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Effect of cobalt and tungsten carbide particles inclusions into the aluminium composite on the hardness and wear properties

U.B. Gopal Krishna [1] ✉, B. Vasudeva [1], V. Auradi [1], M. Nagaral [2]

[1] Siddaganga Institute of Technology, Karnataka, India

[2] Hindustan Aeronautics Limited (HAL), Karnataka, India

✉gopalkrishnaub@gmail.com

Abstract. Using liquid metallurgy route, Al7075 composites comprising 6, 9, and 12 wt. % WC-Co were developed. When testing composites and Al7075, ASTM standards were followed. Increasing the vol. % of the cermet phase enhances the hardness of Al7075-WC-Co composites, according to the experimental data. The produced composites are analyzed using scanning electron microscopic images and energy dispersive microscopy technique before and after the wear. Improvement of 80.23 % on hardness of the composite are observed over the base alloy. For the composite containing 12 wt. % of WC-Co particulates the wear rate is less than the base alloy and other prepared composites.
Keywords: aluminium, tungsten carbide; MMC; hardness; wear

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Introduction

Aluminium metal matrix composite (AMMC) a paradigm shift in the field of automobiles, aerospace, tools, military applications. The key properties like high strength with light weight, capable wear resistance, protective to corrosive environment, better temperature stability made these composite to use in extensive conditions [1–2]. Series of aluminium are exist which are capable of heat treatable, weldable, adapting to elevated temperatures and impact loads. 7075Al with Zn and Mg as major alloy exhibits all those properties and made selecting it as matrix among other aluminium series. Reinforcements like B_4C, WC, Al_2O_3, TiB_2 etc., can be added into the base matrix which enhances the properties stated at maximum level [3–4]. The processing of AMMCs is challenging (wettability concern) in stir casting method, when it processed with the addition of high dense objects as reinforcements [5]. In common, the composites prepared with ceramics as reinforcements exhibit high hardness with poor ductility in nature.WC is a hard ceramic particle reinforcement for Al alloy matrices that is employed in high-temperature applications. With a density of 15.8 g/cc tungsten carbide is a famous refractory metal that is used in fabrication of cutting tools, drill bits, single point cutting tool and extrusion dies. Drill bits and cutting tools composed of WC particles are commonly used in the oil industries [6]. At elevated and room temperatures, the combination of WC and Co particles will have increased characteristics. Low thermal coefficient of thermal expansion and high strength are expected when hard ceramic WC particles reinforced with Co particles for carbide tool products [7]. Since they achieve excellent wear resistance, hot hardness, low coefficient of friction and good chemical stability properties, cermet based composites can be successfully utilized for high speed cutting tool for better surface finishing and high class cutting applications in the current era [8]. Utilization of aluminium based composites in variety of industries can be observed due to its high strength because of the addition of proper reinforcing materials and practical wear resistance, including aviation, architectural, energy sector, vehicle industry, construction, naval, army based products, sports, and recreation. This sparked interest in investigating the effects of adding desirable combinations of WC-Co as reinforcement to the characteristics of Al7075 alloy. Correspondingly the improvement in hardness and wear rate of the composite compared to base alloy can be expected.

Experimental details

Chemical composition of Al 7075 alloy, which is used as a matrix, is shown in Table 1. Al7075 alloy is a significant alloying element that contains zinc, magnesium, and copper. This alloy's properties are based on its strengths and resistance, and it is a major alloy used in aircraft applications (Landing gear, wing body, brakes etc). In comparison to other aluminum alloysseries, as the 7 series aluminum have greater corrosion resistance capacity, they have made their way into structural applications.

