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Preparation and Evaluation of Hardness and Wear Properties of WC-Co Particulates Reinforced 7075Al Composites

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Abstract

Aluminium matrix composites (AMCs) have found uses in aircraft, rocket engineering, vehicle engineering, energy sector, infrastructure areas, marine and military applications, sports and recreation utilization because of its enormous mechanical strengths and sensible wear resistance features. The experimental results of 7075Al-WC-Co composites' mechanical and tribological properties are provided in this article. The matrix is Al7075 and the reinforcement is planetary ball milled WC-Co in cermet form with particulates size range from 30-40 µm. Liquid metallurgy route was followed to develop 7075Al composites reinforced with 6, 9 and 12 wt.% of WC-Co. The tests were carried out on 7075Al and composites in accordance with ASTM specifications. According to the experimental results, the hardness of 7075Al-WC-Co composites is discovered to be raised by increasing the percentage volume of cermet phase. Wear attributes of the WC-Co containing composite were superior in terms of wear resistance. The manufactured composites were characterized using SEM and EDAX. Worn surface of the composite samples are studied before and after wear test.

Keywords: *Aluminium, metal matrix composites, tungsten carbide, wear and hardness.*

1.0 Introduction

Service from the machinery area is highly necessary in the present working environment which connects the key areas in certain applications of piston rings, driving mechanisms, brake pads, bushes bearings and many other moving parts. With the continuous utilization of these parts under variable speeds, different environmental conditions, different applied loads and other parameters the working condition and life of the parts will differ. With combining many key features all properties cannot be seen in single metal alone. Hence, it is required to deliver a new material to the world by developing it that can hold as many as key properties which are highly essential and have the capacity in satisfying combinational properties as per engineering requirements.

Nowadays, aluminium based metal matrix composites (AMMCs) gained attraction towards its extensive utilization around the globe to pursue research activities in military applications to manufacture armour tank, bullet proof jackets, automobile body parts, aeronautical applications, space etc. as they possess or showcased improvements in key properties like minimum thermal conductivity, excellent resistance to wear and corrosion at both room and elevated temperatures. Few aluminium alloys which can be heat treatable (2021Al, 6061Al and 7075Al) and also shows higher strength to weight ratios are widely used in preparation of composite that exhibit superior sustainability at both room and elevated temperatures [2-3]. AMMCs properties can be improved by proper selection of reinforcements with respect to its geometry, shape, type and route for fabrication method [4].

For the matrix with medium strength, low stiffness, medium ductility, a high strengthen hard ceramic particles can be added thereby enhanceing properties which lie in between base matrix and ceramic [5]. The properties of the prepared composite are highly influenced with the route of processing it. The selective processing route depends on the type of reinforcement adding to it, whether in liquid phase or in solid phase [6]. Among many composite processing methods stir casting method will stand above as it leads to many advantages like flexibility, economical, ability to produce components in bulk [7]. The aim of this paper is to prepare the composite with hard ceramic and metallic particles as reinforcement to 7075Al matrix, followed by understanding the effect of addition of reinforcement in enhancement of hardness and resistance to wear in the prepared composite.

2.0 Experiment Steps

2.1. Selection of Materials

With zinc as major element 7075 aluminium alloy (7075Al) is an alloy with other alloying ingredient that is employed as the matrix in this study. These alloys exhibit greater corrosion resistance than the alloys from 2000 series. In these alloys as the micro segregation happens that leads to embrittleness than many other alloys. Because of these key features the alloy holds major mechanical qualities like, good fatigue resistance, maintaining of good ductility, good strength etc. 7075Al alloys have a unique feature of heat treatable at different temperatures. Table 1 represents the contents of the matrix as extracted using an atomic absorption spectrometer.

Tungsten carbide and cobalt particulates (37μm / 400 Mesh size) in combined cermet form are used as reinforcements in this work. As the ceramic material tungsten carbide (WC) is well known for its many top mechanical properties like extreme level of hardness, withstand of high temperatures and higher war resistance. Also it owns better thermal and chemical stability. Soft ductile metallic element like cobalt into the aluminium can enhance the toughness of the composite which avoids the brittle fracture in maximum by giving the ductile touch. Cobalt, a soft substance with a density of 8.9 g/cc, is utilised in conjunction with WC due to the combined impact of higher mechanical capabilities at both room and heated temperatures.

