Visual Abstract

Mechanical characterization and tensile fractography of Al7075-WC$_P$-Co$_P$ composite

U. B. Gopal Krishna
Dept. of ME, SIT, Tumkur; Dept. of ME, AIET, Moodabidire, Dakshina Kannada, Karnataka, India
gopalkrishnaub@gmail.com, https://orcid.org/0000-0001-8224-6810

B. Vasudeva, Virupaxi Auradi
Dept. of ME, SIT, Tumkur, Karnataka, India
bva@sit.ac.in, http://orcid.org/0000-0003-3555-9472
vsauradi@gmail.com, http://orcid.org/0000-0001-6549-6340

Madeva Nagaral
Aircraft Research and Design Centre, Hindustan Aeronautics Limited, Bangalore, Karnataka, India
madev.nagaral@gmail.com, http://orcid.org/0000-0002-8248-7603

ABSTRACT. The demand for materials with an unusual combination of properties has increased tremendously at a level that cannot be attained through the use of conventional materials. This is especially true for materials used in aircraft, automotive and power generation applications. The microstructure and mechanical properties of Al7075 – 6, 9 and 12 wt.% WC-Co particles reinforced composites are shown in this study. Liquid metallurgy is used to create the composites. The planetary ball milling method is utilized to turn the WC-Co mixtures into cermets, and the particles with a size range of 30-40 μm are employed as reinforcement. SEM and EDS analyses were used to characterize the microstructure. ASTM standards are used to test the mechanical characteristics of both as cast Al7075 and Al7075-6, 9 and 12 wt.% WC-Co composites. SEM was used to perform fractography study on the prepared composite.

KEYWORDS. Al7075; Cermet; Liquid Melt Method; Mechanical Behavior; Fractography.

OPEN ACCESS

Citation: Gopal Krishna, U. B, Vasudeva, B, Auradi, V., Nagaral, M., Mechanical characterization and tensile fractography of Al7075-WC$_P$-Co$_P$ composite, Frattura ed Integrità Strutturale, 60 (2022) 283-290.

Received: 17.11.2021
Accepted: 31.01.2022
Online first: 27.02.2022
Published:01.04.2022

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INTRODUCTION

The phrase "composite material" has caused a paradigm shift in the field of material science. It presents a new designed material with enhanced qualities for the applications that are required [1]. Among the various types of composites, metal matrix composites have wider applications owing to their enhanced material properties. Aluminium metal matrix composites [AMC] have their own space, particularly in the field of aerospace, marine and automotive industry [1-3]. Furthermore, the properties of the aluminium may rise by converting it as In terms of metallurgical, mechanical and tribological aspects, a thorough examination of the developed properties of metal matrix composites is required. The alloy Al7075 is widely employed in aircraft structures and automotive applications. Several types of reinforcement, such as oxides, carbides, nitrides, and borides, play an active role in improving material qualities [4].

AMCs can be synthesized in a variety of ways depending on their final applications. To meet the above requirements, there are a few options for creating manufacturing techniques and looking for alternative materials. Two of the most extensively utilized manufacturing techniques in the production of aluminium composites are liquid casting and powder metallurgy [4-7]. Ceramic particulate aluminum-based composites have better properties than unreinforced aluminium alloys [7-8]. They are commonly used in tribological applications due to their outstanding strength, density, and wear resistance ratio [9-10]. In this study, the matrix is Al7075, which has zinc as a major alloying component. Ductility, strength and fatigue resistance are all improved with this alloy. The Al7075 matrix alloy is strengthened with tungsten carbide (WC) hard ceramic particulates and soft ductile Cobalt (Co) particulates with particulate size ranging from 30-40 μm. The CERMET form has been used to merge brittle ceramics and ductile metallic elements as reinforcements in the current function.

EXPERIMENTAL DETAILS

The composites Al7075-WC-Co, containing 6, 9 and 12 wt.% of WC-Co particulates are synthesized in the present work. The density of Al7075 is 2.81g/cm^3 and density of WC and Co are 15.6g/cm^3 and 8.91g/cm^3 respectively [11]. The chemical composition of Al7075 and properties of WC and Co are shown in Table 1 and Table 2 respectively. For the present work WC-Co mixture with particle size ranging from 30-40μm are used.