Table 1. Chemical composition of Al7075 alloy

Elements	Silicon	Iron	Copper	Manganese	Magnesium	Zinc	Aluminium
Amount in wt. %	0.42	0.51	1.60	0.61	2.51	1.50	Balance

In the current work tungsten carbide (WC) is selected as reinforcement; a well-known cutting tool material with a hardness of 1500 BHN and density of 15.63 g/cc. As previously stated, the reduction in ductility of composites is overcome by adding Cobalt (Co), a soft ductile material with density of 8.90 g/cc, as second reinforcement material. Both WC and Co particulates are fused to cermet form with the help of planetary ball milling operations and used it as combined reinforcements. The presence of cobalt can act as an internal lubricant, improve reinforcement wettability, and increase composite ductility. Following the ball milling operation, the ceramic mixture is sieved, and a particle size of 400 mesh or 37 μm is chosen as the intermediate particle size.

The composite was produced by adding 6, 9, and 12 wt. % of WC-Co particulate reinforcement to the 7075Al alloy matrix. A quantity of 400 grams of matrix is brought to molten state in crucible (graphite-clay) using resistance furnace. Careful control of temperature is done using a digital temperature controller to an accuracy of ± 5 °C. When the temperature of the liquid metal reaches 730 °C, solid hexachloroethane (C_2Cl_6) is used to drive out entrapped gases. Constant stirring is maintained at 300 rpm using steel rod coated with zirconia. Into this vortex, preheated WC-Co cermet is introduced. After the addition of reinforcement, constant stirring action is performed for 60 seconds duration to ensure a complete distribution of the reinforcements into the matrix. Later, the well stirred and constant temperature maintained liquid metal mixed with the reinforcements has been poured into a permanent cast iron preheated mould having dimensions of 125 mm length and 15 mm diameter. These prepared composites were characterized microscopically using SEM and EDAX studies. For microstructural characterization, central portions of the castings having size of 5 × 10 ×5 mm were taken and were metallographically polished. The electropolished samples were etched using Keller's reagent.

As-cast samples and composite samples are prepared for wear test operating conditions and hence the samples are prepared with the dimensions of 30 mm length and 10 mm diameter as per ASTM G99 standard. The sliced samples are then metallographically polished to worn out preliminary layers on its end. Using DUCOM pin on disc wear testing machinethe prepared samples are tested. All the samples are tested under dry sliding conditions only. The wear samples are tested for varying load, varying speed and varying distance conditions.

Results and discussions

Microstructure analysis. Composite prepared for 37 μm particle sizes of WC-Co reinforcement are subjected to SEM analysis and corresponding microphotographs are shown in Fig. 1. During casting, the structure of dendrites gets altered, affected by numerous variables, such as discontinuity of the dendrites, thermal conductivity imbalance, lack of dendrite growth between particles and melt. Here the ceramic particles act as an obstruction for dendrite growth which is more prominent when the rate of cooling is high.

