A Study on Mechanical Properties of Al-17Si Metal Matrix Composites

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Abstract. Aluminum metal matrix composites (MMC) are finding applications in aerospace, automobile and general engineering industries owing to their favourable microstructure and improved mechanical behaviour. Aluminium alloy Al-17Si and Zirconium Silicate (ZrSiO\textsubscript{4}) composites were obtained by stir casting technique. Four different weight percentages (3, 6, 9 & 12) of ZrSiO\textsubscript{4} particles were added to the base alloy. The specimens were prepared as per ASTM standards and tested. Hardness properties of the composite showed an improvement as compared to the alloy without ZrSiO\textsubscript{4} additions. From the experiment result it is found that tensile strength of the composite will increase with addition of ZrSiO\textsubscript{4} till 3% and thereafter decreases. The present paper highlights the salient features of casting technique and characterization of aluminum alloy Al-17Si and ZrSiO\textsubscript{4} metal matrix composite.

1. Introduction

Metal matrix composites are materials with metals as the base and distinct, typically ceramic phases added as reinforcements to improve the properties. The reinforcements can be in the form of fibers, whiskers and particulates. Properties of the metal matrix composites can be tailored by varying the nature of constituents and their volume fraction. They offer superior combination of properties in such a manner that today no existing monolithic material can reveal and hence are increasingly being used in the aerospace and automobile industries. The principal advantage MMCs enjoy over other materials lies in the improved strength and hardness on a unit weight basis [1].

Al-Si alloys have the potential to be used in the tribological applications such as internal combustion engines, plain bearing, compressor and refrigerator/1/. [2] It was concluded that a slight increase in the ultimate tensile strength is noticed with the increase of silicon content from 3% to 8% and that the elongation % reaches a maximum value at 12% Si from 8% to 15% Silicon. [2]

When compared with the metal matrix alloys, the Micro hardness and Tensile strength will be higher in hybrid composites. And an enhancement in strength is noticed with the increased content of reinforcement followed by heat treatment.[3]

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In the study of the Structure and Mechanical Properties of Aluminium Al356 alloy base composite with Al2O3 particle additions it is concluded that the compo casting process led to a transformation of a dendritic to a non dendritic structure of the base alloy. A favorable distribution of strengthener particles in the matrix has been achieved which enhance mechanical properties in the composites [4].

In the study on Al6061-SiC and Al7075-Al2O3 Metal Matrix Composites reported that the tensile strength properties of the composites are found higher than that of base matrix and Al6061-SiC composites superior tensile strength properties than that of Al7075- Al2O3 composites [5]is reported in the study on Mechanical Properties of Al6063SiC Composites reported that the tensile strength, Hardness and compressive strength of the composites found increased with increased SiC content. Finer the grain size better is the hardness and strength of composites leading to lowering of wear rates [6].The purpose of the encouragement or reinforcement in a composite element is essentially to increase the mechanical property of the base alloy. Each of the various particulates/ fibres included in composites possess different characteristics and so influence the properties of the blend in numerous techniques. The properties of the reinforcements include:

- High strength
- Ease of fabrication and low cost
- Good chemical stability
- Density and distribution

In the present work the synthesis and characterization of MMC, Mechanical properties are conducted on Al-17Si Aluminum alloy and Al-17Si-ZrSiO4 metal matrix composite reinforced with different wt% of Zirconium Silicate (ZrSiO4) particles. The matrix alloy of the composite used in the process is Al-17Si.

2. Materials used

The specimen manufactured based on the standard E8 is placed in the UTM between the specimen holder, while the assembly is clean, a consistent condition of load is employed on the either ends of the specimen that are equivalent as well as opposite in direction. The setup of the UTM with the specimen is shown in the figure

2.1 Properties of Aluminium alloy

Aluminium alloy has a relatively high thermal conductivity (30 Wm−1K−1[12]). In its most commonly occurring crystalline form, called corundum or α-aluminium oxide, its hardness makes it suitable for use as reinforcing agent in MMC Aluminium oxide is responsible for the resistance of metallic aluminium to weathering. Since Metallic aluminium is very reactive with atmospheric oxygen. Table 1 shows the properties of aluminium alloy. Table 2 shows the composition of aluminium alloy.

Table-1 Physical properties of Aluminium alloy[7,8].

| Property                          | Value      |
|----------------------------------|------------|
| Color                            | Silver white |
| Crystallographic Structure       | FCC        |
| Density                          | 2.7g/cm3   |
| Volume change on solidification  | 4 %        |
| Melting point                    | 660°C      |
| Specific Heat                    | 385 J      |
| Latent heat of fusion            | 205 J / g  |
Thermal Conductivity (0 – 1000°C) 399 W/mK
Electrical Conductivity 100-103 IACS
Electrical Resistivity 0.01673 mm²/m
Hardness 90 VHN
Tensile Strength 115-145

| Table-2: Chemical composition of Aluminium alloy. |
|-----------------------------------------------|
| Cu   | 4.0-5.0% |
| Mg   | 0.4-0.7% |
| Si   | 16-18%   |
| Fe   | 1.1%     |
| Mn   | 0.3%     |
| Ni   | 0.1%     |
| Zn   | 0.2%     |
| PbO  | 1.0%     |
| SnO  | 1.0%     |
| Ti   | 0.2%     |
| Al   | Remainder |