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.45	0.55	1.55	0.56	2.4	0.14	1.3	0.24	Bal.

Table 1: Base alloy Al7075 compositions in percentage.

Property of materials	Density (g/cm^3)	Brinell hardness	Ultimate Tensile Strength (MPa)	Modulus of elasticity (GPa)
Al7075	2.81	150	572	71.7
WC	15.63	1500	5000	686
Co	8.9	470	760	209

Table 2: Properties of Al7075, WC and Co [18, 19]

Stir casting is used to make composites with 6, 9 and 12 % reinforcement in an Al7075 matrix alloy. The alloy matrix has a higher density due to the presence of hard ceramic and soft ductile metallic reinforcements. The density component was crucial in reinforcing the structure and sustaining the wettability levels. As a result, the components are preheated in a heating oven to a temperature of 250°C. A batch of aluminium alloy is first heated to liquid temperature in a graphite crucible. A proper degasification is achieved using a solidhexachloroethane (C_2Cl_6) tablet once the alloy reaches liquid temperature. As a result, the creation of a gaseous mixture is prevented. The reinforcing particles, on the other hand, are warmed to remove any moisture content and improve the wettability conditions. The warmed reinforcement particles were slowly introduced into the matrix at a continuous flow rate. At 300rpm, a zirconia coated stirrer was used to maintain steady stirring. The composite material was immediately poured into the metallic die and allowed to set. As cast samples were examined, Keller's reagent was used to clean and etch them suitably [12]. Specimens are produced in accordance with metallurgical procedures, and microstructural characterization is carried out using a scanning electron microscope. Micro-Vickers hardness tests are carried out on the as cast composite specimens at fifteen separate sites with a load of HV 0.3 and a dwell time of 15 seconds, with an average of the fifteen values taken into account. The tensile test was performed on as cast specimens manufactured according to the ASTM E8 standard.

RESULTS AND DISCUSSION

Microstructural Analysis

Fig. 1(a-d) shows SEM microphotographs of Al7075 matrix and Al7075-WC-Co cermet based composites. The reinforcement is distributed quite evenly throughout the composite. Several aspects influence the form of dendrites during casting, including dendrite discontinuity, dendritic particle growth limitation, and thermal conductivity imbalance between the particles and the melt. Ceramic particles also act as a barrier to dendrite formation, and this effect is more pronounced when the rate of cooling is high [13, 14]. The matrix is well bound to the reinforcing particles, as can be seen. Dendritic interruption can be linked to the shearing of the beginning dendrite arms due to the stirring motion. Mechanical stirring evenly disperses the particles and reduces particle settling during the solidification process [15, 16]. Local solidification occurs as a result of temperature differences between the particles and the melt during particle addition.