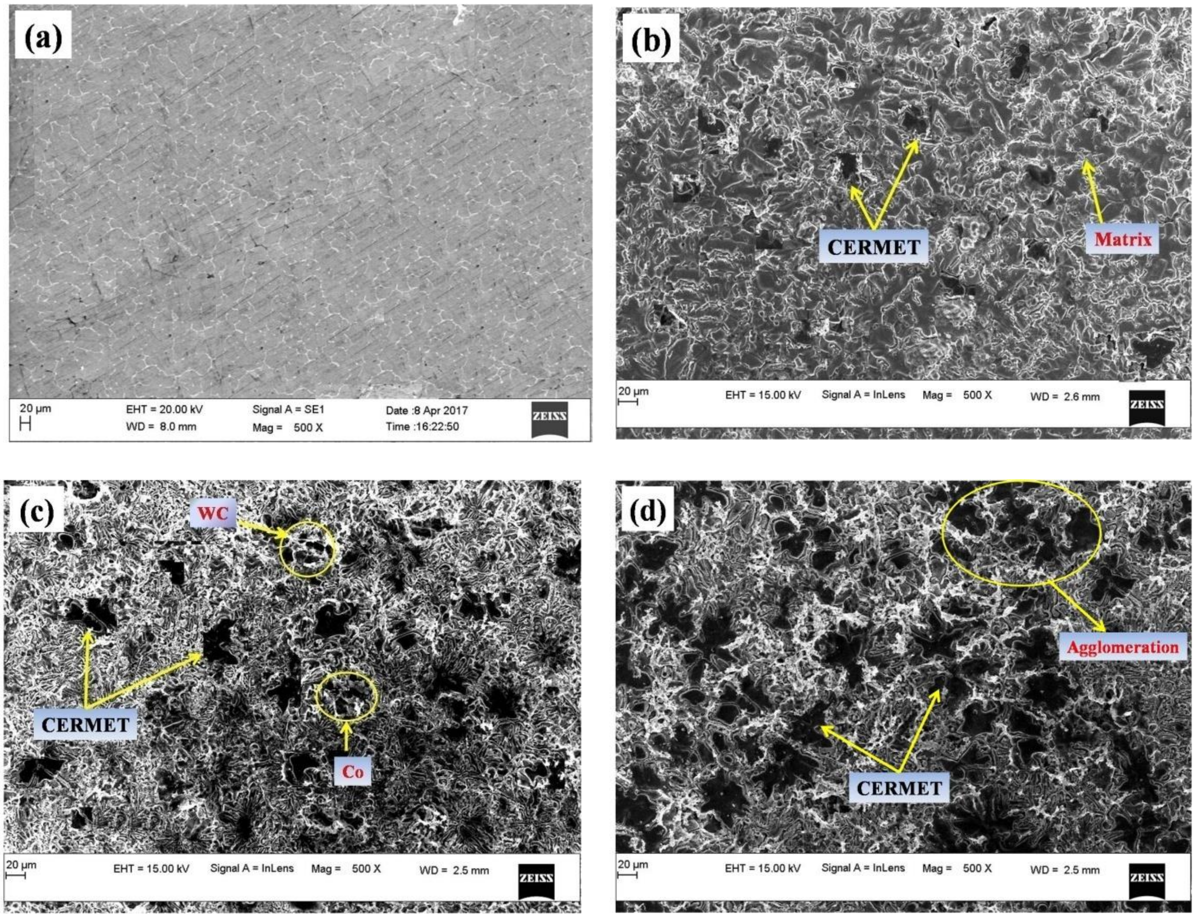

Fig. 1. SEM images of (a) as– castbasealloy, (b) Al7075 + 6 wt. % WC-Co, (c) Al7075 + 9 wt. % WC-Co and(d) Al7075 + 12 wt. % WC-Co composite

Mechanical stirring action disperses the particles consistently as well as reduces settling of the particles during the solidification and shearing of the starting dendritic arms can relate to the dendritic fracture because of the excess stirring action [9,10]. Local solidification takes place due to the variations in the temperature with respect to matrix and reinforcements. Finally, synthesized composite shows the uniform and homogeneous dispersion of WC-Co particles within the alloy matrix.

The strong interface offers excellent properties enhancement for mechanical and tribological zone, as the load transmission occurs. Due to existence of hard ceramic particles which limits the dendrites development and changes the matrix with a progressively refined structure results in improving the strength. As the reinforcement's weight percentage rises, the minimum distance between the particles is seen. Additionally, this might prevent the dislocation from moving.

EDAX analysis. As-cast base alloy Al7075 and Al7075 + 6, 9, and 12 wt. % WC-Co particles added composites underwent an elemental analysis using EDAX analysis. Figure 2 displays the findings. The elemental analysis of the Al7075 + 6, 9, and 12 wt. % WC-Co composite shown in Fig. 2(b-d) confirms the presence of W, Mg, Co, Zn, C, Si in the matrix of the Al alloy.