2.2. Composite Preparation

The stir casting process is used to create composites in the current work. Figure 1 depicts a resistance furnace used in composite manufacturing. A 400 g batch of 7075Al matrix is brought to liquid state by melting in a graphite crucible using a resistive furnace. Using digital controlling of temperature ±5°C precision was maintained carefully. When the liquid matrix reaches 730°C, imprisoned gases are released using solid hexachloroethane (C_2Cl_6). To induce vortex in the liquid matrix, constant stirring at 300 rpm is maintained using zirconia coated stainless steel rod. To obtain homogenous reinforcement distribution in the matrix, preheated WC-Co cermet is injected into the vortex and constantly stirred for 60 seconds. Finally,

Figure 1: Apparatus used in preparation of composite [Stir casting setup]

Table 1: 7075Al Alloy Composition									
Composition of 7075Al	Zn	Mg	Mn	Fe	Cr	Cu	Si	Ti	Al
wt%	5.5	2.5	0.3	0.5	0.15	1.6	0.4	0.2	Balance

at a temperature of 730°C, the liquid was transferred into a permanent cast iron warmed mould. The aforesaid technique is used to create 7075Al alloy reinforced with 6, 9, and 12 weight per cent WC+Co particles. SEM/EDAX analysis was used to analyse these produced composites microscopically.

2.3. Wear Analysis of Composite

Using DUCOM built pin on disc apparatus the sliding wear parameters were examined. Prepared composite materials used for wear analysis are prepared asper ASTM G99 standard [8]. Samples with 30 mm height and 10 mm in diameter are polished metallographically before the testing. Using acetone solution each samples was cleaned and precisely weighed using single pan weighing equipment with a precision of 0.0001g. Set up used for wear testing is represented in Figure 2. Figure 2 depicts the pin-on-disc apparatus used for wear studies. During the test, the pin was held and pushed on the surface of a hardened EN32 steel disc (60 HRC) by applying a load that functions as a counterbalance and balances the pin. All of the specimens followed the same 90mm diameter track with tangential force. By monitoring arm movement, the LVDT (load cell) on the lever arm assists in assessing wear at any moment in time. When the contact surface wears away, the load drives the arm to maintain contact with the disc, and the arm's movement generates a signal. At the end of each test, the specimen was removed, cleaned with acetone to remove any debris, and re-weighed to calculate the volumetric wear rate. By converting the wear mass loss to the wear volumetric loss and dividing by the sliding distance, the volumetric wear rate was computed.

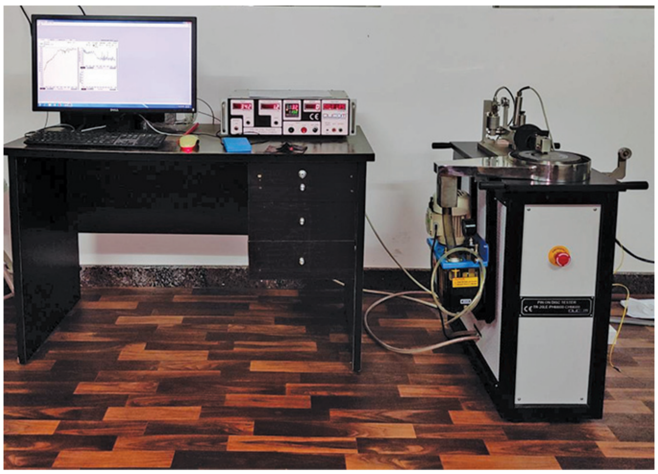

Figure 2: Apparatus used in testing the composite wear resistance

3. Results and Discussions

3.1. Microstructural Inspection

Microstructural investigations are carried out on samples sectioned from mid portion of the composite samples. SEM attachment with EDAX content is used to observe the presence and overlaying of WC-Co cermet particles in Al matrix. Figure 3(a-d) indicats SEM imags of 7075Al matrix and 7075Al+(37µm) WC+Co cermet based composites with 6, 9, and 12 wt. per cent reinforcements.

