

# Microstructural evolution in WC-Co cermet reinforced - Al7075 metal matrix composites by stir casting

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**Abstract:** Aluminium metal matrix composites (AMMCs) are preferred because of their enhanced properties like high strength to weight ratio, stiffness and wear resistance. In the present work, an attempt is made to develop cermet (WC-Co) reinforced with Al7075 metal matrix composite by stir casting technique. WC-Co cermet is reduced to an average size of 10 $\mu$ m through ball milling using Alumina as grinding media. Ball milled WC-Co Cermet in an amount of 6 wt. % is used as reinforcement in Al7075 matrix. Microstructural characterization of the prepared composites is carried out using SEM/EDX and XRD studies. X-ray diffraction studies have revealed the peaks corresponding to  $\alpha$ -Al, WC, Co and minor Al<sub>5</sub>W phases. SEM/EDX characterization revealed the uniform distribution of cermet in Al matrix. Further studies also revealed that, addition of WC-Co cermet to Al7075 matrix has resulted in improvement in hardness and Densities of Al7075 matrix.

## 1. Introduction

Nowadays AMMCs gain a worldwide focus in the field of research for aerospace and automotive industries because of their enhanced properties like high strength, lightweight, low thermal conductivity, excellent wear resistance and high operating temperature [1]. Heat treatable aluminum alloy such as Al2021, Al6061, Al7075 were widely used due to its higher strength to weight ratio and MMC's prepared with these alloys exhibit superior elevated temperature properties [2, 3]. Tungsten carbide, well known for its exceptional hardness, refractory metal with specific density of 15.8g/cc finds application in cutting tool, extrusion dies and drilling of components at elevated temperatures. The cermets of WC-Co can be prepared by means of ball milling technique. In present era less amount of work has been carried on the cermets reinforced MMCs which have been successfully utilized for cutting tool in high speed finishing and semi finishing cutting applications because of their favorable hot hardness, excellent wear resistance, good chemical stability, low coefficient of friction and high thermal deformation resistance [3-6]. Further, cermets reinforced MMCs are also preferred in the field of automotives because of high wear resistance for applications like rock climbing equipment, bicycle components, chassis plates, and rifles.



Srikanth B.G et.al [7] studied that Al6061 reinforced with WC and fly ash particles could effectively increase the tensile, hardness and wear resistance with increase in tungsten carbide and fly ash content. Rang Zhou et.al [8] demonstrate the effect of volume fraction of tungsten carbide particles on erosion resistance of tungsten carbide reinforced with iron matrix composite. The author found that with increase in volume fraction of WC particles, the wear rate of the composite decreases until reaches the minimum and increases. S.Sasikumar et.al [9] studied the mechanical and machining behavior of AA7075-3% TiB<sub>2</sub> in-situ composite and concluded that hardness of the composite was higher than the base matrix due to presence of TiB<sub>2</sub> in the matrix.

G.B. Veeresh Kumar [10] investigated the effect of filler material on density and micro hardness Al7075-Al<sub>2</sub>O<sub>3</sub> metal matrix composites and reported that density and micro hardness increases with increase in filler content. Tribological properties of copper alloy-WC particulate composite were experimented by Eunji hong et.al [11]. They observed that the wear rates of both the composites increased dramatically at shorter sliding distance from 300-600m and increased monotonously at longer distance from 600-3000m. The addition of indium results in increase of the Rockwell hardness of copper-alloy and composite.

A.R.K. Swamy et.al [12] investigated on effect of particles on mechanical properties of Al6061-WC and found that hardness, tensile strength and Young's modulus increases upon addition of particles. S. Saravanan and P. Kumaravel [13] showed that addition of high refractory particles (WC) in to a ductile material Al7075-T6 using stir casting increases the matrix hardness and wear resistance of the composite. S. J. A. Fabian et. al [14] conducted experimentation on densification behavior of aluminum reinforced with WC particulate MMCs processed by powder metallurgy. The results proved that with increase in WC content there is increase in density of the preforms and relative density of 93.73% could be achieved.