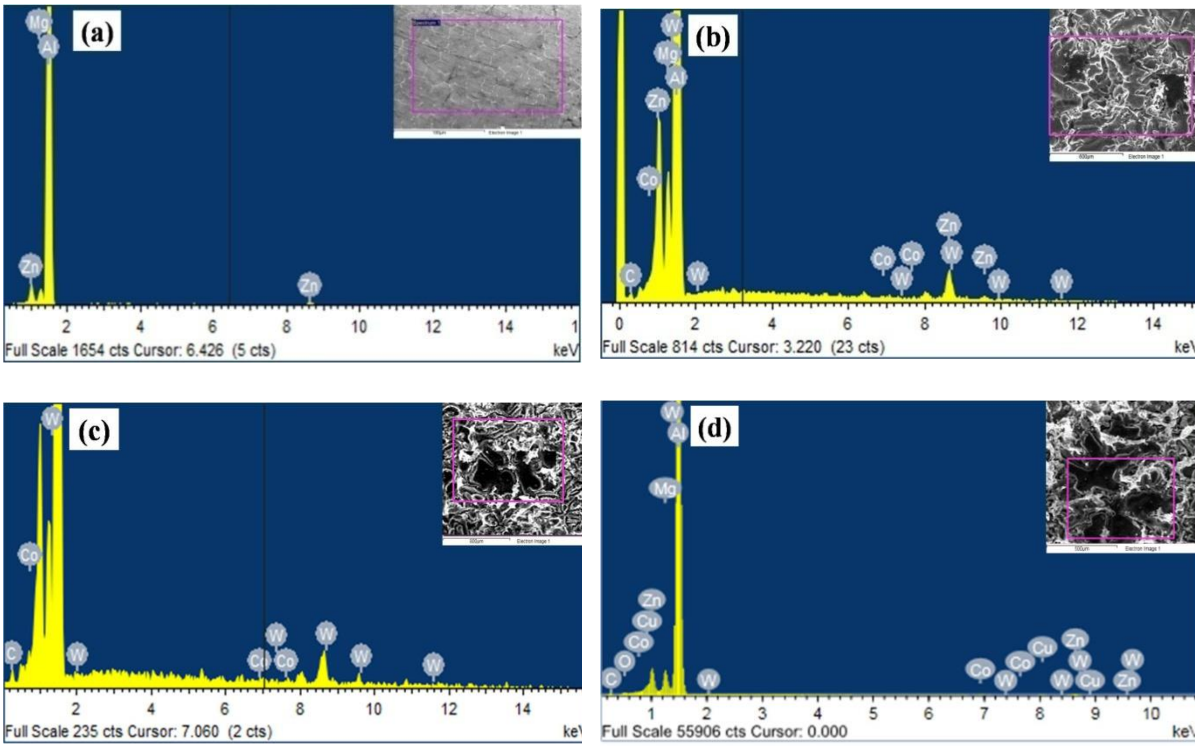

Fig. 2. EDAX spectrum of (a) as - cast Al7075, (b) Al7075 + 6 wt. % WC-Co, (c) Al7075 + 9 wt. % WC-Co and (d) Al7075 12 wt. % WC-Co composite

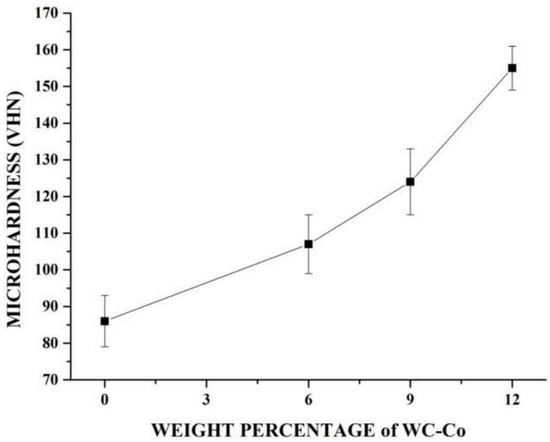

Fig. 3. Microhardness of as-cast Al7075 and Al7075 reinforced with 6, 9 and 12 wt. % of WC-Co particles

