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Effect of Percentage Variation on Wear Behaviour of Tungsten Carbide and Cobalt Reinforced Al7075 Matrix Composites Synthesized by Melt Stirring Method

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Abstract

Aluminium matrix composites (AMC's) focus primarily on improved specific strength, high temperature and wear resistance application. Aluminium matrix reinforced with ceramic particulates has good potential. With high strength and sensible wear resistance properties AMCs found their applications within the field of automobile components, defence materials, die and gear materials, etc. In the present work, the hard ceramic particulates of tungsten carbine (WC) and soft ductile particulates of cobalt (Co) mixtures are used as reinforcements (at 6 and 9 wt%) in CERMET form with a particle size range from 10 to 15 µm. The processing of composite is done by the stir casting method. Optimized processing temperature technique is adapted in processing of composite. The presence of the homogeneously distributed particulates is observed through scanning electron microscope (SEM). XRD analysis also reveals the presence of reinforcement particulates and other phases. Dry sliding wear behaviour of Al−WC–Co composite samples was analysed with the help of a pin on disc wear and friction monitor. The present analysis reveals the improved wear resistance of composite over the base alloy. Synthesized composites exhibit superior wear resistance property over the base alloy. Worn surface morphology was studied with the help of SEM in order to observe the wear behaviour of the samples.

Keywords Al7075−WC–Co · Tungsten carbide · Cobalt · CERMET · Ceramic composite · Wear

1 Introduction

The recently updated technical advances in the field of aluminium matrix composites (AMC) have attracted researchers to engage in various forms of research in these fields. The produced composites are exhibiting superior properties which prompt the usage in many engineering applications. The properties like stiffness, high yield strength, high tensile strength and high wear resistance [1, 2] can be observed in the light metal composites if it is synthesized in a right method.

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Because of their low weight and excellent thermal conductivity properties, aluminium alloys are favoured engineering materials in the automotive, aerospace and mineral processing industries for producing highly performing components that are used for various applications. Al7075 is one of the aluminium alloy series that has received a lot of attention. Al7075 alloys are preferred in the aerospace and automotive industries because of their high strength and durability [3]. Aluminium alloy composites have a lot of appeal because of their high strength, crack durability, and wear resistance and stiffness. When reinforced with ceramic particles, these composites are also superior in design for high-temperature applications [4]. Aluminium alloys, on the other hand, have weak tribological properties. As a result, research into the tribological behaviour of aluminium-based materials becoming more relevant. The enhancement of wear properties can be achieved by adding several types of reinforcements like boron carbide, tungsten carbide, alumina, silicon carbide, etc., into aluminium matrix in the form of micro- or nanoparticulates [5]. Cylinder blocks, pistons, piston insert rings, brake discs and callipers are among the uses for ceramic particulate reinforced composites. It has been stated that as the volume fraction of reinforcement's increases, the wear resistance of the composite increases [6]. Based on their final applications, AMCs can be synthesized in various ways. There are a few choices for developing manufacturing processes and seeking alternative materials to satisfy the above requirements. Out of many fabrication techniques, liquid casting technique and powder metallurgy technique are wide adopted methods in processing of aluminium composites.[4–7]. Ceramic particulate aluminium-based composites have stronger enhanced properties than unreinforced aluminium alloys[7, 8] and are most commonly used in tribological applications because of their high strength, density and wear resistance ratio [9, 10]. On the wear resistance properties of particulate reinforced Al7075 composites, it can be concluded that there is insufficient evidence of evaluating CERMET-based reinforced Al alloy composite. In this present work, Al7075 with zinc and magnesium as a primary element is used as matrix. Al7075 matrix alloy is reinforced with hard ceramic particulate of tungsten carbide (WC) and soft ductile particulate of Cobalt (Co) are used with a particle size range of 10−15 µm. Al7075 alloy wear resistance is improved by adding WC–Co particulates in steps of 6 and 9 wt%. To know the significance of the addition of weight percent reinforcement on the wear behaviour of Al alloy, wear studies have been carried out as per AS™ standards. During the present research, work limitation is found with the density factors. The reinforcements WC and Co used in the current study has higher densities of 15.63 g/cc and 8.9 g/cc, respectively, compared with base alloy Al7075 density of 2.81 g/cc; found a limitation in preparation of the composite. To overcome the wettability and settling down deficiencies of reinforcement into the Al7075 matrix optimum stirring speed and stirring time was adopted. Corresponding details to overcome the wettability condition and the significance of the composite prepared are explained in detail below.