The SEM and EDAX characterization of composite samples were examined by SEM with EDAX attachment. SEM was adopted to observe the surfaces and the proper distributions of reinforcement particulates all over the matrix. It confirms that most of WC-Co particles are distributed uniformly in 7075Al alloy. Further, these figures reveal the homogeneity of the prepared composite and grains are visible properly with less porosity. The composite microstructure includes primary a-Al dendrites and Si; the reinforcements are accumulated in the territories of it.

The presence of magnesium (Mg) content in the base alloy in a range of 2-2.5 wt.%, maintaining the optimized novel melting temperature of 730°C and stirring the melt at 250 rpm during the addition of preheated reinforcement particulates have led to the breakdown of the dendrite shape into the equiaxed structure [3, 9, 10], thus improving the wettability and distribution of cermet particulates more consistently in the 7075Al matrix. This improved wettability of WC-Co in the matrix, will further help in enhancing the properties of 7075Al alloy composites. It is also noted in the Figure 3 (b-d) that the WC-Co particle is distinct and shows the good bonding between the 7075Al matrix.

The prepared samples (as-cast 7075Al and 7075Al + 6, 9, and 12 wt. per cent WC-Co reinforced composites) are analysed under EDAX, same has represented in Figure 4(a-d), to validate the presence of elements such as Zn, Mg, Si, Co, W, and C in the Al alloy matrix.

3.2. Hardness Test

Micro hardness testing is a technique for assessing material hardness on a small scale. The ASTM E384 standard [11] is used for testing. Zwick/Roell indenter digital micro hardness tester was used to calculate micro hardness. Vickers hardness tests were performed on the fine polished test specimen using a Zwick hardness indenter with a load of 2 N and dwell duration of 10 seconds at 30 separate sites with an

