Characterization of aluminium matrix reinforced with tungsten carbide and molybdenum disulphide hybrid composite

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Abstract. Metal matrix composites are formed by combination of two or more materials having dissimilar characteristics. In the present investigation, Aluminium (Al7075) is taken as base matrix metal, Tungsten Carbide (WC) particulate and Molybdenum Disulphide (MoS₂) as reinforcements. The metal matrix composites are fabricated by stir-casting process. The Tungsten Carbide particulate was added in proportions of 2%, 4%, 6%, 8% and 10% and Molybdenum Disulphide was added in constant proportion of 4% on mass fraction basis to the molten metal. The different combination sets of composites were prepared. Mechanical properties like hardness and tensile strength were studied for both reinforced and unreinforced Al7075 samples. Microstructure examination was carried by using Metallurgical Microscope to obtain the distribution of Tungsten Carbide particulate and Molybdenum Disulphide in base matrix. From the results, it was found that the hardness and tensile strength of the prepared metal matrix composites increases with increasing weight percentage of Tungsten Carbide, however a decreasing trend of hardness is found at 8% and 10% of Tungsten Carbide. This could be attributed to agglomeration of the Tungsten Carbide particles due to insufficient rpm of the stirrer.

1. Introduction

In the recent times there has been a heavy demand for new generation of materials which caters advanced engineering applications [1]. Hybrid aluminium matrix composites is one of the most sought material of this category. Presently engineering materials are developed with high specific strength at lesser cost. One of the typical example is the development of composite materials for automotive applications which improves the fuel economy as well as engine performance. Modern engineering systems demands materials with wide spectrum of properties which are not achievable through the usage of homogenous materials [2]. Hybrid aluminium composites fulfils the demand such as ease of processing, reduction in cost and improved mechanical properties. The reliability and the performance of these composites depends on the right choice of reinforcing materials, weight percentage and processing conditions of the materials [2].
Aluminium alloys are ideal engineering material for automobile, aerospace and mineral processing industries for various high performing components and are being used for these diverse applications due to their lesser weight, exceptional thermal conductivity properties [3]. Among several series of aluminium alloys, Al7075 is ample explored due to their admirable properties. These alloys are heat treatable. Al7075 alloy are extremely resilient to corrosion and exhibits moderate strength [4]. Al7075 finds much useful in the fields of construction, automotive and marine applications. The composites made out of aluminium alloys are of wide interest owing to their high specific strength, fracture toughness, wear resistance and stiffness [5].

Tungsten carbide is a fine dark powder which can be squeezed and framed into shapes for use in manufacturing industries, cutting devices, abrasives, defensive layer penetrating rounds, other equipments and tools [6]. Tungsten carbide is double the density of steel and is nearly two times stiffer than steel [7]. Cubic boron nitride and diamond powder wheels are used for polishing tungsten carbide which is equivalent to corundum in hardness [7].

Molybdenum disulphide is comparatively stable. Oxygen and dilute acid does not affect it. It is generally utilized as a solid lubricant due to its reduced abrasion and resilience [8]. Molybdenum disulphide has exceptional chemical and thermal stability. They can shape an exceedingly productive dry greasing up film [9]. Molybdenum disulphide particles has low rubbing coefficient, excellent catalytic activity, and exceptional physical properties [9]. They likewise have a vast dynamic surface zone, excessive reactivity, and expanded adsorption limit contrasted with the mass material [9].

2. Materials and Methods

2.1 Materials

The common characteristics of aluminium and its alloys are progressive determining aspects for engineers, industrialists and modern clients who are dependably watchful for superior-performing materials and pioneering techniques. The composition of Aluminium 7075 is given in the table 1.

| Table 1. Composition of Al 7075 |
|-------------------------------|
| Si   | Fe   | Cu | Mn  | Mg  | Cr  | Zn  | Ti  | Al  |
| 0.08 | 0.24 | 1.5| 0.06| 2.4 | 0.20| 5.8 | 0.07| Rem |

2.2 Fabrication of Composite

Fabrication of the composites is done by stir-casting process. The melting of the aluminium alloy Al7075 ingot is carried out in the graphite crucible inside the furnace. Tungsten carbide(WC) and Molybdenum disulphide (MoS₂) powders are mixed together and preheated to 450 °C to remove the adsorbed hydroxide and other gases from the surface. The crucible with aluminium alloy Al7075 is heated at 800 to 850°C. The furnace completely melts the pieces of aluminium alloy Al 7075. Tungsten carbide and Molybdenum disulphide is added into the crucible. The stirring is carried at 1000 rpm for 10 minutes to uniformly disperse the reinforcing particles in the aluminium alloy matrix. The temperature of the furnace should be maintained between 800 to 850°C during the stirring process. The molten metal matrix from the graphite crucible is poured into the mould and allowed to cool down at
room temperature for 30 to 60 minutes [10]. The aluminium metal matrix is taken out from the mould then the mould is cleaned and kept ready for next casting. The same method is followed to get the metal matrix composites of different weight percentage of the reinforcing phase. The composition of samples is given in the table 2.

| Sample No. | Tungsten Carbide (WC) (%) | Molybdenum Disulphide (MoS2) (%) |
|------------|--------------------------|---------------------------------|
| 1          | -                        | -                               |
| 2          | 2                        | 4                               |
| 3          | 4                        | 4                               |
| 4          | 6                        | 4                               |
| 5          | 8                        | 4                               |
| 6          | 10                       | 4                               |

2.3 Testing

Testing for mechanical properties like hardness and tensile strength is carried out on the fabricated specimens. The Microstructure analysis is carried out to know the dispersion of the reinforcement in the metal matrix.