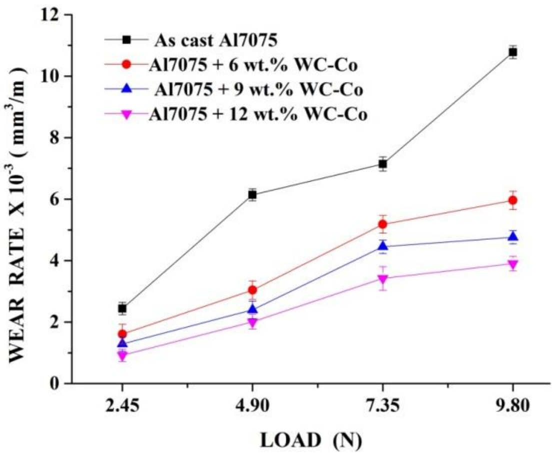

Fig. 4. Impact of variable load on wear rate of the prepared composite keeping sliding speed and sliding distance as constant

Evaluation of hardness of the composite. Vickers microhardness testing is performed on both manufactured composites and as-cast metal. The hardness readings for the Al7075 alloy as-cast and the Al7075 reinforced with WC-Co particles at different weight percentages (6, 9, and 12 wt. %) are shown in Fig. 3. The graph below demonstrates how the toughness of the composite grows significantly as WC-Co particle quantity is increased. Al7075 reinforced with WC-Co composites for 12 wt. % of the particle exhibits a hardness enhancement of around 80.23 % when compared to Al7075 alloy. WC-Co particles greatly improve the hardness of Al7075-WC-Co composites because they are tougher and harder than other materials. This increase in hardness is both evident and predicted. As stated by Velmurugan et al. [11], earlier research has shown that hardness factors are always directly proportional to the hardness of reinforcing particles. Localized matrix deformation during indentation is caused by tougher and harder micro tungsten carbide and cobalt particles present in the lattice. It is clear that the bulk of composites are harder than the matrix. The hard reinforcing particles, which act as a protection to slide dislocation movement within the matrix, are what give materials their increased hardness [12,13].

Wear rate analysis. Impact of variable load on wear rate. The effects of increasing load on the rate of wear for as-cast Al 7075 and Al 7075 + 6, 9, and 12 wt. % of WC-Co particulate composite with varied loads are tested by maintaining the speed (400 rpm) and sliding distance (500 m) consistent (2.45, 4.90, 7.35, and 9.8 N). Figure 4 demonstrates that for all composite materials, the wear rate rises with increasing load and falls with decreasing load. The alloy Al7075 has the highest rate of wear when it is cast. Ramesh et al. [14] claim that, as the applied force is increased, both the as-cast Al and composite specimens experience increased wear loss. Furthermore, the data definitely shows that at a specific transition load, incremental volumetric wear loss observed in both reinforced and unreinforced materials. Pressure at the pin-on-disc contact grows as load increases. Due to the fact that metals usually contain an oxide layer, the wear analysis for maximum loads results in increased material losses.

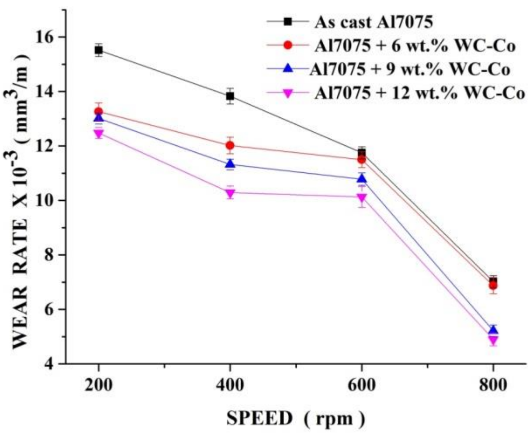

Fig 5. Impact of variable speed on wear rate of the prepared composite keeping constant load and sliding distance

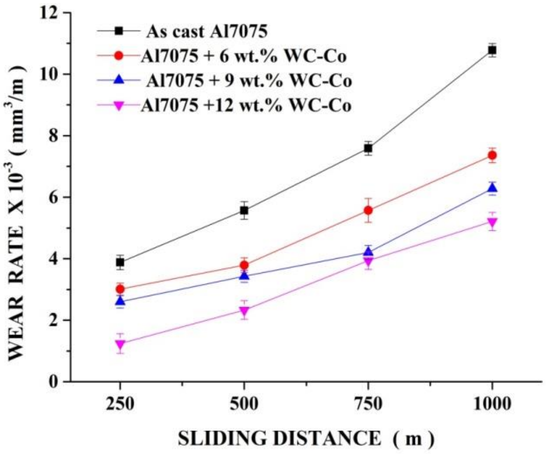

Fig. 6. Impact of variable sliding distance on the wear rate of the prepared composite keeping constant load and speed