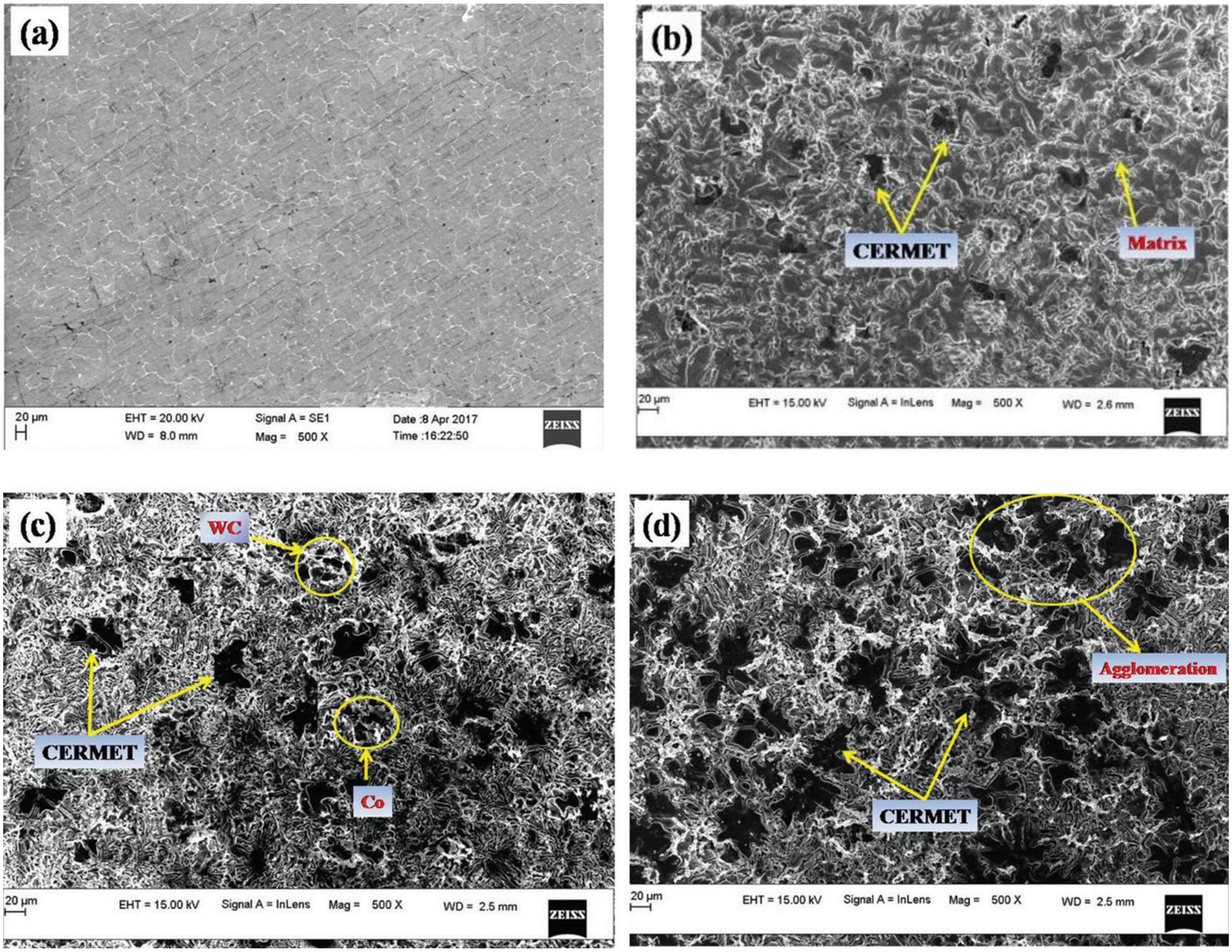

Figure 3 (a-d): SEM images of (a) As cast 7075Al, (b) 7075Al + 6wt.% Composite, (c) 7075Al + 9wt.% Composite and (d) 7075Al + 12wt.% Composite

average result of 50 readings. The above graph (Figure 5) shows that the hardness of the composite improves significantly as the amount of WC-Co particles in the matrix alloy increases. The hardness enhancement is extremely visible and predicted, since WC-Co particles are hard dispersoid that contribute favourably to the hardness of 7075Al-WC-Co composites.

3.3. Sliding Velocity Effect on Wear Rate

Figure 6 depicts the wear rate of 7075Al and 7075Al -6, 9 and 12 wt. per cent WC- Co, examined at changing speed (200, 400, 600, and 800 rpm) while maintaining load (9.8 N) and sliding distance (500 m) constant. At increasing speeds, the contact temperature rises, causing the material to weaken. As a result, the interfacial bonding strength weakens and the wear debris is removed by sliding action. As a result, the WC-Co composite outperforms the unreinforced alloy in terms of wear resistance. The current solid lubricating coating thickens and may fracture at greater sliding speeds. Furthermore, if the solid film is damaged, the fragment solid films become jammed between the rubbing surfaces, increasing friction. Also, the temperature rise at this sliding speed is quite significant, resulting in increased plastic deformation of mating surfaces, which leads to more asperity junctions and an increase in volumetric wear loss.

3.4. Varying Load Effect on Wear Rate

Figure 7 depicts the wear rate of 7075Al and 7075Al-6, 9 and 12 wt. per cent WC-Co composite at three different loads (2.45, 4.90, 7.35, and 9.8 N) while maintaining the speed (400 rpm) and sliding distance