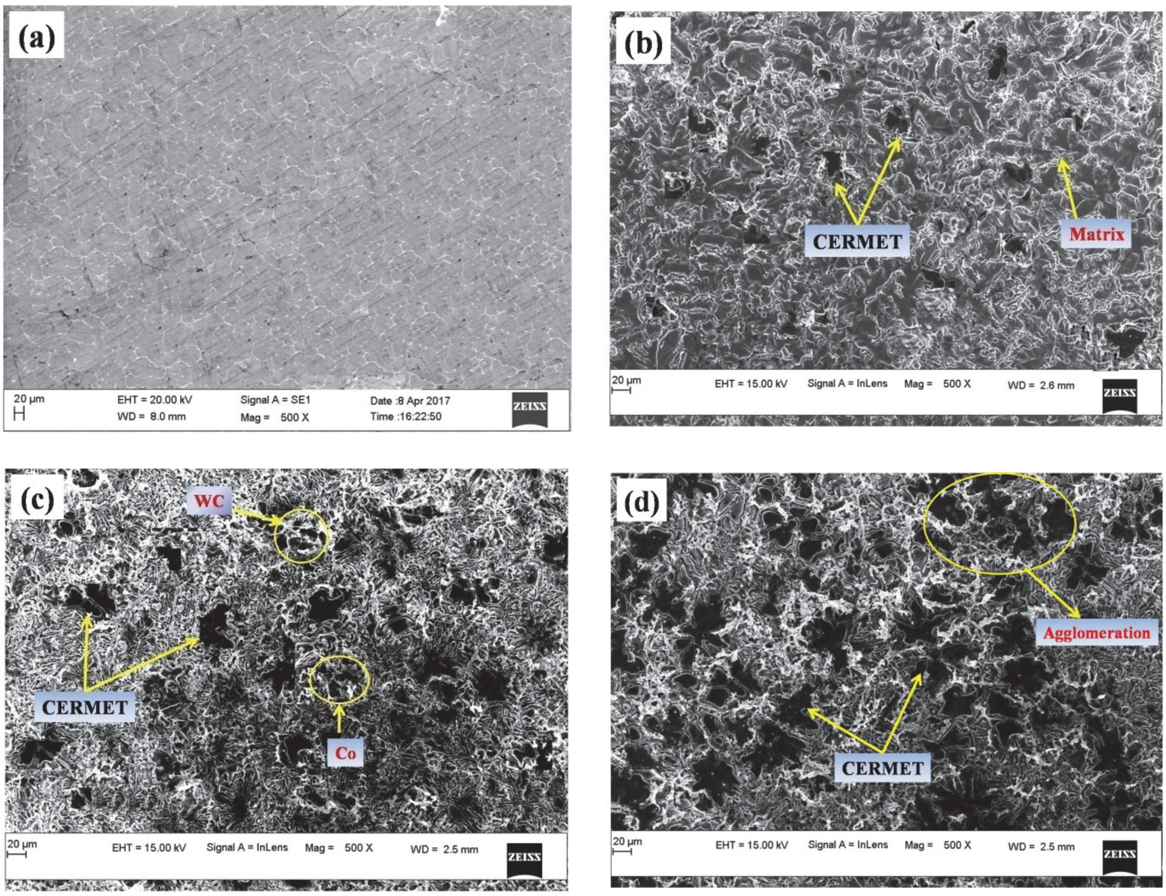


Figure 1 (a-d): SEM images of (a) as-cast Al7075 alloy, (b) Al7075-6 wt.% WC-Co, (c) Al7075-9 wt.% WC-Co and(d) Al7075-12 wt.% WC-Co.

Because the load is transmitted across the interface, the strong interface has superior mechanical and tribological qualities. Because of the presence of hard ceramic particles, which prevent dendrite formation and transform the matrix to a more refined structure, the strength improves. The distance between the particles get minimal as the weight percentage of reinforcement increased. This may also obstruct the movement of the dislocation. As a result, WC-Co is likely to inhibit dislocation movement in the Al7075 matrix. As a result, the composites tribological properties may improve. Elemental analysis is also carried out using EDS on as-cast Al7075 and Al7075 - 6, 9 and 12 wt. % WC-Co reinforced composites and is represented in Fig. 2 (a-d). Fig. 2 (b-d) confirms the presence of elements like Zn, Mg, Si, Co, W and C in the Al alloy matrix.