Impact of varying speed on wear rate. The impact on the wear rate for the increasing speed on as-cast Al7075 and Al7075 reinforced with WC-Co with 6, 9, and 12 wt. % WC-Co composite is evaluated by keeping the constant load (9.8 N) and constant sliding distance (500 m). Numerous studies have demonstrated that increasing sliding speed/velocity leads to increased wear, especially at higher sliding speeds [15,16]. Figure 5 illustrates how the rate of wear decreases as speed increases and reaches its maximum at lower speeds. At higher speeds, the contact surface might be decreased. The material's surface becomes smoother as temperature rises, which encourages yielding and leads to delamination of the worn surface. As the speed increases, the material deteriorates because of an increase in contact temperature. Debris is eliminated by sliding motion due to wear and weakened bonding at the contact. The WC-Co composite surpasses the base alloy with respect to wear resistance. The thick layer created by solid lubricating coating may fracture at higher sliding speeds. Furthermore, plastic deformation between the mating surfaces is increased due to high temperature caused due to the sliding speed, which boosts the volumetric wear loss and asperity junction density.

Impact of varying sliding distance on wear rate. Al7075 as-cast and Al7075 reinforced with WC-Co at 6, 9, and 12 wt. % wear out more quickly at higher speeds. The evaluation of WC-Co composite uses a load of 9.80 N and a 400 rpm constant speed. Figure 6 makes it plainly evident that, due to the contact surface weakening caused by heat during the experiment, the rate of wear in composite rises with increasing sliding distance. Because of the longer length of contact between the disc and pin or specimen, temperature conditions vary, in fact getting warmer as the sliding distance rises. The Al7075 matrix alloy and WC-Co reinforcement particulates have enhanced interfacial resistance due to the high surface bond, which hinders particle pull from the Al7075 matrix. Hence, it can be inferred from the aforementioned analysis that the composite reinforcement's greater weight percentage and smaller particle size caused the rate of wear of the samples to be lower than it was for Al 7075 cast as-cast. It may be due mostly to the reinforcing particles' in the matrix having a larger contact surface area.