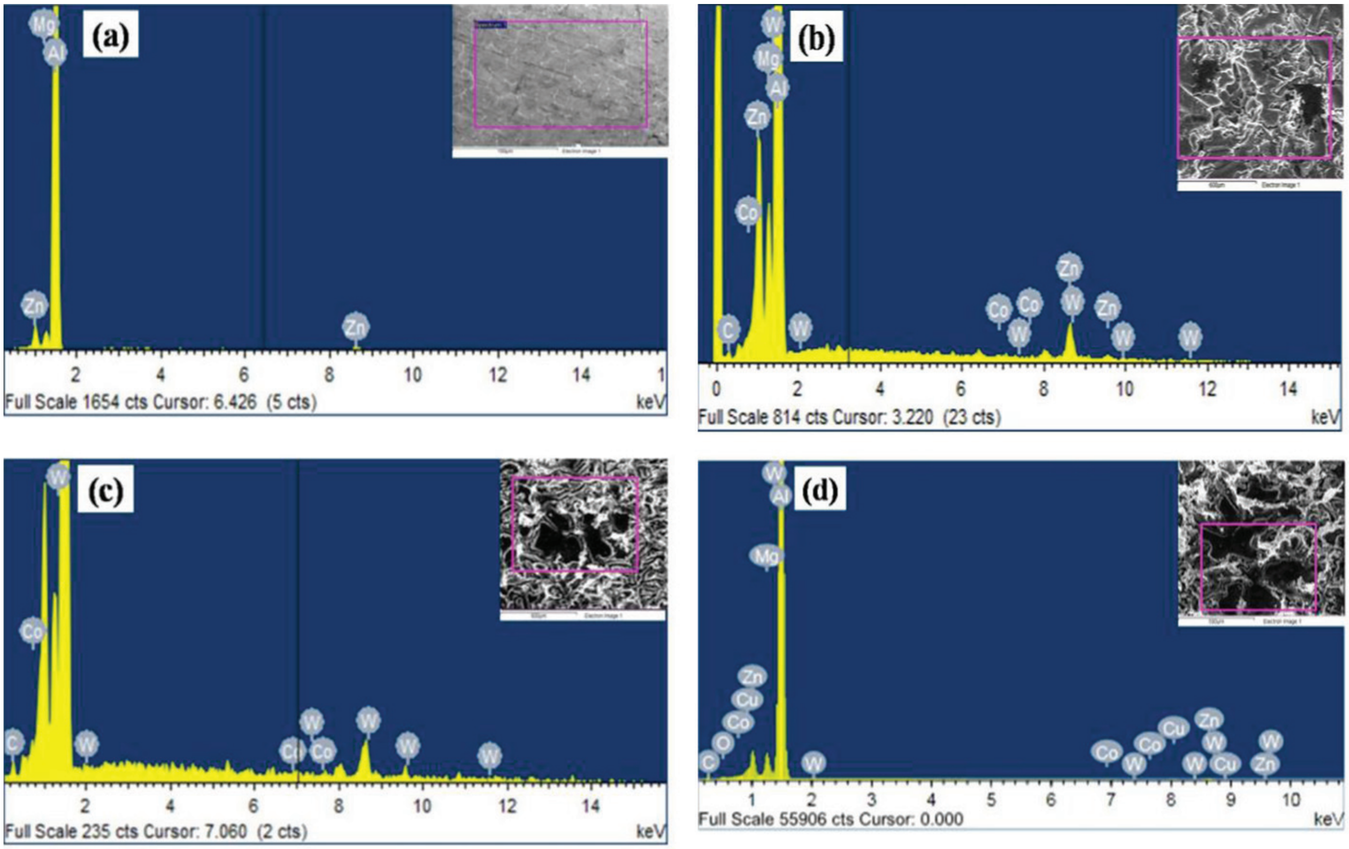

Figure 4 (a-d): EDAX analysis of (a) As cast 7075Al, (b) 7075Al + 6wt.% Composite, (c) 7075Al + 9wt.% Composite and (d) 7075Al + 12wt.% Composite

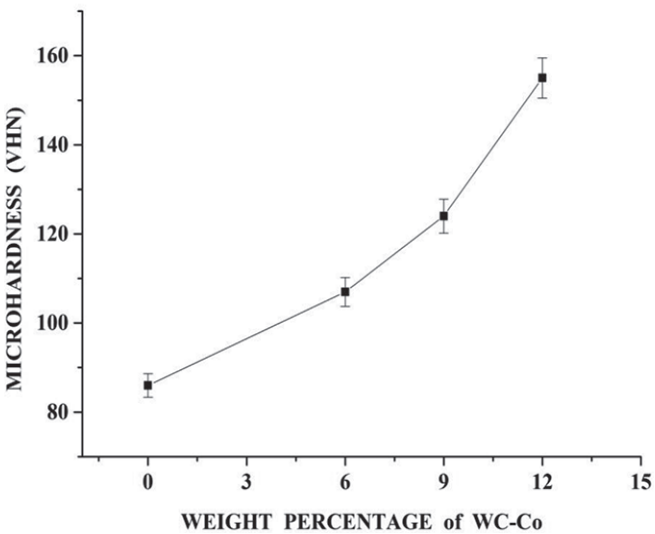

Figure 5: Micro hardness of as cast 7075Al and 7075Al reinforced with 6, 9, 12 wt.% WC+Co composite