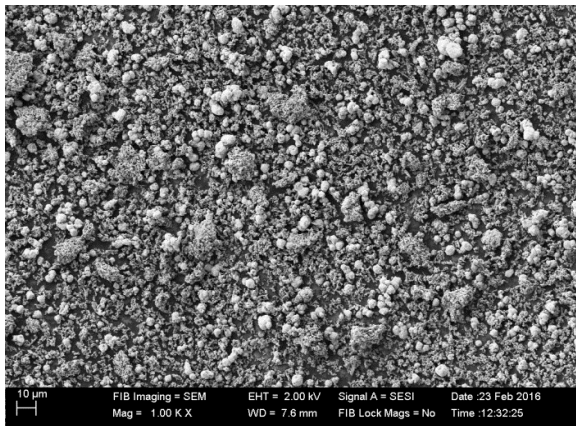
H. P. Pydi et. al. [15] observed that uniform distributions of WC in Al matrix processed via powder metallurgy which led to enhanced mechanical properties of the composite. S. Choudary et.al. [16] Reported that refining the size of WC particles below 100nm, its mechanical, tribological properties could be improved at elevated temperature. Yuan wei et.al [17] demonstrated the fabrication of high-speed steel reinforced with WC composite by spray forming and observed improvement in the bending strength and hardness of the composite.

Studies on mechanical properties of cermets reinforced Al composite is limited. Hence, the present work focuses on processing of Al7075-WC/Co cermet based composite using conventional stir casting technique. Work mainly focuses on studying the microstructural aspects of the prepared composite.

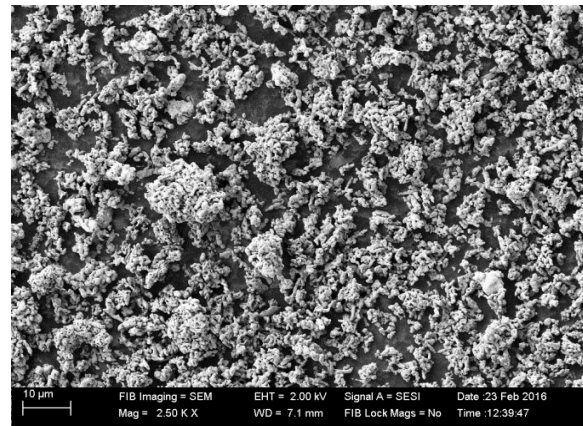
## **2. Experimental work**

### *2.1 Production of WC-Co cermet*

Ball milling is used for the preparation of the cermets as ball milling is an efficient and simple method for the production of sub-micron or micro structured powder materials. The high energy ball milling process produces strong mechanical energy transfer which results in the formation of extremely fine powder. A batch of WC and Co powders each of 3wt% are added to ball mill and dry milling is carried out for 6 hr by maintaining the rotation speed of the planet carrier at 300 rpm. Further, in order to prevent iron contamination, instead of steel, Alumina grinding medias are used. The homogeneous distribution of hard phases in ductile metallic matrices takes place due to counteract breaking and cold welding process. The WC-Co cermet after ball milling has an average particle size of 10 µm analyzed via sieve analysis and SEM images of the same are presented in Figure 1 and 2. The prepared cermets were used as reinforcement for the preparation of composite.



**Figure 1.** SEM microphotographs of WC- Co cermet powder produced by planetary ball milling at 1.00KX magnifications.



**Figure 2.** SEM microphotographs of WC- Co cermet powder produced by planetary ball milling at 2.5KX magnifications.

## 2.2 Preparation of Al7075-WC-Co Cermet composites

Composites containing Al7075 matrix with 6wt% of WC-Co Cermet reinforcement were prepared using stir casting technique at temperature of 750°C. The chemical composition of the Al7075 alloy is analyzed with the help of Atomic Absorption Spectroscopy (VARIAN) and is presented in Table 1. A batch of 400 grams of Al7075 matrix is melted in a clay graphite crucible using resistance furnace. Once the liquid matrix reaches 750°C, degassing is carried out using solid hexachloroethane ( $C_2Cl_6$ ) to expel all the adsorbed gases. To generate vortex in the liquid matrix, stirring is carried out using zirconia coated steel rod with a spindle speed of 300 rpm for 10 min. Preheated WC-Co cermet in an amount equivalent to 6 wt% is then introduced into the liquid matrix. After introduction of the reinforcement, again stirring is carried out for a period of 60 sec to ensure homogeneous dispersion of the reinforcement. The pouring was done at a temperature of 750°C into a preheated cast iron permanent mould (125 mm×Φ15 mm) after holding the melt for an interval of 1-2 minutes.