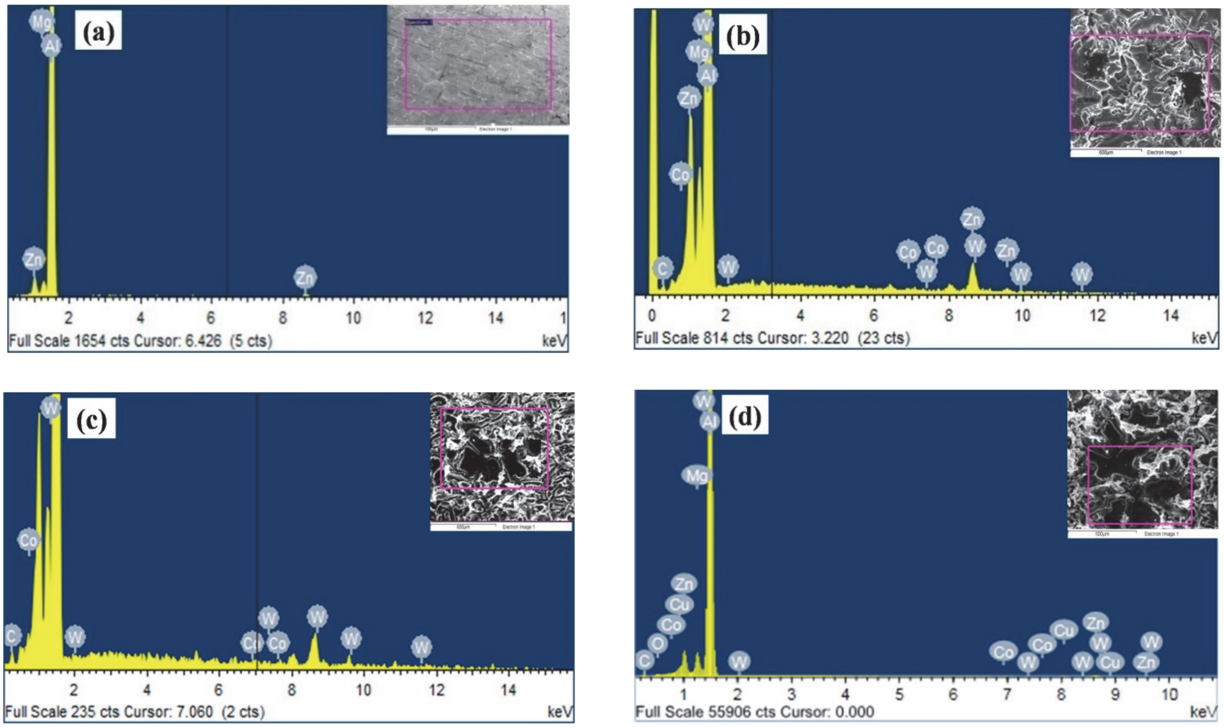


Figure 2 (a-d): EDS spectrum of (a) as cast Al7075, (b) Al7075-6 wt.% WC-Co, (c) Al7075-9 wt.% WC-Co and (d) Al7075-12 wt.% WC-Co composite.

HARDNESS MEASUREMENT

In this work micro hardness is examined on the Al7075 base alloy and composites of Al7075 reinforced with WC-Co particles. The ASTM E384 standard is used to conduct the tests. The indenter digital micro hardness tester from Zwick/Roell was used to calculate micro-hardness. The plot of variation in micro Vickers hardness of Al7075 alloy and Al7075 reinforced with WC-Co particles for various weight percentages is shown in Fig. 3. (6, 9 and 12 wt.%). As can be seen in the graph above, increasing the proportion of WC-Co particles in the matrix alloy improves the hardness of the composite significantly. Because WC-Co particles are hard dispersoids, they contribute positively to the hardness of Al7075-WC-Co composites; the increase in hardness is quite visible and predictable.

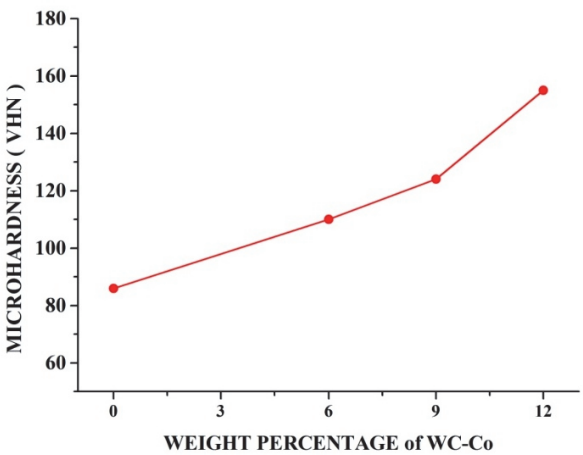


Figure 3: Hardness of Al7075-WC-Co composite with 6, 9 and 12 wt.% variation.

