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ORIGINAL PAPER

Effects of Silicon Carbide and Tungsten Carbide in Aluminium Metal Matrix Composites

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Abstract

In the present study, an attempt has been made to synthesis Al6061/SiC/WC hybrid aluminium composites using stir casting method under various mass percentage of reinforcement. The mechanical properties such as compressive strength, tensile strength, hardness and wear resistance have been characterized and investigated. From the micro structural analysis of hybrid composites, it has been observed that reinforcement particles have been uniformly distributed without clustering of particles in matrix alloy. The precipitate of Mg_2Si and un-dissolved Al6 (Fe, Mn) in aluminium solid solution has been observed as interfacial reaction. The hardness of hybrid composites has been increased due to incorporation of stiffer and stronger reinforcement in the matrix material. The presence of SiC and WC reinforcement in the matrix alloy can significantly enhance the compressive, tensile strength and wear resistance of aluminum hybrid composite.

Keywords Stir casting · Tensile test · Compressive test · Microstructure · Wear analysis

1 Introduction

The need for low density materials with high strength to weight ratio is very essential in automobile industries. It is entailed to enhance the mechanical properties of such composites at normal room temperature and elevated temperatures over monolithic alloys [1]. The interpretation of the materials is mostly subjected to optimal selection of reinforcement materials. The ceramic particles can be reinforced into monolithic light metal alloys such as aluminium (Al), magnesium (Mg), zinc (Zn), copper (Cu) and stainless steel metal alloys for further weight reduction [2]. Aluminium matrix alloy reinforced with SiC or Al_2O_3 has shown better strength, specific stiffness, ductility and fracture toughness over the monolithic alloys [3]. The material properties such as ductility and fracture toughness are considered to be important parameters, since it prevents the failures of composites for shock load applications. This implies to utilize two or more synthetic reinforcing particulates in metal matrix alloy for further property improvement. Owing to higher strength, higher stiffness, low density, controlled thermal expansion coefficient, higher abrasion and wear resistance, the aluminium metallic alloys have been mostly utilized as matrix material [4]. The utilization of hard ceramic particles such as SiC, Al_2O_3, MgO, WC, SiO_2 and B_4C in the aluminium matrix alloy are commonly used as reinforcement material to improve its mechanical properties [5]. Due to its considerable strength to weight ratio, low density, high modulus, strength values, wear resistance, high thermal stability and easy availability, SiC particles can be utilized

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as reinforcement particles in composites [6, 7]. It was observed that the hardness of composites increased due to the increased SiC content [8]. Kumar et al. (2018) observed that the hardness and abrasive wear resistance of metal matrix composites can be increased with increase in SiC content [9]. The Hybrid composites obtain better mechanical properties compared with addition single reinforcement in metal composites. The hybrid metal matrix composites are utilized with more than one type of reinforcement under different size, shape and weight percentages to obtain better mechanical properties [10]. Prasad et al. (2006) stated that reinforcement such as graphite solid lubricants and hard ceramic particles in aluminium alloys matrix to improve its wear properties for automotive applications [11, 12]. Tungsten carbide is widely utilized ceramic material reinforcement material in aluminium alloy owing to its high hardness, low density, high strength, high rigidity, good chemical stability and better resistance at high temperature [13]. From the detailed literature survey, it has been inferred that the addition of two different synthetic ceramic reinforcement in aluminium matrix materials can enhance the mechanical behavior, machining and tribological properties of aluminium hybrid composites. However, it has been noted that only few studies has been performed to find the influence of adding two synthetic ceramic reinforcements in aluminium hybrid composites [14]. Hence an effort has been made to develop aluminium matrix hybrid composites by stir casting process under various weight percentage of reinforcement for obtaining mechanical properties in the present study.