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

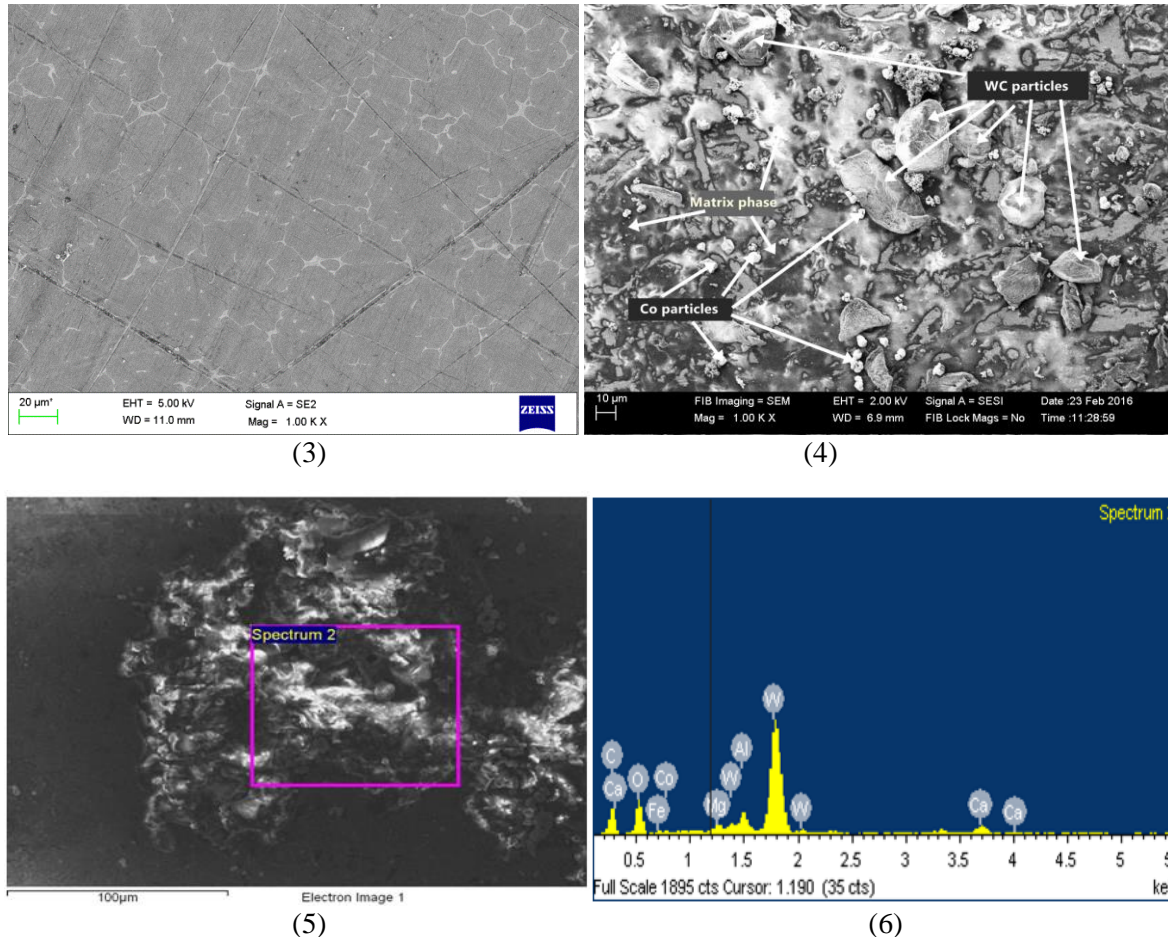
Chemical Composition	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Al7075	0.4	0.5	1.6	0.3	2.5	0.15	5.5	0.2	Bal

## 3. Results and Discussions

### 3.1 Microstructural Characterization

Metallographic test samples sectioned from composite castings are prepared as per metallographic procedure for microstructural analysis. Scanning electron microscopy equipped with EDX (Hitachi Su-1500 model) is employed for identifying presence and distribution of WC-Co cermet particles in Al matrix. The SEM microphotographs of Al7075 matrix and Al7075-WC-Co cermet based composites are presented in Figure 3 and 4 respectively. From Figure 3 it is clear that microstructure of Al7075 matrix consists of  $\alpha$ -Al and Si is being distributed at boundaries and Figure 4 representing the microstructure of Al7075-WC-Co cermet based composite reveals fairly uniform distribution of WC-Co cermet particles in an  $\alpha$ -Al matrix. Figure 5 and 6 shows energy dispersive x-ray analysis being carried out on Al7075-WC-Co cermet based composite. EDX elemental analysis has shown the

peaks corresponding to Al, Mg, W, Co, C, Fe, Si and Ca thus confirming the presence of WC-Co Cermet in Al matrix.

