. The heat is transferred to the metal through convection and radiation. When the crucible kept in the furnace attains 700 to 750°C, the preheated ingots were charged into the crucible. The temperature of the melt was measured and monitored using thermocouple.

Fig 3.3; Stir casting

3.3 POURING OF METAL

The molten metal was poured into the moulds at 710°C. Then the melt was allowed to solidify. After solidification the casting is removed from the mould.

5.4 CASTING PROCEDURE

The Al ingots used for casting, is preheated to a temperature of 250^0C for avoiding moisture. Then moulds are place on wise. The furnace (Induction type) was switched on and the crucible containing Al ingots was placed into furnace. The tongs and skimmer are kept above the furnace for preheating. The remaining alloy (other than master alloy) is in powder form.

When the temperature of the melt reached around 700^0C. Then stirring is started with the help of crucible and remaining alloy according to the required wt% was added. Then crucible containing Al alloy again heated to 5-10min.Then the crucible is taken out and slag is removed by using skimmer. Then with in 5min the melts was poured at 700^0-710^0C into the preheated mould and allowed to solidify. After solidification the casting was taken out. The dimension of the plate was 100x100x10 mm

4 CHARACTERIZATION TECHNIQUES

In this chapter, certain characterization techniques such as mechanical characterization (hardness test, tensile test), wear characterization and SEM analysis were conducted.

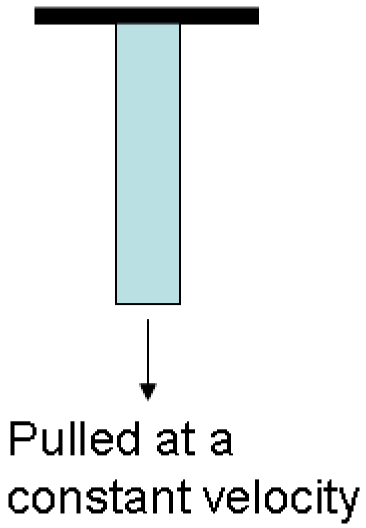
4.1 MECHANICAL CHARACTERIZATION

This section describes about the hardness test and tensile test that were conducted for determining the mechanical properties of Al9Si alloy with Cu, Ni and Sr fabricated

4.1.1 Tensile Test

Tensile test is one of the most important mechanical property evaluation test. In this test a cylindrical or a plate shaped specimen is deformed by applying a uniaxial force as shown in the figure below. One end of the sample is fixed in a static grip while the other end of the specimen is pulled at a constant velocity. The load is continuously monitored during the test. It is usual to conduct this test until the sample fractures. During the test, the instantaneous elongation of the sample can be calculated from the velocity of deformation or can also be measured by using an extensometer.

The resulting output from such a test is recorded as load versus displacement/elongation and can be graphically displayed as a load versus elongation curve.



The tensile properties that can be obtained from the stress-strain curves are yield strength, tensile strength, fracture strength, percent total elongation, uniform elongation, strain hardening exponent, modulus of resilience, and modulus of toughness. The experiment is conducted

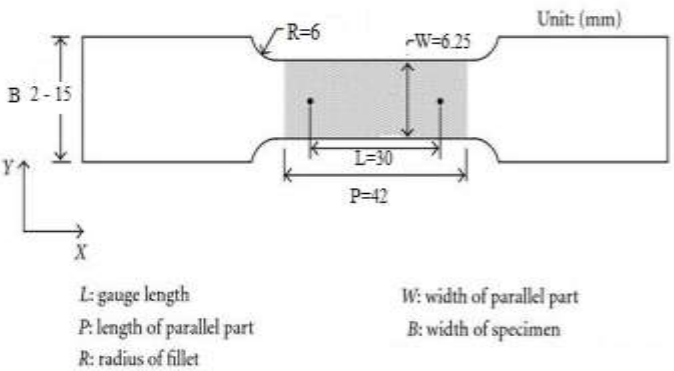


Fig 4.1; Tensile testing specimen dimension

4.1.2 Hardness test

Hardness is defined as the ability of a material to resist plastic deformation, usually by indentation. The term may also refer to resistance to:

- Scratching
- Abrasion
- Cutting
- Penetration

Hardness is the property of a metal which gives it the ability to resist being permanently deformed when a load is applied. Therefore, hardness is important from an engineering standpoint because resistance to wear by either friction or erosion by various elements generally increases with hardness. The greater the hardness of the metal, the greater resistance it has to deformation.