2 Details of Experiments

2.1 Raw Materials Used

The Al7075 alloy with zinc and magnesium as the key material is used as a matrix in the present work. Table 1 presents the corresponding composition of the alloy used. The properties of the alloy used can be customized via the heat treatment process, and under high conditions, it also has excellent strength [11].

The reinforcements used in this present work are WC and Co. The particulate mixtures are brought to the CERMET form using planetary ball milling process and used the same by extracting particle size of 10−15 µm size by sieving analysis. During the ball milling process, the ceramic particulates are cold welded [12] with metallic particulates and a surface layer of metallic finish is achieved. The presence of these combinations may exhibit a better ductile property and wear resistance in the composites.

2.2 Composite Preparation

Composite with 6 and 9 wt% of the reinforcement to Al7075 matrix alloy is synthesized by stir casting method. The stir casting setup used for the processing of composite are shown in Fig. 1. The presence of hard ceramic and soft ductile metallic reinforcements are owns higher densities than the matrix alloy. The density factor played a vital role in the addition of reinforcement and maintaining the wettability levels. Therefore, the components that are used are preheated to 200 °C temperatures using a heating oven.

Initially, a batch of aluminium alloy is melted in a graphite crucible up to its liquidus temperature. Once the alloy reaches liquidus temperature, a proper degasification is performed using solidhexachloroethane (C_2C_{16}) tablet. Thereby, ensuring the formation of gaseous mixture is eliminated. On the other end, the reinforcement particulates are also preheated to remove any moisture content in it and to increase the wettability conditions. Once the liquidus temperature

Fig. 1 Stir casting setup used for the composite processing

Table 1 Composition of Al7075 alloy in %

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.4–0.5	0.5–0.55	1.5–1.6	0.5–0.6	2.3–2.5	0.15	1.2–1.5	0.2–0.25	Balance

reaches 768 °C, the preheated reinforcement particulates were added slowly with constant flow rate. A constant stirring was performed with zirconia-coated stirrer at 300 rpm. Immediately, the composite mixture was poured to the metallic die and allowed to solidify.

2.3 Sample Preparation

After successful solidification, the samples are taken out of metallic die and middle portion was cut and taken for sample preparation for microstructural characterization. Sliced composite samples are polished using disc polishing machine using different grade size of silicon carbide emery papers followed by velvet cloth and diamond paste. The entire processes are carried out as per metallographic procedure of sample preparation. The wear samples are prepared as per G99 standard and wear studies are carried out by using computerized DUCOM wear testing machine as shown in Fig. 2. During the testing, the composite samples are made to slide on EN32 steel disc and corresponding readings are noted.

3 Results Obtained

3.1 Microstructural Observations

Microstructural investigations are performed using scanning electron microscope (SEM) equipped with EDX (Hitachi Su Model) to observe the reinforcement distribution. Figure 3a–c represents the SEM images of as-cast Al7075 alloy and Al7075 alloy combination with 6, 9 wt% of WC–Co particulates. Microstructure of WC−Co reinforced Al7075 matrix composite reveals the homogeneous uniform distribution of reinforcements over matrix. Si and α-Al are distributed at the boundaries of Al7075 matrix can be observed

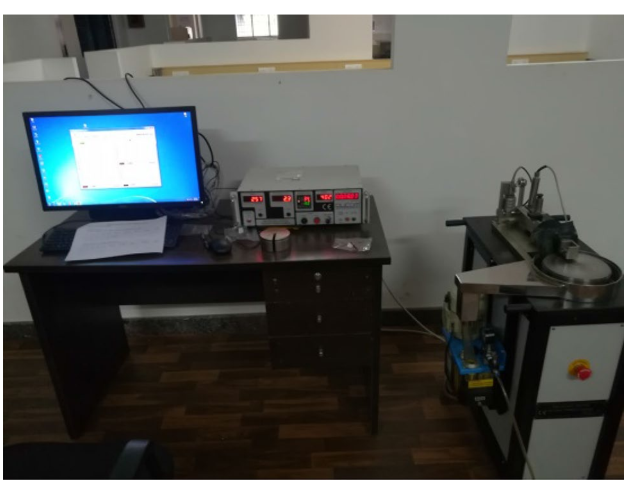


Fig. 2 Computerized DUCOM wear testing equipment

in the microstructure. Figure 3d–e and f–g represents EDAX analysis of surface of Al7075−6 wt% and 9wt% WC−Co composite specimen which signifies the existence of tungsten (W), carbon (C) and cobalt (Co) in the Al7075 matrix thereby confirming the presence of WC−Co particulates.