2 Materials and Methods

Aluminium Alloy (Al 6061) has been used as the base material due to its importance in automobile industries. The chemical composition and physical properties of the work piece are listed in Tables 1 and 2. The ceramic materials such as silicon carbide (SiC) and tungsten carbide (WC) has been chosen with the particle size of 125 μm and 3 μm respectively. The reinforcement particles have been included in hybrid Aluminium metal matrix alloy under various weight percentages of 5, 7.5 and 10%. This liquid metallurgy technique is the most inexpensive method for producing metal matrix hybrid composite. Among various liquid metallurgy process stir casting process has been utilized for fabrication Al6061/SiC/WC hybrid composites [15, 16]. The alloy has been melted in a crucible furnace at 750 °C for twenty minutes. The furnace temperature has been raised above the liquidus temperature of matrix alloy near about 780 °C. The reinforcement particles have been preheated at 500 °C to remove moisture presence in the reinforcement to enhance the wettability of reinforcement between matrix alloy and reinforcement. Then the preheated reinforcement particles with different weight percentage have been added manually in to the vortex. The uniform dispersion of the reinforcement particles in the aluminum matrix alloy depends on the parameters such as stirring speed and stirring time [17, 18]. In the present study, the stirring speed and stirring time has been maintained at 400 RPM and 5 min respectively to ensure the uniform distribution of the particles in the liquid. This creates superior interface bond between reinforcement and matrix alloy. The stir casting of Al6061 has been carried out in an electrical resistance heating furnace. The furnace has been maintained at a temperature of 450 °C before loading the matrix material into the furnace. The aluminium material has been placed in electrical resistance heating furnace for a period of 10 min. The composite mixture has been reheated after stirring at semi-solid phase and hold at a temperature 900 °C to make the composite mixture in liquid phase. Stirrer RPM was then gradually reduced to the zero. The mixture was immediately poured into the mould cavity (size 150 × 15 × 15 mm) and allows this for cooling at room temperature.

Table 1 Chemical compositions of Al (6061) alloy (Weight Percentage)

Mg	Si	Fe	Cu	Ti	Cr	Zn	Mn	Al
.90	.75	.25	.22	.09	.10	.05	.04	Bal

3 Results and Discussion

3.1 Microstructure of Al6061/SiC/WC Composites

The microstructure performs a significant role on evaluating the mechanical properties of any alloys and composites [19]. The properties of aluminium hybrid composites depend on the microstructure, reinforcement particle size, shape and distribution of reinforcement in the matrix alloy. The prepared samples have been examined to study the distribution of reinforcement in the matrix alloy using optical microscope. The higher percentage additive of reinforcement particles showed marginal effect in the distribution and some lower agglomeration of the particles

Table 2 Properties of Al6061

Properties	Al6061	SiC	WC
Elastic Modulus Gpa)	70–80	410	530
Density (g/cc)	2.7	3.1	15.25
Poisson's Ratio	0.33	0.14	0.2
Hardness (HB500)	30	280	1700
Tensile Strength(T)/ Compressive strength (C) (Mpa)	115(T)	3900(C)	370(T)

observed as shown in Fig. 1. The addition of dissimilar weight percentage of reinforcement material in matrix alloy has modified the surface morphology of the composites. The reinforcement particles have dispersed uniformly in the matrix. However at some location of the casting, the agglomeration of the reinforcement particles has been observed. The prepared samples have been examined to study the reinforcement particles and their distribution in