4.2 WEAR CHARACTERIZATION

Wear occurs as a natural consequence when two surfaces with a relative motion interact with each other. Wear may be defined as the progressive loss of material from contacting surfaces in relative motion. Experiments have been conducted in the Pin-on-disc type wear testing machine. In a pin-on-disc wear tester, a pin is loaded against a flat rotating disc specimen such that a circular wear path is described by the machine.

The machine can be used to evaluate wear and friction properties of materials under pure sliding conditions. Either disc or pin can serve as specimen, while the other as counter face. Pin with various geometry can be used. A convenient way is to use ball of commercially available materials such as bearing steel, tungsten carbide or alumina (Al_2O_3) as counter face, so that the name of ball-on-disc is used. Experiments were conducted on DUCOM TR20LE Pin on disk wear testing machine with WINDUCOM software.

Samples were machined according to the standard shape and dimensions (ASTM G99) to hold the samples into the holding chuck. The allowed dimensions of the wear testing samples should be about 10mm X 10mm X 30mm. It is versatile equipment designed to study wear under sliding condition only. Sliding generally occurs between a stationary pin and a rotating disc. The disc rotates with the help of a D.C. motor; having speed range 0-2000 rev/min with wear track diameter 50 mm-180 mm, which could yield sliding speed 0 to 10 m/sec. Load is to be applied on pin (specimen) by dead weight through pulley string arrangement. The system has a maximum loading capacity of 200N.

The experiment has been performed on a group of specimens for duration of 17 minutes, and load of 1 Kg, with speed 191.0828 rpm. The set up is connected to a Data Acquisition System which computes friction force and coefficient of friction of said material. By fixing any two parameters with one variable parameter experiment is performed. Graphical representation of wear rate along with friction force and coefficient of friction is given by WINDUCOM software and the results will show the coefficient of friction in relation with (time, speed and load) and the systematic comparisons of one material with the other. Friction is a force that resists sliding and is measured by a coefficient which is generally considered to be constant and specific to various material. Care has been taken that the specimens under test are continuously cleaned with woollen cloth to avoid the entrapment of wear debris.

The test has been carried out under following conditions;

1. The specimens under tests were fixed to the collect (Figure 6.4). The collect along with the specimen (Pin) is positioned at a particular track diameter.

2. Load is applied through a dead weight loading system to press the pin against the disc.

3. Frictional force arises at the contact can be read out from the controller

4. Each set of test was carried out for a period of 17 minutes run.

4.3 SCANNING ELECTRON MICROSCOPE (SEM)

A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that contain information about the sample's surface topography and composition. The electron beam is generally scanned in a raster scan pattern, and the beam's position is combined with the detected signal to produce an image. SEM can achieve resolution better than 1 nanometer. Specimens can be observed in high vacuum, in low vacuum, in wet conditions (in environmental SEM), and at a wide range of cryogenic or elevated temperatures.

The most common SEM mode is detection of secondary electrons emitted by atoms excited by the electron beam. The number of secondary electrons that can be detected depends, among other things, on the angle at which beam meets surface of specimen, i.e. on specimen topography. By scanning the sample and collecting the secondary electrons that are emitted using a special detector, an image displaying the topography of the surface is created.

5 RESULTS AND DISCUSSIONS

The mechanical properties such as tensile test, hardness test and wear test, and SEM analysis of the alloy fabricated are discussed in this chapter. A glance on the results obtained from this work showed a positive response to the increasing addition of strontium to Al9Si alloy with Nickel and Copper

7.1 MECHANICAL TEST RESULTS

This section discusses the tensile test, hardness test and wears test results of Al9Si alloy with addition of Cu, Ni, and Sr fabricated. Tensile, Hardness and wear properties showed a positive response to the increasing addition of Sr Al9Si alloy with Cu and Ni.