TENSILE STRENGTH

Tensile samples of as-cast and composites are examined using computerized universal testing machine. The samples used for these tests are prepared non-conventionally as per ASTM E8 standard. Fig. 4 shows the graphical representation of ultimate tensile strength and yield strength variations among base alloy and composite. Fig. 5 (a-d) shows the stress strain curves for Al7075 base alloy, Al7075-WC-Co with 6, 9 and 12 Wt.% of WC-Co composite respectively.

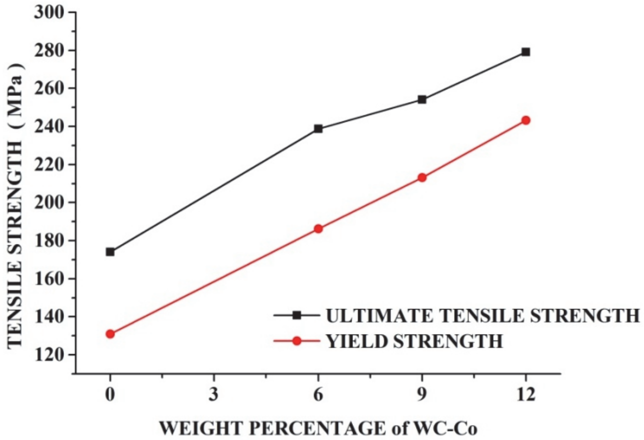


Figure 4: Ultimate tensile strength and yield strength of Al7075-WC-Co with 6, 9 and 12 wt.% variation.

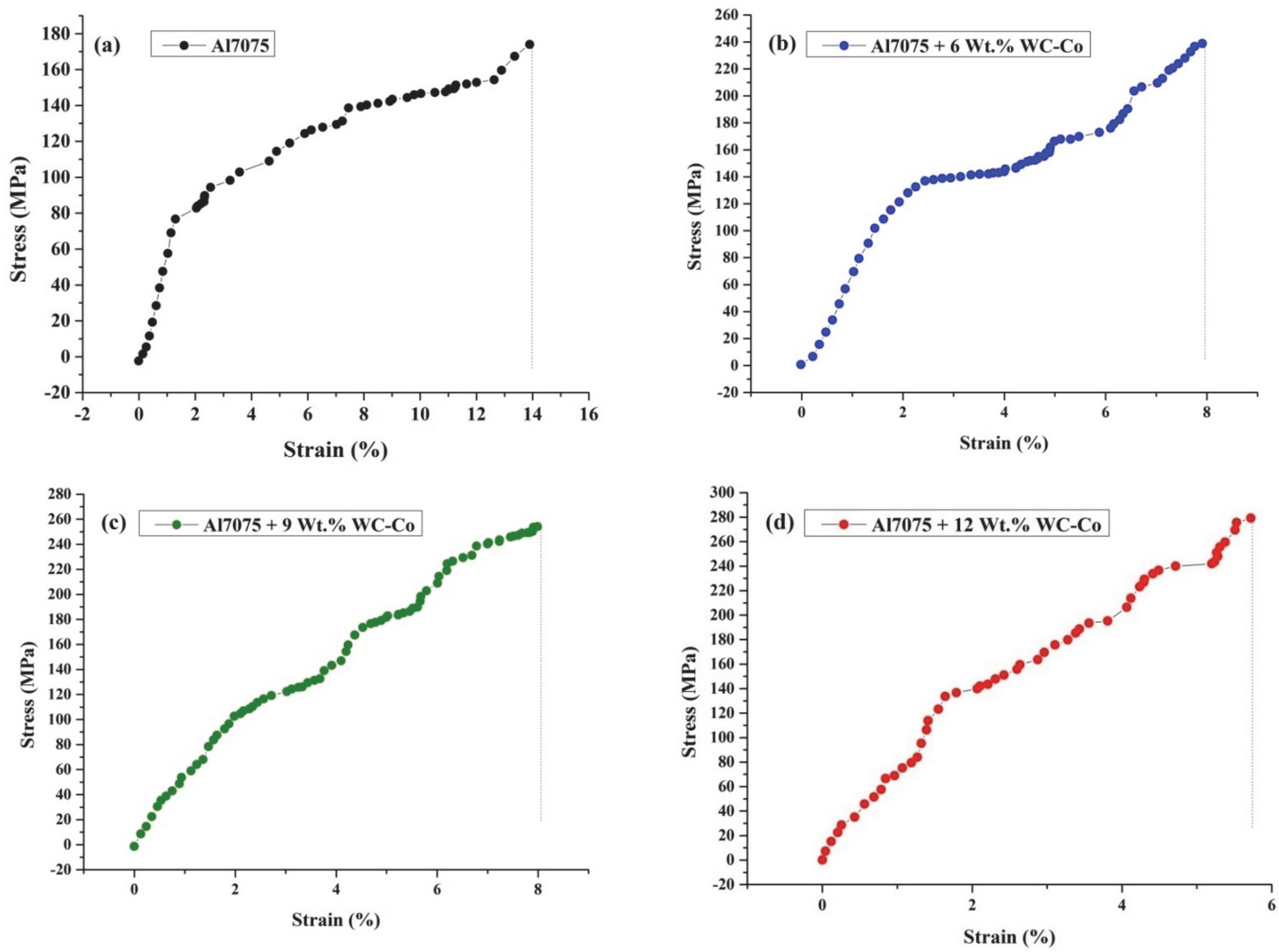
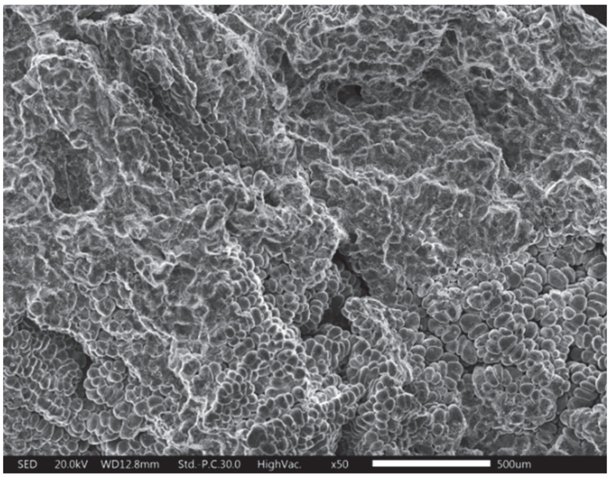