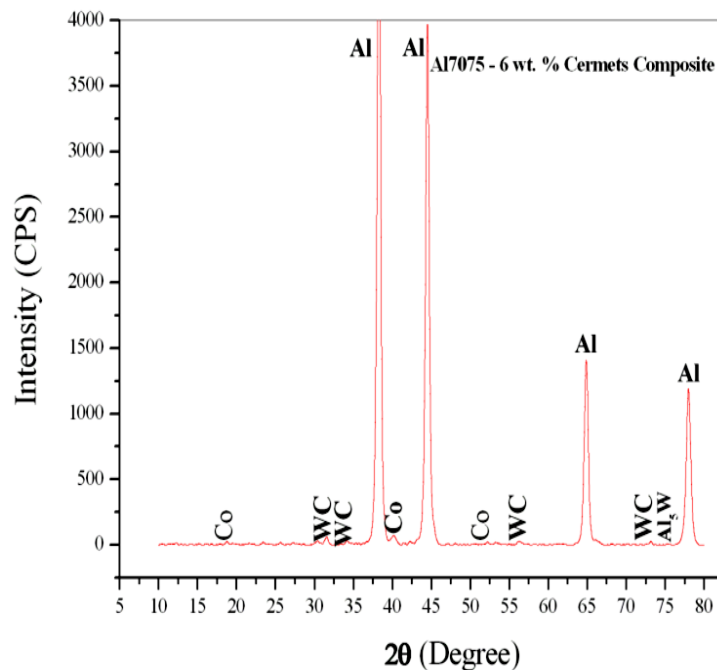


**Figure 3-6.** SEM microphotographs of (3) Al7075 matrix (4) Al7075- 6wt% of WC-Co cermet composite produced at 750°C by stir casting (5) Region for EDX spectrum (6) EDX spectrum of Al7075- 6wt% of WC-Co cermet composite.

### 3.2 X-Ray Diffraction analysis

XRD is a technique that is widely used in the applications range from phase identification, quantification and determination of crystallite and particle size. Crystallite size can also cause peak broadening. Once the instrument effects have been excluded, the crystallite size is easily calculated as a function of peak intensity, peak position and wavelength.

X-ray diffraction (XRD) analysis of the Al7075- 6wt% of WC-Co cermet composite was done using XRD Machine-7000; M/s Shimadzu Analytical India Pvt. Ltd. and is presented in Figure 7. The  $2\theta$  range was selected such that all the major intense peaks of the phases expected were covered. Analysis of the XRD pattern shows the peaks corresponding to major phases of Al, WC, Co and minor phases of  $Al_5W$ . Probably the  $Al_5W$  phase might have been formed at the interface by the reaction between Al matrix and WC-Co cermet particles. Therefore, detailed interfacial studies are necessary in order to fully understand the chemical interaction products formed at the Al7075 and WC-Co cermet interface.

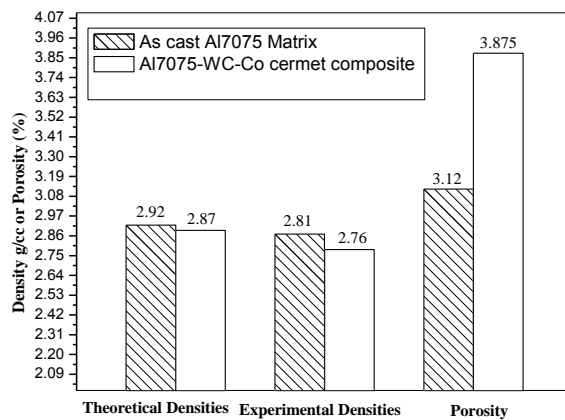


**Figure 7.** X-ray diffraction pattern of Al7075-6Wt% of WC-Co cermet composite prepared at 750°C using melt stirring method

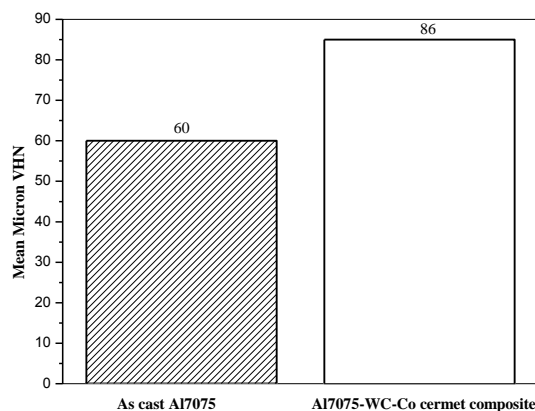
### 3.3 Hardness and Density Measurements

