Investigation on the Microstructure and Mechanical Properties of Aluminum 7075 Reinforced With Different Weight Percentage of Tungsten Carbide and Cobalt Metal Matrix Hybrid Composites

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Abstract: - In this paper an effort has been made to develop and characterize Al7075 alloy reinforced with Tungsten carbide (WC) & Cobalt (Co). For uniform grain size and homogeneity of the reinforcements with the matrix, Cermets (WC-Co) of grain size 50 microns were prepared with the help of ball milling operation. An experiment was conducted to evaluate the microstructure: mechanical properties like hardness test & tensile test as per the standards for different weight percentages of Cermets like 3, 6 and 9wt. %. Micrographs were studied to know the micro structure of the composite material and the result showed that, randomly dispersed reinforcement particles & fine interdendritic precipitates were seen. A comparative study was conducted for the microstructure and mechanical properties by using Cermets with varied weight percentages reinforced with Al7075 matrix. Mechanical properties results reveal that there is a considerable improvement in tensile strength and hardness as the percentage of Cermet increased from 3 to 9wt. %.

Keywords: Al7075, Tungsten carbide, Cobalt, Hardness, Cermet, Stir casting;

1. Introduction
Composites are materials made from more than one material, which has physical and chemical properties and differs widely when compared to other materials. Depending on the mechanical properties of the composite material, the elements used may be a matrix or reinforcement. The newly produced composite chosen over pure form can be processed easily, wear-resistant and resistant to corrosion in comparability to other materials. Composites are produced in order to improve mechanical and physical properties by incorporating and mixing the ingredients to the metal matrix. Aluminum matrix composites (AMCs), due to their inherent properties, are latest trending materials for different applications. We observe increased functional strength, tear, creep and fatigue compared to traditional engineered materials by the addition of reinforcing materials in the metal matrix. MMC is a highly capable material in the nonferrous family because of their outstanding properties such as low densities, high strength to weight ratio, good thermal and electric conductivity and fluidity, and it plays an important role in aerospace applications [1]. High specific strength, longevity, electrical and thermal conductivity, poor thermally expansion and wear resistance are vital advantages of aluminum matrix composites [2]. By injecting a ceramic material into a metal matrix, composite materials create a combination of attractive mechanical properties which cannot be attained by monolithic alloys [3]. Due to the rising production volume and the wider market applications one needs knowledge on the processing methods and mechanical behaviour of particulate matter MMCs. Particulate-reinforced MMCs are being increasingly focused, mainly due to the simple availability of particulate matter and economic strategies for particle-enhanced MMCs processing [4]. The main interest in strengthening alloy matrices with ceramic particulates is due to the low density, low thermal expansion and high strength of reinforcement as well as their wide availability [5]. Cermet products such as WC-Co (tungsten carbide and cobalt) were commonly used and investigated for their high resistance against the corrosion of brittle (hard) and ductile (soften) phases and the exceptional combination of high hardness and resilience. Tungsten
Carbide is famous for its excellent hardness and resistance to wear. Ductile elements, such as cobalt, increase their resistance significantly in order to prevent cracks [5]. Various researchers [6-9] have successfully fabricated composites using stir casting techniques. Currently, substantial research has been conducted during the past few years in reinforced MMC (WC-Co) cerments, which have low wear tolerance, high temperature and corrosion resistance applications.

2. Experimental details

2.1 Matrix and Reinforcement:

In the present research work Al7075 alloy is used as metal matrix. The spectroscopic structure analyzed for atomic absorption of Al 7075 is tabulated in Table I. Reinforcement was produced by mixing and preparing a Cermet which is a mixture of tungsten carbide (WC) and cobalt (Co) with a mean size of 50μm processed by ball milling.

| Si  | Fe  | Cu  | Mn  | Mg  | Cr  | Zn  | Ti  | Al  |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 0.40| 0.50| 1.60| 0.30| 2.50| 0.15| 5.50| 0.20| Balance |

Table 1. Chemical composition of Al7075 matrix used in the present study

2.2 Preparing Cermet (WC-Co)

30 grams of reinforcements of WC and Co accurately weighed and measured was added to the ball mill and a dry milling operation was carried out. The grinding balls along with WC-Co powders were rotated with a prescribed speed of 300rpm for 3 hours. During ball milling, alumina pounding balls were used instead of steel balls to avoid the iron contamination and to maintain purity and homogeneity. Homogeneous dispersion of hard phases in flexible metallic networks occurs due to the process of cold welding. The WC-Co mixture produced has a size less than 50μm which is analyzed by sieve analysis. The WC-Co Cermet manufactured by the ball milling process has been used as reinforcement for the fabrication of matrix composites.