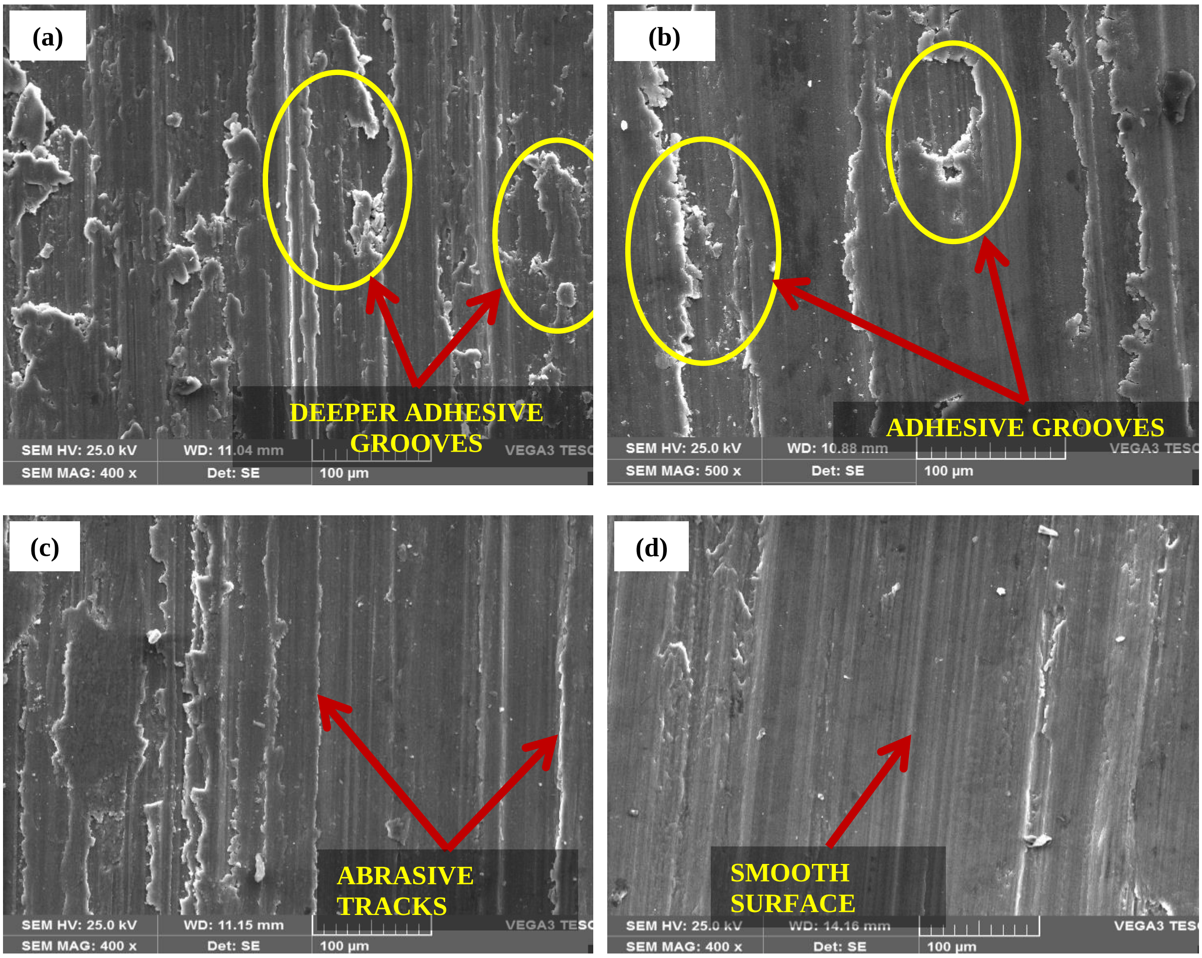

Fig 7. Images showing worn surfaces of (a) as–cast Al7075 alloy, (b-d) Al7075 reinforced with WC-Co at different compositions (6, 9 and 12 wt. %) with a load of 9.8 N, sliding disc speed of 400 rpm and sliding disc distance of 500 m

Worn surface studies. Figure 7 depicts a composite made of WC-Co particles and demonstrates the presence of grooves that are both shallow and sticky. As the weight percentage of the reinforcement grows in the composite, the area that originally formed grooves became smoother. The composite displays stronger wear resistance than the as-cast alloy because there is little material loss and there is a maximum reduction in wear rate. The ease with which the composite surface delaminates depends on both the wt. % of reinforcement and the particle size. In comparison to the alloy as cast, Al7075 reinforced with 12 wt. % WC-Co composite shows very little delaminated area and the formation of grooves, according to a general analysis of the worn surface.

Conclusions

(1) Use of WC-Co particulates as reinforcement in preparation of Al composites is successful.
(2) Studies utilising SEM and EDAX analysis have shown that the reinforcements in the matrix system are distributed fairly uniform.
(3) Al7075 reinforced with WC-Co composites for 12 wt. % of the particle exhibits a hardness enhancement of around 80.23 % when compared to Al7075 alloy.
(4) Wear rate effect of the composite under different load, speed and distance shows good wear resistance compared to base alloy.

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THE AUTHORS

U.B. Gopal Krishna
e-mail: gopalkrishnaub@gmail.com

B. Vasudeva
e-mail: bva@sit.ac.in

V. Auradi
e-mail: vsauradi@gmail.com

Madeva Nagaral
e-mail: madev.nagaral@gmail.com