Hardness is a function of the stress required to produce specific types of surface deformation. The micro-hardness of prepared composite and the alloy was measured on polished test specimen by Zwick micro-Vickers hardness tester under a load of 2N with dwell time of 10sec at 30 different locations and an average value of 50 readings was reported. The density measurement was done using water displacement technique (Archimedes's Principle) and theoretical densities were measured using rule of mixture. The results of Density, Porosity and Hardness measurements of the matrix and reinforcements are represented in Figure 8 and 9. Figure 8 shows that measured density of the composite is lower than that of the Al7075 matrix.

The decrease in density is as expected because addition of high denser material to a less density matrix, decreases overall density of the composite. However, porosity of the composite is greater than the porosity of the matrix. The increase in pores can be attributed to factors like gas entrapment during stirring, hydrogen evolution, pouring distance from crucible to mold and shrinkage during solidification. Figure 9 compares the microvickers hardness of Al7075 matrix and Al7075-6wt% of WC-Co cermet composite. Graph clearly says that the composite has higher hardness than the matrix. It has been reported that the presence of hard reinforcement particles offer resistance to plastic deformation and due to the increased strain energy the hardness of the composites is increased at the peripheral of the particles dispersed in the matrix. Further, the increase in hardness due to the addition of WC-Co Cermet particles can be attributed to uniform distribution of cermet particulates leading to particulate strengthening effect of the matrix alloy.



**Figure 8.** Variations in density and porosity of as cast Al7075 matrix and Al7075-WC-Co Cermet composite.



**Figure 9.** Variations in hardness of Al7075 matrix before and after addition of 6wt% of WC-Co Cermet particulates prepared at 750°C.

### 3.4 Tensile properties

Table 2. Tensile properties of Al7075 matrix and Al7075-WC-Co composite.

Composition	Yield Stress N/mm <sup>2</sup>	Tensile Strength N/mm <sup>2</sup>	% Elongation
Al7075 matrix	83.54	101.26	9.45
Al7075-6wt% of WC-Co cermet composite	162.54	190.63	2.52

The tensile properties of the matrix and prepared composites were carried out using computer controlled Instron 8801 Universal testing machine as per ASTM E8 M standards. The tests were carried out on three samples of matrix and composites each and average value is reported in the Table 2. It is clearly observed from the tensile results that the Al7075-6wt% of WC-Co cermet composite has shown higher tensile properties (Yield and Tensile stress) when compared to the matrix alone. An improvement of 94.56% in Yield stress and 88.25% in Tensile strength were obtained with the addition of 6wt% of WC-Co cermet to Al7075 matrix. Improvements in tensile properties (Yield

and Tensile stress) of the composite obtained can be attributed to even distribution of WC-Co cermet particles throughout the Al7075 matrix. The strengthening of the matrix could be due to Orowan strengthening, grain and substructure strengthening due to generation of dislocations and due to work hardening between elastic particles and matrix. On the contrary, additions of 6wt% of WC-Co cermet particles have resulted in decrease in ductility from 9.45% to 2.52% which was as expected. Decrease in ductility could be due to brittleness of the reinforcing WC-Co cermet particles.

#### 4. Conclusions.

Studies on microstructural evolution in Al7075-6wt% WC-Co cermet based composite prepared by stir casting route has led to the following conclusions.

1. WC-Co cermet with an average particle size of 10 $\mu$ m was successfully produced using planetary ball milling technique using Alumina as grinding media.
2. Al7075-6wt% WC-Co cermet based composite was successfully synthesized by conventional stir casting technique at a temperature of 750 $^{\circ}$ C.
3. Microstructural characterizations carried out using SEM studies have revealed fairly uniform distribution of the WC-Co cermet particles in the Al7075 matrix system.
4. X ray diffraction analysis has revealed the presence of major phase of Al, WC, Co and minor phase of Al<sub>5</sub>W.
5. Addition of WC-Co Cermet particles to Al7075 matrix has resulted in improvement in hardness, yield and tensile strength of the matrix while decrease in density and ductility of the matrix.

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