3.2 XRD Analysis

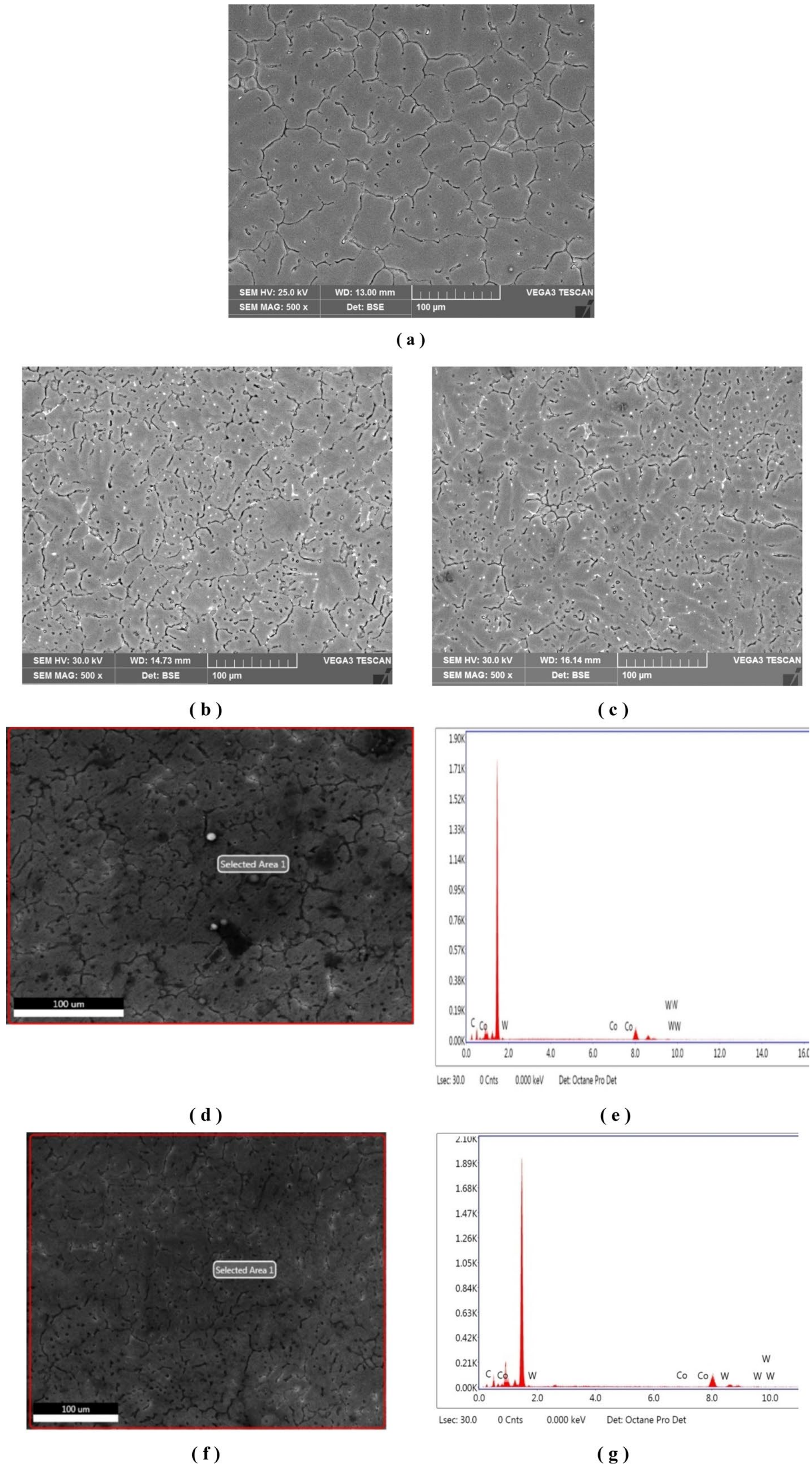
X-ray diffraction (XRD) technique is that the wide used methodology for part or phase recognition, identification and determination of crystallization and particle size. The X-ray diffraction analysis of the Al7075-6 and 9 wt% of WC–Co cermet composite was done by using XRD Machine−7000: M/s Shimadzu Analytical India PVT. Ltd. and also the outcomes are represented in Fig. 4a–b, respectively. The 2θ 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 Al13Co4 [JCPDS No. 44-1304], α-W2C [JCPDS No. 35-0776], Al9Co2 [JCPDS No. 30-0007] phase might have been formed at the interface by the reaction between Al matrix and WC–Co cermet particles. By the observation of XRD peaks, we can clearly point out there is no peaks indicating the oxide formation in the composite.