5.1.1 Tensile test of casted alloy

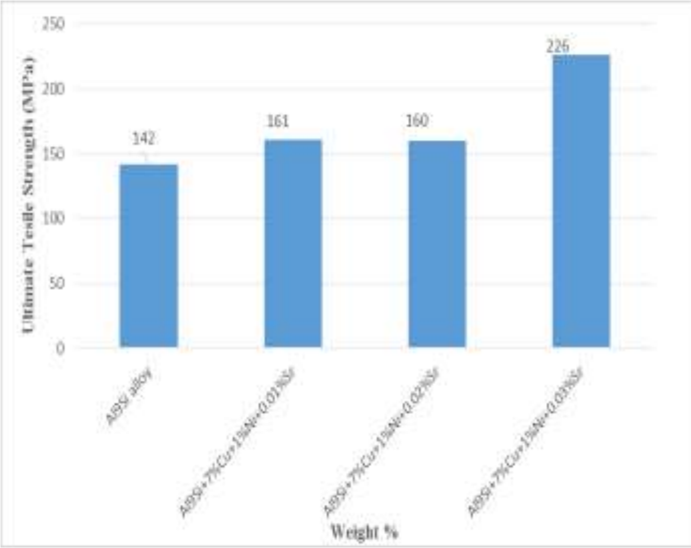


Fig 5.1; Tensile Strength for various weight %

As the weight percentage of strontium is increased at 0.03%, it is seen that the ultimate tensile strength is increasing. Four samples were tested for each trial. The values of ultimate tensile strength in terms of elongation were obtained There is a slight reduction in ultimate tensile strength at 0.02%Sr i.e.; 160 MPa. This decrease is small and is negligible due non uniform stirring in the stir casting process. The materials that have Sr content of 0.03 wt % show higher ultimate tensile strength than that of Al9Si alloy. So the ultimate tensile strength is maximum for Al9Si +7Cu+1Ni+0.03%Sr compared to Al9Si alloy

5.1.2 Hardness of casted alloy

Variation of Brinell hardness number with increasing addition of Sr with same percentage Ni particles are shown below. Results of Brinell hardness measurements are summarized in figure 5.2. The brinell hardness test is conducted with 10mm Ball/3000 kg load.

Samples S2 and S3 have the highest hardness because of its highest brinell hardness value (HBW) while considering the different weight percentage of Strontium particle, while the sample S1 have lower brinell hardness value (HBW). The alloy produced by adding strontium, copper, and nickel to Aluminium-Silicon alloy have higher hardness when compared to that of Al9Si alloy. Sample S4 and S5 shows a fair similarity in hardness value that is 97.22 and 97.87

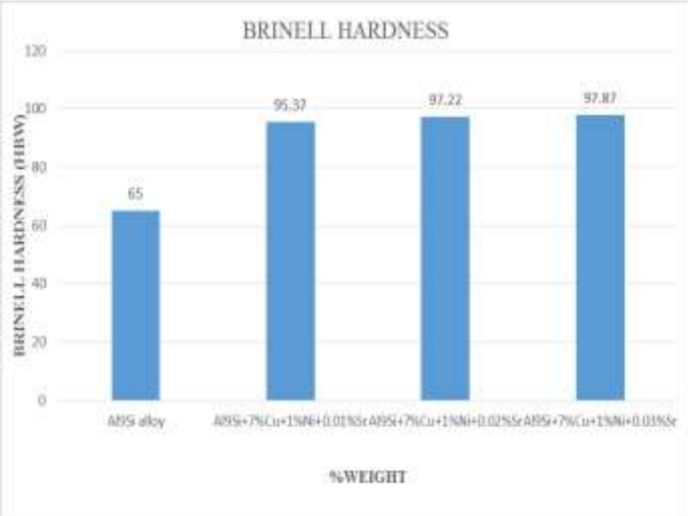


Fig. 5.2 Brinell hardness for Different Weight %

From the above graphs, it is clear that the Brinell hardness number (HBW) is improved with the addition of copper, nickel and strontium to Al9Si alloy. The hardness values were increased with the addition of Sr from weight percentages of 0.01and 0.02% also with 7%Cu and 1%Ni, and it also show a constant value at 0.02 and 0.03 % by weight. Also comparing to Al9Si the hardness value is very high. It has been seen that the load transfer across the interface is responsible for strength and stiffness.