Figure 5: (a-d) Stress-strain curves for Al7075 and Al7075 reinforced with WC-Co particulate composite

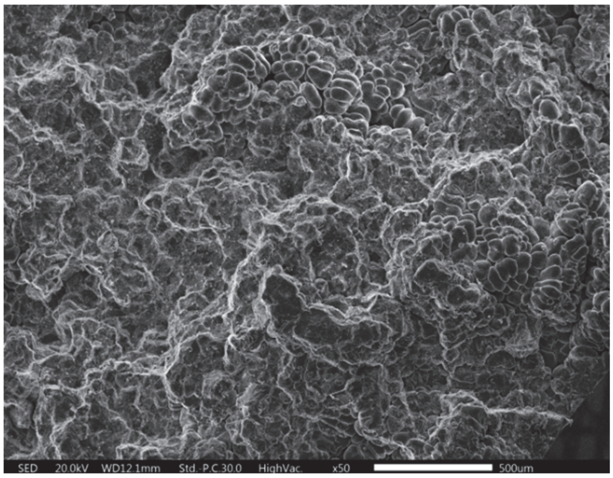
The UTS of the prepared composite increased when the weight percentage of WC-Co reinforcement was increased. For 6, 9 and 12 weight percentages of reinforcements, the improvement in UTS of the generated composite is about 37.24%, 46.04%, and 60.34%, respectively. For 6, 9 and 12 weight percent of reinforcements, the yield strength of the resulting composite increases by around 42.18%, 62.61%, and 85.64%, respectively.
The increased strength is attributed to proper interaction between the matrix and reinforcing components. The greater the grain boundaries, the greater the strength and quality of composites, resulting in increased wear resistance [7-17]. This could be owing to the reinforcement's load transmission to the matrix, which strengthens the structure. The dispersion of hard WC ceramic and Co particles contributes to the increase in strength.