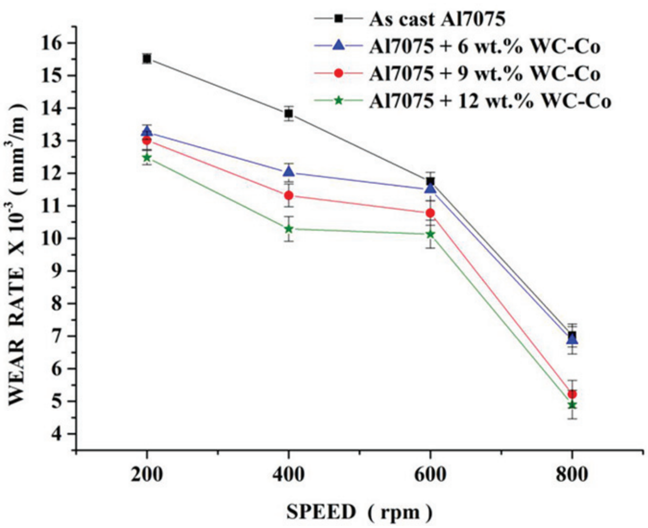

Figure 6: Wear rate of (a) as cast 7075Al and 7075Al reinforced with WC-Co particulate composite with different speed at constant load and sliding distance

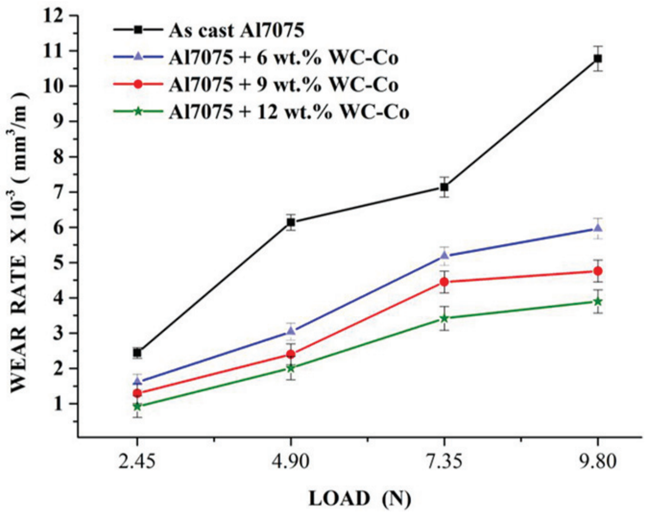

Figure 7: Wear rate of (a) as cast 7075Al and 7075Al reinforced with WC-Co particulate composite with different loads at constant sliding speed and sliding distance

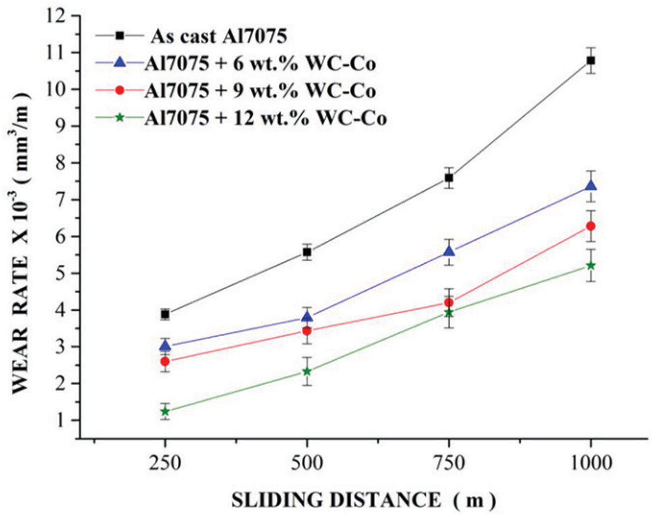

Figure 8: Wear rate of (a) as cast 7075Al and 7075Al reinforced with WC-Co particulate composite by varying sliding distance at constant sliding speed and load