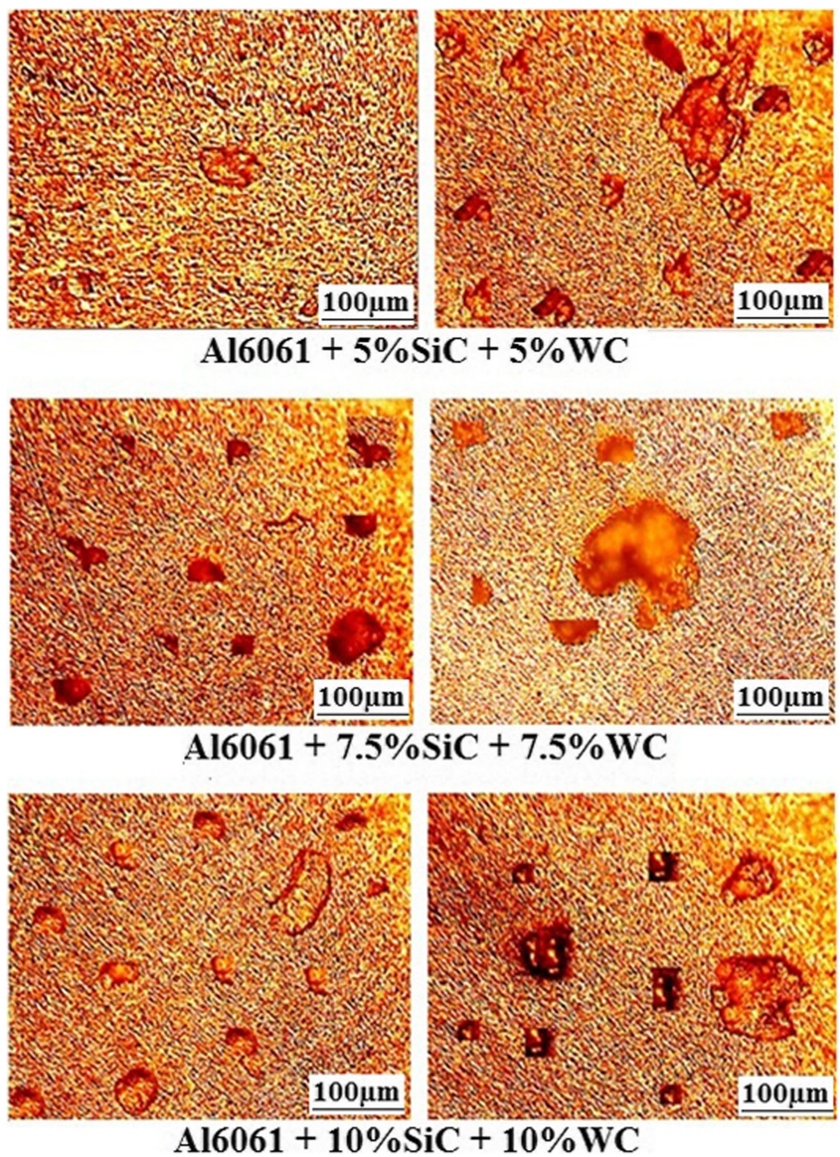

Fig. 1 Microstructure of Al6061/SiC/WC hybrid composites

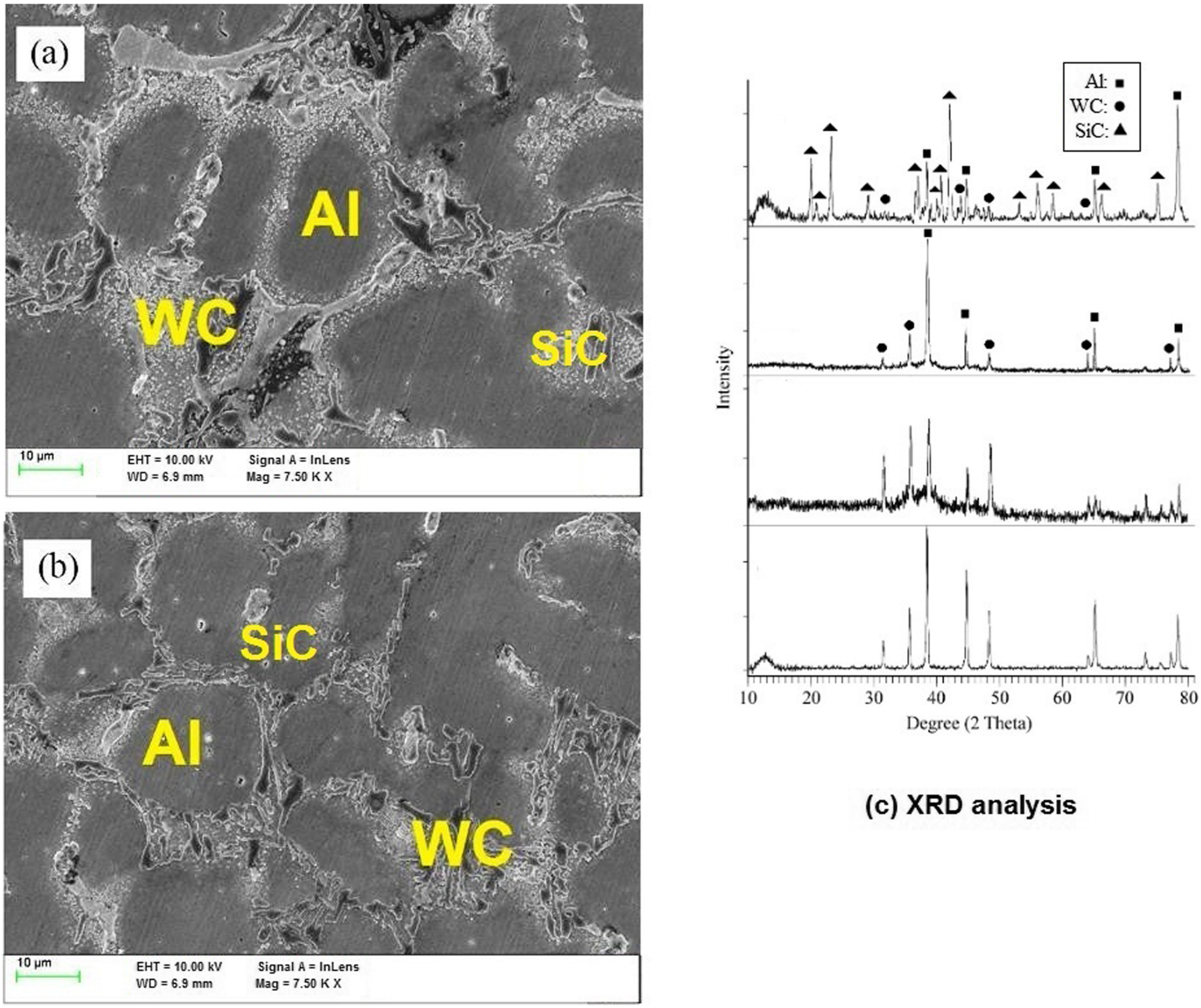

Fig. 2 **a** SEM analysis of synthesized composites with 5% of reinforcement (**b**) SEM analysis of synthesized composites with 7.5% of reinforcement (**c**) XRD analysis

the matrix alloy using Scanning Electron Microscope (SEM) and XRD analysis as shown in Fig. 2. The etched matrix clearly indicates the position of the reinforcement particles more preferential at the grain boundary cavity. The interfacial reaction obtained between