7.3 WEAR CHARACTERISTICS OF CAST

Wear in general is a consequence of the interaction between surfaces moving in contact, causing gradual removal of material and since the denture or bone is subjected to heavy wear during their life time, the study of wear behavior of the denture was considered important. Before conducting the wear test, the surfaces of the pin-on-disk wear testing apparatus were polished with sand papers, so that the contact will be a smooth one. The tests were carried out as per standard under unlubricated condition in a normal laboratory atmosphere at 50-60% relative humidity and a temperature of 28-32^{0}C.

Based on the results, a graph is plotted and presented in figure 5.3 for different percentage of strontium. It is seen from the plots, with the addition of copper, nickel and strontium, the wear rate of the alloy tends decreasing. Sample which have 0.01%Sr shows the maximum wear resistant as compared to other weight percentage of strontium. It has been clearly identified that by the addition of wt % of strontium and copper and nickel to Al9Si alloy the wear rate reduces.

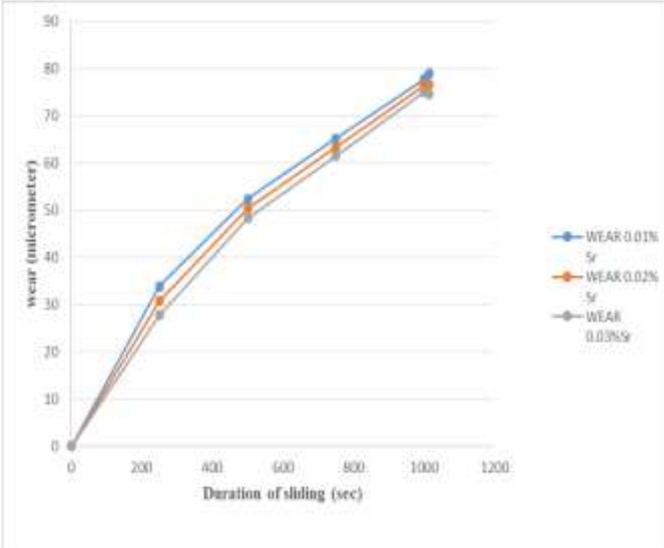


Fig. 5.3; Comparisons on the effect of sliding time on wear

Figure 5.3 clearly shows that the variation of wear rate with the addition of 0.03% strontium to Al9Si with copper and nickel. Due to the density variation of Cu, Ni, Sr particles and Al9Si, reinforcement particles are sediment during mixing at lower stirring speed; heterogeneity in particle distribution weakens the composite and promote wear.

5.4 SCANNING ELECTRON MICROSCOPY OF CAST ALLOY

A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons.

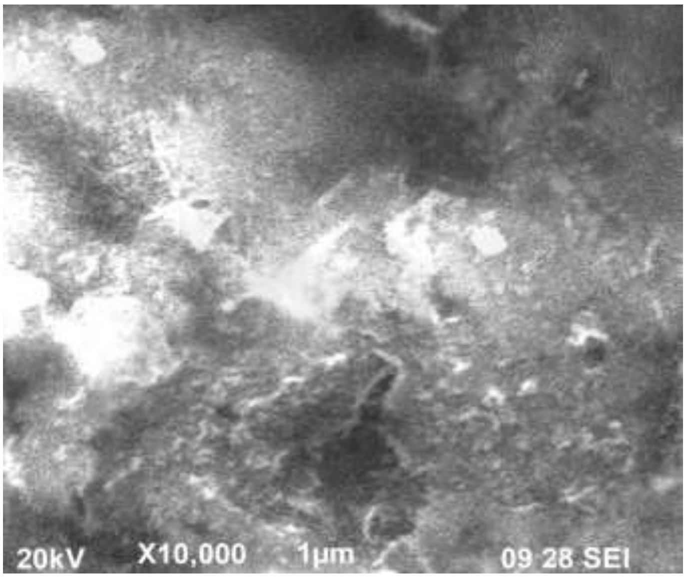


Fig 5.4; SEM image of Al9Si alloy with 7%Cu, 1%Ni and 0.01%Sr

Figure 5.4 shows the SEM image of SEM image of Al9Si alloy with 7%Cu, 1%Ni and 0.01%Sr in which silicon has a plate like structure. Therefore the weight percentage of Sr is increased from 0.01% to 0.03%.