(500 m) constant. The graph shows that the wear rate is low at low loads and increases with increasing load for all composites, with as cast 7075Al alloy having the highest wear rate. At increasing loads, the wear conditions of the Al matrix change, whilst the composite specimen has better wear resistance than the alloy specimen. Pressure at the pin-on-disc contact increases as load increases. Because metals are generally covered by an oxide coating, higher material losses are seen during the wear test at maximum loads. Because Al is a softer material, it is subject to adhesive wear, resulting in a greater wear rate in 7075Al alloy. Hard ceramic particles are present. The WC and Co particles in the produced composite will withstand the applied pressure, and the bonding between the Al, WC, and Co particles prevents material loss from the contact surface, resulting in abrasive wear with a reduced wear rate.

3.5. Sliding Distance Effect on Wear Rate

Figure 8 depicts the wear rates of 7075Al and 7075Al-6 at 9 and 12 wt.%. The WC- Co composite was tested at different sliding distances (250, 500, 750, and 1000 rpm) while maintaining the load (9.8 N) and speed (400 rpm) constant. Wear resistance is higher in 7075Al-WC-Co composite due to the presence of strong ceramic WC particles that defend against high temperature effects. As temperature rises at longer sliding distances, an oxide layer develops owing to oxidation of the aluminium alloy matrix, acting as a lubricant and reducing wear rate in composites. Furthermore, because of the strong surface bond, there is increased interfacial resistance with 7075Al matrix alloy and WC-Co reinforcement particulates, which hampers particle pull from the 7075Al matrix.

3.6. Worn Surface Analysis

Figure 9 (a-d) shows electron microscopy of wear tracks of 7075Al alloy and 7075Al-WC-Co (6, 9, and 12 wt. per cent) composite evaluated at a larger load of 9.8 N, sliding speed of 400 rpm, and sliding distance of 500 m. The emergence of deep grooves, adhesion, and abrasion phenomena are seen parallel to the sliding direction for unreinforced 7075Al alloy and the complete composite.

Figure 9 (a) represents the worn surface images of Al7075 alloy. The examination of 7075Al alloy shows large grooved regions on the worn surface. Also 7075Al contains deeper adhesive grooves, craters on the worn surface and delamination of unreinforced material. A significant adhesive grooves shows that the frictional heat renders the matrix soft. The wide and bigger delamination regions reveal the predominant adhesive wear in as cast 7075Al matrix alloy.

Figure 9 (b-c) depicts a composite with 37 μm WC-Co particles that has adhesive and shallow abrasive grooves. The grooves get smoother as the weight fraction of the reinforcement rises. As a result of the tiny quantity of material loss, the wear rate also decreases to the greatest extent, indicating that the composite has superior wear resistance than an unreinforced matrix alloy.