FRACTOGRAPHY

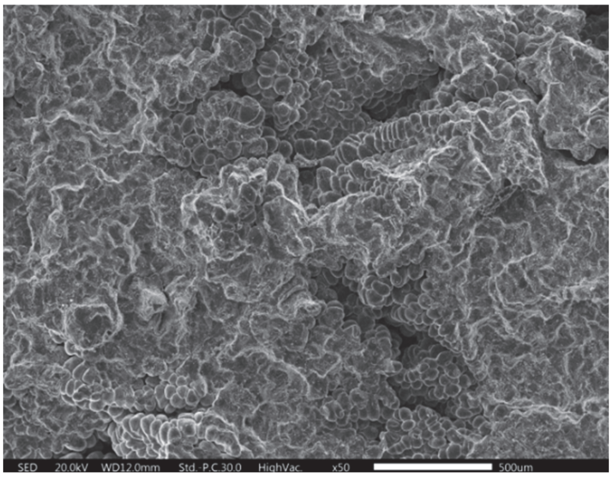
Fig. 6(a-d) demonstrates the tensile fracture behavior of Al7075 and Al7075-WC-Co (6, 9 and 12 wt.%) composite. Fracture surface reveals the very small dimples in the matrix. The interface between particles and matrix stays unchanged, what supports the proposal that the shear strength at the interface is greater than that of the particle fracture. A virtually ductile intermediate fracture with reinforcement dimples can be seen in the composite.



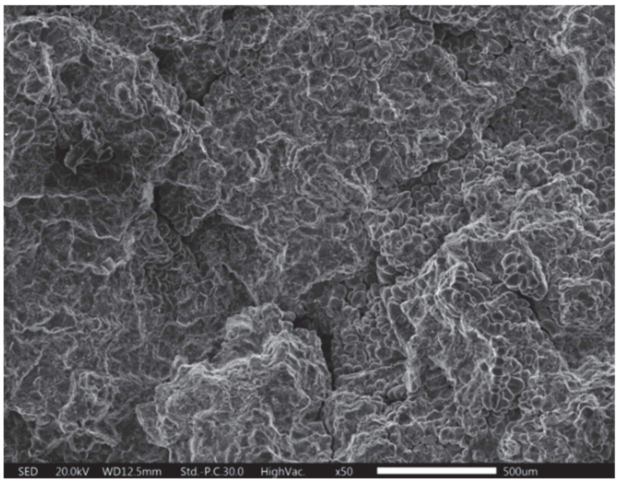
(a) Al7075 matrix



(b) Al7075-6Wt.% WC-Co Composite



(c) Al7075-9Wt.% WC-Co Composite



(d) Al7075-12Wt.% WC-Co Composite

Figure 6(a-d): SEM images tensile fractured surface of Al7075 and Al7075-WC-Co composite with 6, 9 and 12 Wt.% variation

Debonding of the reinforced phase from the matrix material, on the other hand, shows that normal stresses generated at the interface have exceeded the bond strength, resulting in void formation. The restricted flexibility of aluminium alloy in the presence of cermet reinforcing phase is demonstrated by fracture initiation in the matrix. In addition to the aforementioned mechanisms, nucleation of micro voids is followed by void coalescence via void linkage. Thermally generated stresses as a result of a thermal mismatch between matrix and reinforcement can cause Al7075-WC-Co composites to fail.

Conclusions

Using the stir casting method, Al7075-WC-Co composites with 6, 9, and 12 weight percent of WC-Co with particle sizes ranging from 30 to 40 µm were successfully produced. Microstructural analysis and major mechanical performance, such as hardness, ultimate tensile strength, yield strength, and fractography behaviors are examined. The matrix is virtually pore-free as-cast alloy, with evenly dispersed WC-Co in the manufactured composite, as evidenced in SEM micrographs. EDS analysis confirms the presence of elements like Zn, Mg, Si, Co, W and C in the Al alloy matrix. When compared to unreinforced Al7075 as-cast material, the mechanical properties of Al7075-6, 9 and 12 Wt percent WC-Co composites are superior and enhanced.

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