3.3 Wear Analysis

3.3.1 Wear Rate Analysis by Varying Load

The differences in matrix wear rate and 6 and 9 wt% WC–Co reinforced composite with constant sliding distance and speed of 500 m and 400 rpm under different loading conditions are shown in Fig. 5. It is apparent from the figure that when compared to unreinforced alloy at all loads, the addition of WC and Co particles results in a lower wear rate. The applied load has a significant impact on the wear rate of Al alloys and composites, and it is the most important factor influencing wear behaviour [13–15]. Load at the pin-on-disc interface becomes higher with increasing load. The wear rate is lower at lower loads. The wear rate of composites varies linearly with the usual load, which is an example of Archard's law, which is significantly lower in case of composites [15]. The volumetric wear loss for matrix alloys and composites increases as the load increases. The wear resistance of the composites, however, was superior to the matrix alloy at all loads tested [16]. Since Al is a softer material, the Al7075 alloy undergoes adhesive wear resulting in higher wear rate. In the prepared composite, the presence of hard ceramic particles WC and Co particles will resist the pressure applied and the bonding between Al, WC and Co

Fig. 3 SEM images of **a** Base alloy, **b** 6wt% composite, **c** 9 wt% composite, **d**–**e** EDAX spectrum of the 6 wt% composite, **f**–**g** EDAX spectrum of the 9 wt% composite