2.3.1 Microstructure test

The samples utilised for microstructure investigation is set up in the form round bits of 15 mm thickness, and 30 mm diameter as shown in figure 1. Mounting of metallographic specimen serves as a protection to the specimen edges and its irregular shape, enabling both easy manual and automated grinding/polishing operation. Samples were polished by following standardised metallographic procedure. Keller’s reagent is used to etch the polished surface. Specimens are examined using De-Wintor Inverted Trinocular metallurgical microscope.
2.3.2 Hardness test

As per ASTM E92 norms the hardness tests were conducted using Vickers hardness tester. Tests were performed at arbitrarily chosen points on the surface by keeping up adequate space between indentations and separation from the edge of the sample. Hardness test specimens are same as that of the microstructure specimen as shown in figure 1. Hardness test is performed using Wilson hardness tester.

2.3.3 Tensile test

Tensile test is carried out as per ASTM B557 standard in computerized UTM (F-100 Model Machine). The specimens used for tensile test is shown in figure 2.
3. Results & Discussions

3.1 Microstructure:
Microstructure structure of material plays a vital role in the performance of composites. Physical properties such as robustness, endurance, compliance, stiffness, wear and corrosion resistance are strongly influenced by the microstructure of the material [11]. The microstructure of different composites is shown below.

![Figure 4. Microstructure of Al7075](image)

![Figure 5. Microstructure of Al7075 – 2% WC & 4% MoS₂](image)

The microstructure of chill cast Al7075 is shown in figure 4. The photo-micrograph shows the inter-dendritic primary aluminum grains. The grain boundaries are precipitated with eutectics like Mg₂Si, Mg₂Al₂ Cu-Al₂ and Zn-Al₂. They are solidified as inter metallic compounds at the grain boundaries. The particles of the composites are clearly resolved at the grain boundaries and bigger particles inside grains of primary aluminium as shown in figure 5.

![Figure 6. Microstructure of Al7075 - 4% WC & 4% MoS₂](image)

![Figure 7. Microstructure of Al7075 – 6% WC & 4% MoS₂](image)
The higher addition of WC in the casting showed more reinforcing particles in the matrix. These particles invariably occupied the grain boundaries sites is shown in figure 6. The grain boundaries were also present with the eutectic particles. The presence of tungsten carbide particles is resolved at the grain boundaries of primary aluminum as shown in figure 7.

High percentage of WC occupied larger area in the matrix and masked the presence of MoS$_2$ which is shown in figure 8. The particles of the composites are clearly resolved at the grain boundaries and bigger particles inside grains of primary aluminium shown in figure 9. The higher addition of WC in the casting showed agglomeration of particles due to their higher density, however the distribution of MoS$_2$ is uniform in the matrix.

3.2 Hardness:

Increase in the weight percentage of Tungsten Carbide increased the hardness of the material up to 6% wt. The hardness decreased on addition of further reinforcements. The decreasing trend in hardness with increasing weight percent of WC could be attributed to the agglomeration of the reinforcing particles. The results are tabulated in table 3. The trend of increase hardness is shown in figure 10.
Table 3. Hardness test result

| Sample No | Reinforcement content (%) | Mean Hardness (HV) |
|-----------|---------------------------|--------------------|
| 1         | -                         | 121.1              |
| 2         | 2% WC and 4% MoS₂         | 121.5              |
| 3         | 4% WC and 4% MoS₂         | 122.1              |
| 4         | 6% WC and 4% MoS₂         | 122.6              |
| 5         | 8% WC and 4% MoS₂         | 120.9              |
| 6         | 10% WC and 4% MoS₂        | 118.5              |

Figure 10. Graph showing the trend of Hardness

3.3 Tensile Strength:

The tensile strength improved with increase in the weight fraction of reinforcements, however a decreasing trend of hardness is found at 8% and 10% of Tungsten Carbide and Molybdenum Disulphide. This could be due to agglomeration of the WC particles as well as may be insufficient stirrer rpm for higher concentration of the reinforcing particles. The tensile test result is given in table 4.
Table 4. Tensile test result

| Sample No | Reinforcement content (%) | Tensile Strength (Mpa) |
|-----------|---------------------------|------------------------|
| 1         | -                         | 166.02                 |
| 2         | 2% WC and 4% MoS₂         | 190.26                 |
| 3         | 4% WC and 4% MoS₂         | 198.39                 |
| 4         | 6% WC and 4% MoS₂         | 218.96                 |
| 5         | 8% WC and 4% MoS₂         | 170.51                 |
| 6         | 10% WC and 4% MoS₂        | 160.71                 |

Figure 11. Graph showing the trend of Tensile Strength

4. Conclusion

The Al7075–WC–MoS₂ composites is prepared by stir casting process. The mechanical properties of base metal and samples were assessed and compared. The conclusions made from the study are as follows:

1. Aluminium composite is successfully fabricated by stir casting technique with fairly uniform distribution of WC & MoS₂.
2. Maximum tensile strength in the aluminium metal matrix is observed at 6% WC & 4% MoS₂.
3. Maximum hardness in the aluminium metal matrix is observed at 6% WC & 4% MoS₂.
4. Agglomeration of tungsten carbide particles at 8% and 10% weight may be due to insufficient rpm of stirrer, which effectively distributes lesser quantity of tungsten carbide.

5. References

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