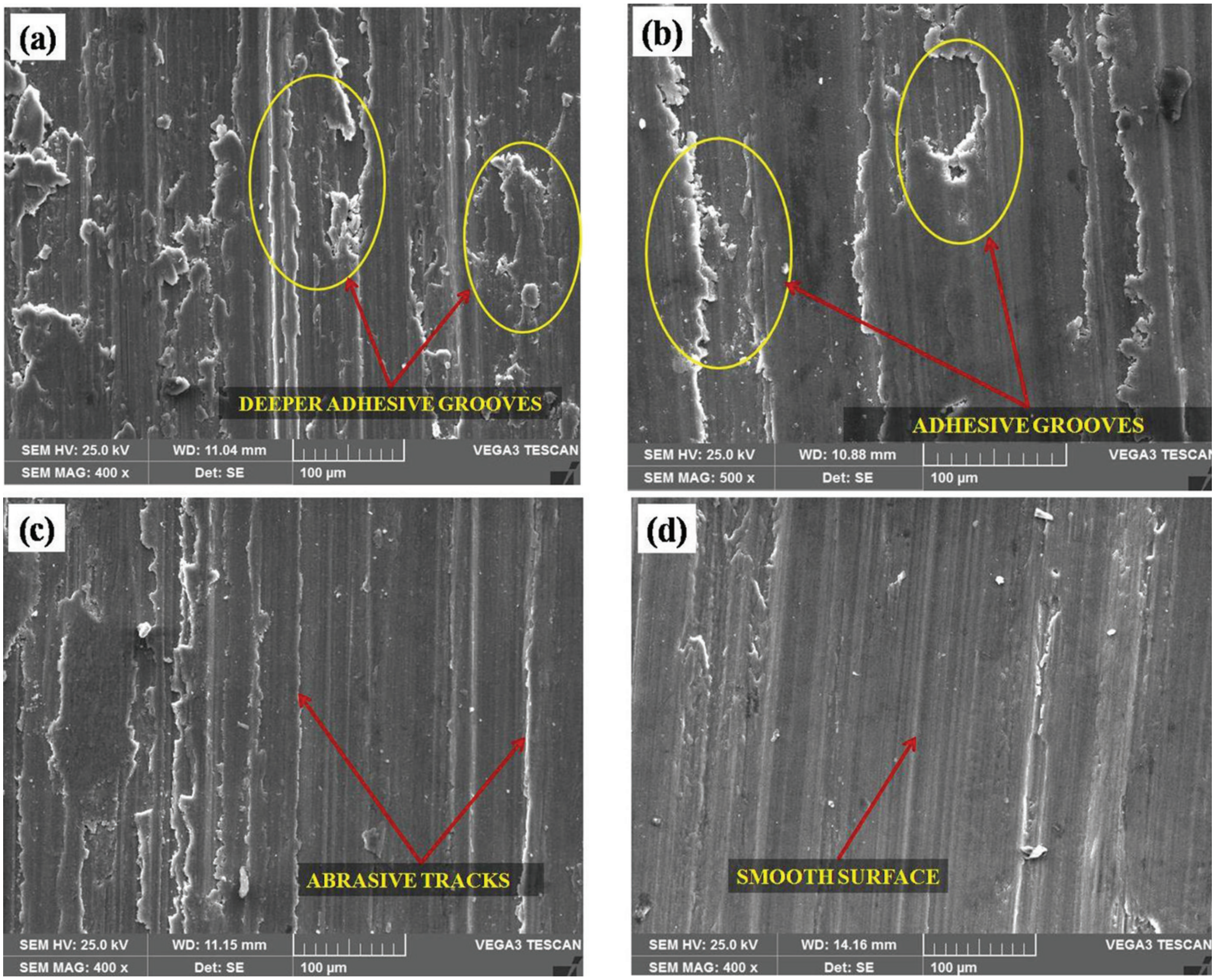

Figure 9 (a-d): Worn surface SEM images of (a) ascast 7075Al, (b) 7075Al +6wt.% WC-Co Composite, (c) 7075Al +9wt.% WC-Co Composite and (d) 7075Al +12wt.% WC-Co Composite

4. Conclusions

7075Al alloy reinforced with WC–Co composites can be employed in aerospace and automotive applications. It is particularly employed in landing gears, drive shafts, and engine cylinder liners. The inclusion of ceramic materials as reinforcement can increase their qualities such as high strength, low density, and high wear resistance. This study attempted to improve and recognise the influence of changing reinforcement weight percentages on 7075Al-WC–Co composite wear characteristics. This attempt at work contributed to the subsequent discoveries.

- The stir casting method's liquid metallurgy pathway was effectively used in the preparation of 7075Al-WC–Co composites with reinforcement amounts of 6, 9, and 12 wt %.
- Microstructural analysis reveals the presence and uniform distribution of WC–Co particles in the 7075Al matrix. The bonding between the matrix and the reinforcements has improved, resulting in effective load transmission from the matrix to the reinforcing material.
- The created composite has a greater wear resistance than the basic metal. With both matrix and composite, increasing applied loads and distances resulted in higher wear rates, but increasing speed resulted in lower wear rates.

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