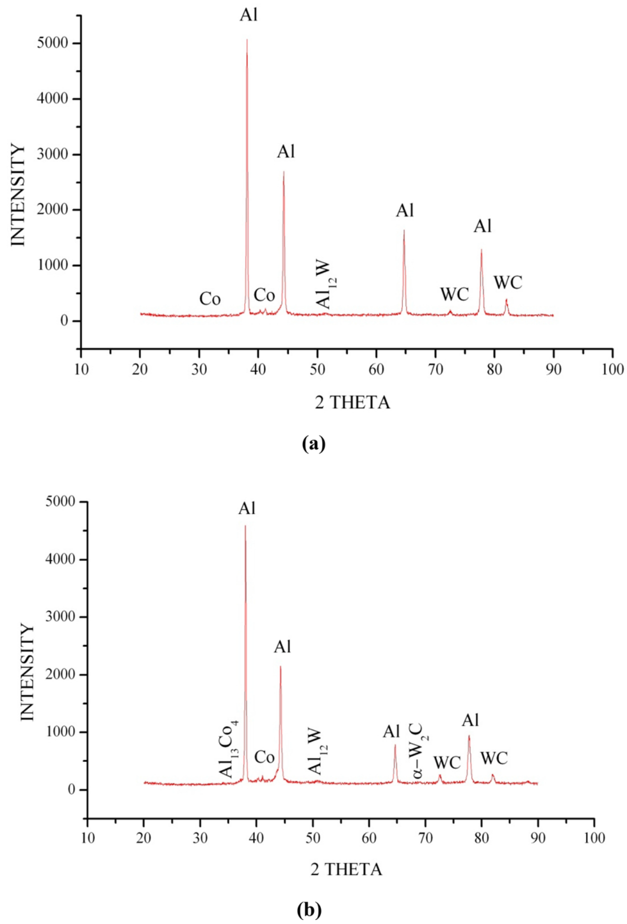


Fig. 4 XRD patterns of **a** 6 wt% WC–Co composite **b** 9 wt% WC–Co composite

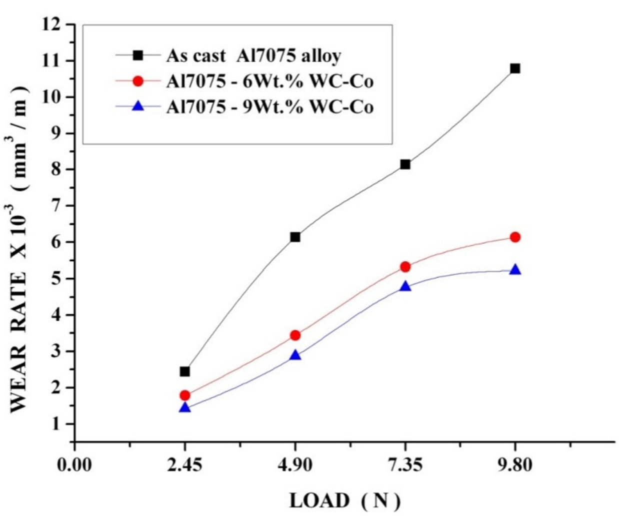


Fig. 5 Graph showing the wear rate of Al7075 alloy and Al7075—6 and 9wt% of WC–Co composite under different loading conditions

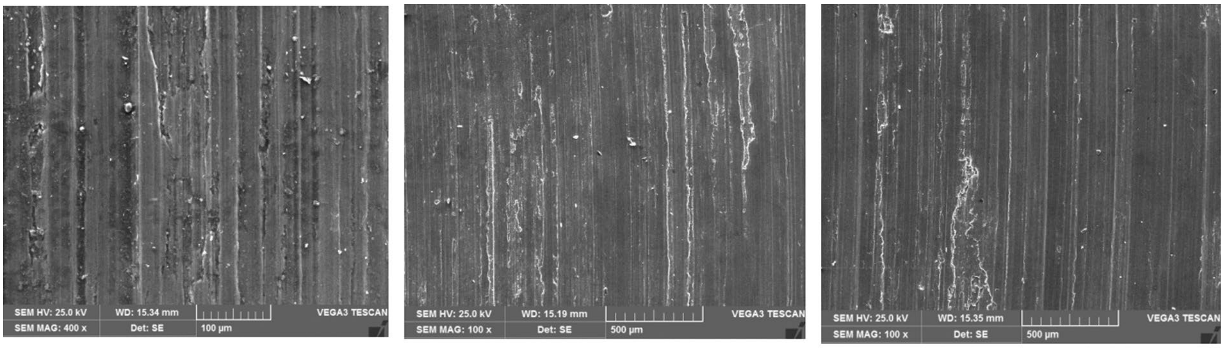
particles also prevents material loss from the contact surface, resulting in abrasive wear with a reduction in wear rate.

Figure 6 represents SEM photographs of worn surfaces of as cast Al7075 alloy and its WC–Co reinforced composite at an applied load of 2.45, 4.9, 7.35 and 9.8 N with constant sliding distance of 500 m and speed of 400 rpm. Damaged regions can also be seen in the SEM micrographs, which could result in flake-shaped debris. There is a tendency for the reinforcement in Al-based MMCs with reinforcing stages, such as WC and Co, to act as a second-body abrasive against the counterface thereby increasing counterface wear. Furthermore, wear debris liberated as reinforcement serves as a third-body abrasive on both the matrix and reinforcement surfaces [17]. The degree of grooves formed at the worn surface of the matrix alloy and composites containing lower volume fractions of SiC reinforcement are much larger at higher loads, and they undergo extreme plastic deformation, resulting in severe wear.

3.3.2 Wear Rate Analysis by Varying Speed

The differences in matrix wear rate and 6 and 9 wt% WC–Co reinforced composite at varying sliding speeds of 200, 400, 600 and 800 rpm at 9.8 N constant load and 500 m sliding distance are as shown in Fig. 7. Wear rate of matrix alloy and composite decrease as the sliding speed increase. Compared to matrix alloy, wear resistance is greater in the composite Al7075-WC–Co. The main reason for this is that mechanically mixed layers such as oxide layers and worn-out debris serve as lubricating materials between the disc and the sample [18]. The contact surface may decrease at greater speed and the localized surface of the material may become smoother due to increased temperature. The delamination of the wear surface promotes yielding and induces abrasive wear. [18, 19] The WC–Co composite is also more resistant to wear than an unreinforced alloy.

The reduction in wear rate is primarily due to mechanically mixed layer formation. It works between the spinning steel disk and the specimen as a lubricating material and plays an important role in keeping the wear rate minimal. Figure 8a shows that the width of grooves and scratches decreases with additional reinforcement. This is due to the resistance to the wear of the specimen provided by the particles. More scratches and grooves were found at higher loads and at greater speeds [20]. This illustrates the abrasive wear mechanism characteristics. In the prepared composite, Fig. 8b and c abrasive wear is observed. This is largely due to the rough particles of WC present on the wear surface. In the case of Al7075-cermet composites, as WC–Co particles limit the delamination phase, the wear resistance is higher.