2.2 Zirconium Silicate
A fine white mineral powder which is chemically inert as well as stable to quite high temperatures. Insoluble in water, dilute acids as well as hot concentrate sulphuric acid solution. Depending on applications, Zircon sand may be determined at high temperatures providing a stabilized product. Table 3 & 4 shows the chemical composition and physical properties of zirconium silicate.

| Table-3: Chemical composition of Zirconium Silicate. |
|-----------------------------------------------|
| ZrO₂+HfO₂ | 66%   |
| SiO₂     | 33%   |
| Fe₂O₃    | 0.1%  |
| TiO₂     | 0.15% |
| Al₂O₃    | 0.1%  |

| Table-4: Physical properties of Zirconium Silicate. |
|-----------------------------------------------|
| Molecular formula | ZrSiO₄ |
| Molar mass       | 183.31 g/mol |
| Exact mass       | 181.861288700 g/mol |
| Appearance       | Colourless crystal |
| Density          | 4.56 g/cm³ |
| Melting point    | 2550°C, 2823 K, 4622°F (Decomposes) |
| Specific Gravity | 4.6 |

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2.3 Processing
In the present investigation stir casting method which is a liquid state method used to produce the composites. Initially the matrix material is cut into small pieces to accommodate in the crucible. In the electric furnace the matrix material Al17-Si is melted. The dispersed phase of ZrSiO4 particles were pre heated mixed with the molten matrix Al17-Si alloy and stirred by means of a mechanical stirrer. The speed of the stirrer is adjusted to get the vertex formation in the molten metal inside the crucible. During the process of casting scum powder is used for slag removal and Hexo-chloroethane used as degassing agent. The liquid composite material is then cast by pouring the molten metal in to the preheated mould.

![Stir casting setup.](image)

3. Results and Discussions

3.1 Tensile Test
Tensile testing, is also known as tension testing, is an elementary materials engineering experiment wherein a specimen is confronted with a controlled tensile forces until breakdown. The outcome from the experiment are generally utilized to decide a material for an application, for quality regulation, as well as to estimate exactly how a material is going to respond under other forms of stresses.
In accordance with ASTM standard E8 requirements, the blend examples were intended for tensile analysing to obtain the material characteristics. Each and every specimen has a length of 96mm, diameter of 12mm and gauge length of 30mm as shown in the figure 4.1. Using this, the SHIMADZU Universal Testing Machine (UTM) is fixed with suitable jaws and the primary improvements are made. All the dimensions of the specimen are written into the computer along with the highest possible load and displacements. The speed of elongation of the specimen (0.5mm/min) is also entered into the computer. After the specimen fails, the computer reveals stress, strain and force on the specimen.
3.2 Procedure for tensile test
The specimen manufactured based on the standard E8 is placed in the UTM between the specimen holder, while the assembly is clean, a consistent condition of load is employed on the either ends of the specimen that are equivalent as well as opposite in direction. The setup of the UTM with the specimen is shown in the figure 3. Figure 4& 5 are the specimen for tensile test.
Figure 5: Experimental specimen after the tensile test.

Figure 6: Tensile strength graph.

Figure 6 shows the effect of tensile strength for different composition zirconium silicate. Usually the tensile property of the composite will get loose on addition of reinforcement, the same has been happened in the Zircon sand alone and Alumina alone reinforced composites. From graph it is found that tensile strength of composite is increases with ZrSiO4 particles till 3% and thereafter started to decrease. This is because zirconium has higher hardness than aluminium matrix hence with addition of ZrSiO4 particles will increases the tensile strength. With addition of 3% ZrSiO4 particles to aluminum matrix 15% increase in tensile strength is found. The resultant graph shows the peak value in the
aluminum alloy having higher tensile strength over the Zircon sand alone and Alumina alone reinforced composites.

3.3 Hardness

From figure 7 it is observed that the hardness of the composite is decreasing with the increase of reinforcing particulate content till 6% afterwards it is increasing. This increase in hardness is expected since ZrSiO4 particles being very hard dispersoid contribute positively to the hardness of the composite. Further it is observed that as percentage of reinforcement increased in the base alloy there is decrease in hardness of the composite. Maximum hardness will be for aluminium alloy then 3% Zirconium silicate. Hence from the mechanical properties it is found that 3% of Zirconium silicate will have good composite.[9]

![Figure 7: Brinell Hardness graph](image)

4. Conclusion

The significant conclusions of the studies carried out on Al17-Si - ZrSiO4 composites are as follows. The Al17-Si reinforced with ZrSiO4 particulates that is Al17-Si - ZrSiO4 metal matrix composite were successfully fabricated through stir casting for 0%, 3%, 6%, 9% and 12% reinforcement. The hardness of the cast composite shows decreasing initially then with addition beyond 6% it is increasing. Hence 3% of Zirconium Silicate found to be better composite material for aluminum alloy.

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