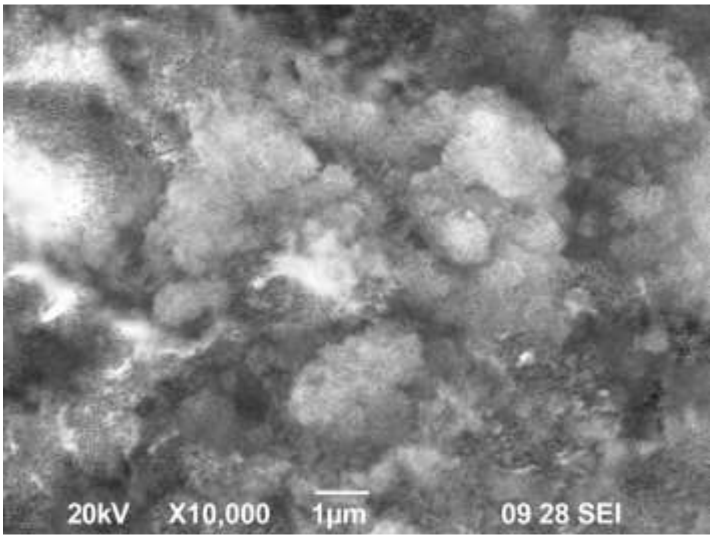


Fig 5.5; SEM image of Al9Si alloy with 7%Cu, 1%Ni and 0.02%Sr

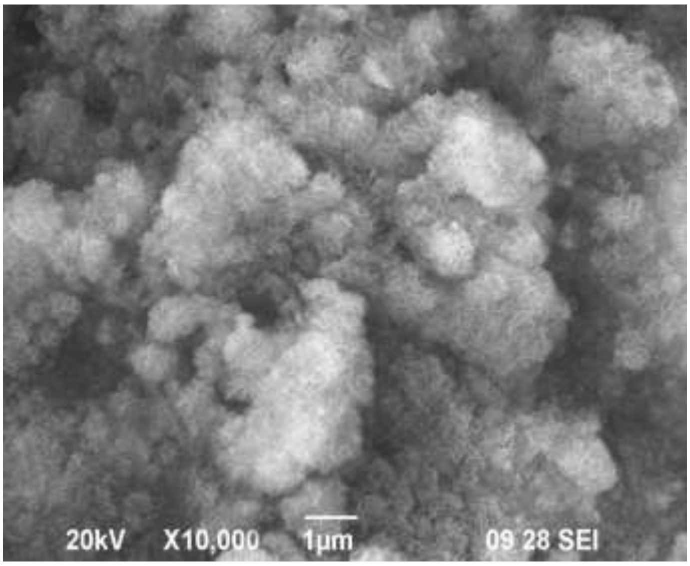


Fig 5.6; SEM image of Al9Si alloy with 7%Cu, 1%Ni and 0.03%Sr

The distribution of Si particle is clearly seen in the SEM image. Further increasing addition of Sr to Al9Si alloy with Cu and Ni, results in a fine and fibrous silicon structure during solidification and form a cluster. The Sr addition can reduce the rejection rate and improves the casting quality. It is seen that the plate like structure if silicon on Al9Si alloy is slightly changed to fibrous form with increased addition of strontium. Since the fibrous structure of Si is obtained on 0.03% Sr, the strength as well as hardness is increased, also the wear is reduced.

6 CONCLUSIONS

The performance of any new alloy is often judged by its response under different physical and mechanical conditions as it becomes essential for selecting the material of proper composition for any given application. Therefore, in the present work, addition of Sr, Cu and Ni incorporated in to Al9Si alloy, via powered stir casting method. Various characterization techniques such as micro structural characterization (SEM), mechanical characterization (Tensile Test, Hardness test) and wear characterization studies were also conducted. A brief glance on the results obtained from this work showed a positive response to the addition of Sr to Al9Si alloy with Cu and Ni.

The results of the study can be summarized as follows

- Stir casting technique was successfully adopted for the preparation of Al9Si alloy with 7%Cu, 1%Ni and 0.01,0.02 and 0.03% Sr.
- Hardness increased with the increase in content addition of strontium powder.
- Tensile strength increased with the increase in the addition of strontium from 0.01% to 0.03%
- Wear resistance increased with increase in the addition of strontium powder.
- SEM images of the alloy produced by stir casting method shows the formation of fibrous structure of silicon particle from plate like structure thereby increasing the strength, hardness as well as reduces the wear.

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