2.3 Preparation of Composite by stir casting

Initially aluminium which is available in the form of bar is cut into small pieces as per the melting capacity size of the crucible. The weighted amount (3, 6 & 12wt percent) of WC-Co cerments in different batches were taken through an aluminum foil. These reinforcements were preheated to 250°C in an electric oven and maintained at the same temperature by keeping it in the oven until it is added to molten aluminum matrix. The measured amount of aluminum matrix was melted in a graphite crucible at a melting temperature of 800-850°C in an electric resistance furnace with a melting temperature control unit. During the melting process to extract the oxygen content from aluminum the degasifying agent (C2Cl6-Carbon hexa-chloride) was applied to the molten Al7075 matrix. The molten aluminum was stirred for a while using mechanical stirrer till the formation of slag and then the produced slag was extracted through a metallic spoon. Then the preheated WC-Co Cermet was added slowly to compose the homogeneity with the molten aluminium and stirred continuously for 15 minutes at constant speed using a mechanical stirrer. The stirred mixture of molten metal with a preheated Cermet was then poured into the prepared cylindrical mold (125 mm in height and 15 mm in diameter) using the bottom pouring process. After the melt was poured, it was allowed to cool and solidify in the pot. For the intent of the study, few specimens were cast under identical conditions. The poured mixture is allowed for solidification and then the castings were removed from the mold and the specimens were produced using appropriate machining process as per the ASTM test specifications.

2.4 Preparation of specimens for testing

Tensile test

The prepared specimens were tested for tensile properties as per ASTM-E8 norms. These tests were carried in a tensile testing machine. Specimen is prepared as shown in Fig 1 for the tensile test.
3. Results and Discussions

3.1 Microstructure characterization

The specimens were carefully polished for the studying the microstructures. From the optical microstructures (Fig. 2), inter-dendrite precipitates are seen in the aluminum solid solution matrix the presence of inter-metallic particles in the mixture are also noted from the micrographs. A moderate allocation of WC-Co reinforcement can be visualized in the micrographs. Figure 3 and 4 shows the microstructure image of composite 6% wt and 9% wt of reinforcement respectively.
3.2 Tensile properties
Prepared composite materials were examined for tensile strength as per ASTM requirements and the results are shown in table II and table III. For each test, 3 samples were subjected to loading and the average result was considered as shown in the table 3. Table 4 shows an increase in the tensile strength of 47% was observed in the composite as compared to the base alloy with a decrement in its % of elongation.
Figure 5 shows the variation of mechanical properties for different weight percentage of reinforcement.

| Sample type | Tensile strength N/mm² | Yield strength N/mm² | Percentage Elongation | Compressive strength N/mm² | Hardness BHN |
|-------------|------------------------|----------------------|------------------------|---------------------------|-------------|
| Only Al7075 | 102.26                 | 83.54                | 9.45                   | 575                       | 95          |
| WC-Co 50µ Al7075+WC-Co 3% | 111.429 | 87.797 | 1.62 | 659.195 | 104          |
| WC-Co 50 µ Al7075+WC-Co 6% | 183.775 | 125.024 | 1.63 | 631.52 | 105          |
| WC-Co 50 µ Al7075+WC-Co 9% | 193.928 | 161.108 | 1.4 | 649 | 108          |
Figure 5. Variation of mechanical properties for different weight percentage of reinforcement

Table 3. Average of tensile property values of specimens

| Properties                     | Sample 1      | Sample 2      | Sample 3      | Average       |
|-------------------------------|---------------|---------------|---------------|---------------|
| Tensile strength (N/mm$^2$)   | 210.293       | 184.713       | 184.778       | 193.938       |
| Yield stress (N/mm$^2$)       | 185.002       | 154.790       | 147.743       | 163.128       |
| % Elongation                  | 2.47          | 2.61          | 1.86          | 2.32          |

3.3 Hardness properties

The specimens were prepared according to ASTM E8 norm to analyze the hardness properties. The testing details are tabulated in the table 4. Comparative study conducted between the base metal and the composite material to observe the hardness and found slight increment in the hardness values. Figure 6 shows the variation of hardness for different weight percentage of reinforcement.

Table 4. Hardness testing details

| Machine                        | Briness hardness testing machine |
|--------------------------------|----------------------------------|
| Indentor                       | Ball Indenter                    |
| Specification                  | 5mm ball – Total load 750 kg     |
|                                | (Pre load 250 kg)                |
|                                | 0outside load: 500 kg            |
| Timings                        | 20 secs                          |

Figure 6. Variation of hardness for different weight percentage of reinforcement
4. Conclusions

i. The WC-Co mixture with a particle size 50μ is effectively processed with homogeneity through ball milling process.

ii. Composite of Cermet mixture (WC-Co) and Al7075 are easily produced using stir casting process.

iii. Microstructural characterizations carried out using optical microscope and the study showed homogeneous dispersion of the cermet particles in the Al7075 matrix.

iv. An improvement of 10.52% in hardness was obtained with the addition of Cermet (WC-Co) reinforcement to Al7075 matrix.

v. Addition of Cermet (WC-Co) to Al7075 matrix increases the yield stress and tensile strength by 49% and 58% but drastically decreases the percentage elongation by 84%.

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