(a) (b) (c)

Fig. 6 SEM Photographs of wear tracks of **a** Base alloy, **b**–**c** 6, 9 wt% WC–Co reinforced Composite under different loading conditions

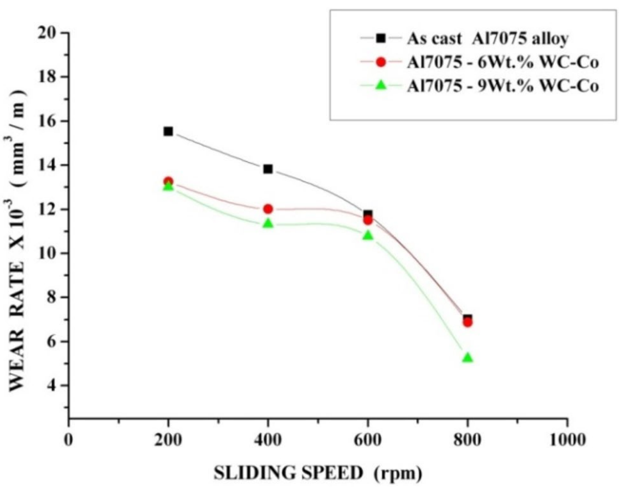
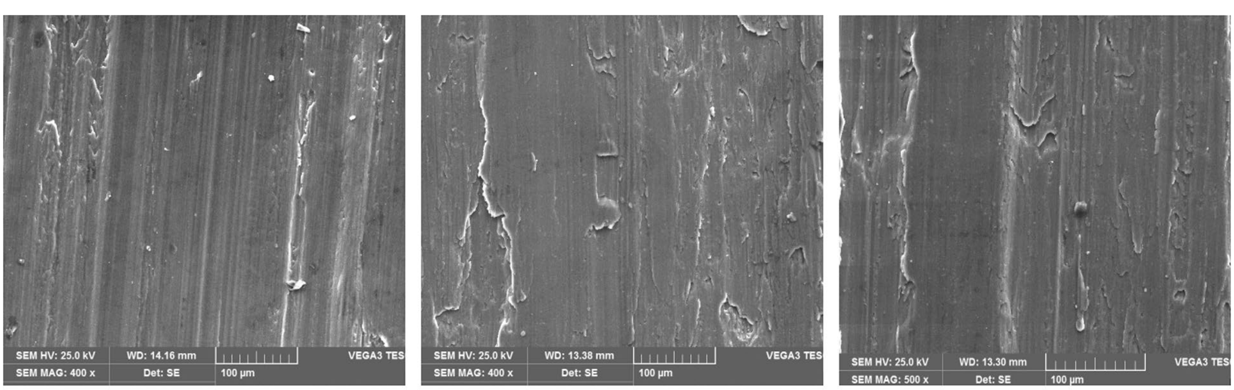


Fig. 7 Graph showing the wear rate of Al7075 alloy and Al7075—6 and 9 wt% of WC–Co composite under variable speeds

3.3.3 Wear Rate Analysis by Varying Distance

The variations in matrix wear rate and 6 and 9wt% WC–Co reinforced composite at constant load and speed of 9.8 N and 400 rpm under varying sliding distances are shown in Fig. 9. The volumetric wear loss for the matrix and composites increases as the sliding distances increase. Higher temperature increases in the sliding surfaces are inevitable at longer sliding distances. This causes the matrix and composite pin surfaces to soften, resulting in heavy deformation at longer sliding distances [20–22]. Longer contact time between the specimen and the disc is more due to higher sliding distance temperature, due to which localized heating occurs at the contact surface. As compared to the matrix alloy, the volumetric wear loss of the composites was much lower at all sliding distances studied, and it decreased with an increase in WC–Co content in the composites.



(a) (b) (c)

Fig. 8 SEM Photographs of wear tracks of **a** Base alloy, **b**–**c** 6, 9 wt% WC–Co reinforced Composite under different speeds

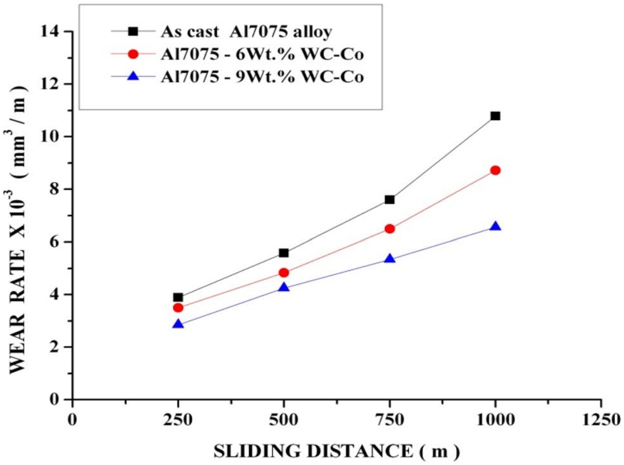


Fig. 9 Graph showing the wear rate of Al7075 alloy and Al7075—6 and 9 wt% of WC–Co composite under different sliding distance

The wear tracks depict the abrasive wear process. Surface delamination can be seen in a few places. However, applying WC–Co ceramic particles to the Al matrix has resulted in a reduction in the amount of material extracted from the composite surface. In addition, as the weight percent of reinforcement increases, the width, breadth, and variety of grooves on the pin's surface decreases. Adhesive wear mechanism can be observed in the worn out surfaces. Sliding distance and speed subsurface miniaturized due to the solid motion of the load. Cracks are created, which eventually result in the exclusion of wear and tear debris [20, 23]. The wear and tear track was protected with a protective chemical compound film, confirming the reduced wear and tear rate at a sliding distance of 1000 m, as shown in Fig. 10b–c

4 Conclusions

In the area of aerospace and automotive applications, Al7075 alloy reinforced with WC–Co composites can be used. It is used in the landing gears, drive shafts, engine cylinder liners in particular. With the addition of ceramic materials as reinforcement, their properties, such as high strength, low density and high wear resistance, can be improved. An attempt has been made in this present work to enhance and recognize the effect of the varying weight percentage of reinforcement on Al7075−WC–Co composite wear properties. This attempt at work contributed to the findings that followed.

- Liquid metallurgy route of stir casting method is successfully adopted in the preparation of Al7075−WC–Co composite containing reinforcement contents in 6 and 9 wt%.
- Microstructural studies reveal the presence and homogeneously uniform distribution of WC–Co particulates in Al7075 matrix. There is a better bonding developed between the matrix and the reinforcements which lead to effective load transfer from the matrix to the reinforcing material.
- The wear resistance of the prepared composite is higher than that of the base alloy. Increased applied loads and distances resulted in higher wear rate whereas with increasing speed resulted in decreased wear rate with both matrix and composite.

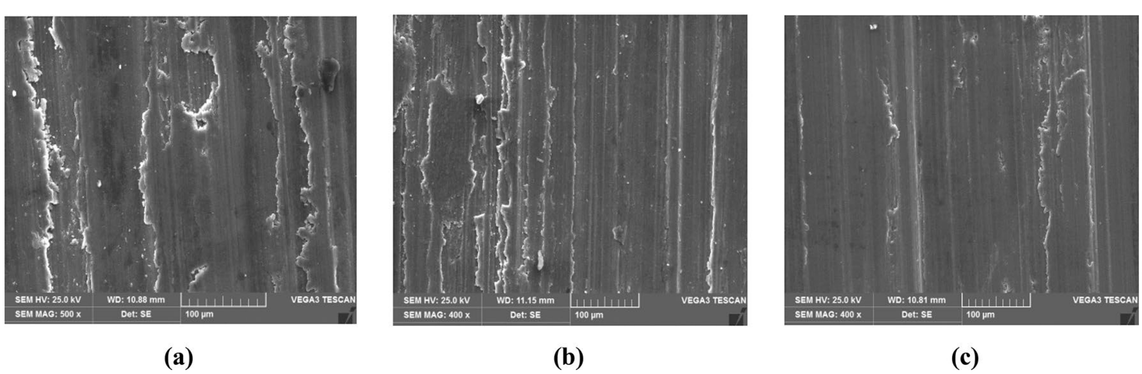


Fig. 10 SEM Photographs of wear tracks of **a** Base alloy, **b–c** 6, 9 wt% WC–Co reinforced composite under different sliding distance

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