the matrix and reinforcement is Mg_2Si with larger grain, some un-dissolved Al6 (Fe, Mn) in aluminium solid solution matrix

Table 3 Hardness of Al6061/SiC/WC Composites

Al 6061-Weight % of SiC and WC	Hardness (HV)
Al6061	65.53
Al6061 + 5%SiC+5%WC	72.83
Al6061 + 7.5%SiC+7.5%WC	86.72
Al6061 + 10%SiC+10%WC	98.54

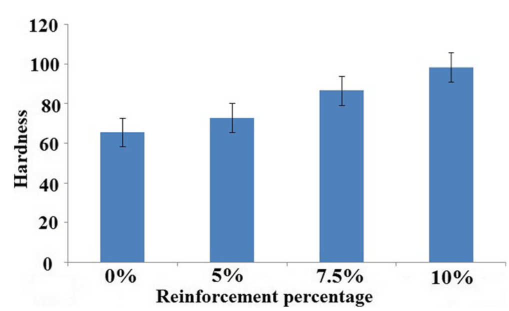

Fig. 3 Hardness of Al6061 hybrid composites

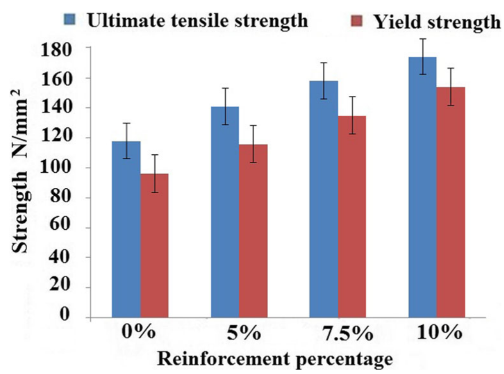

Fig. 4 Tensile strength of Al6061 hybrid composites

alloy which are uniformly distributed throughout the cross of matrix. This enables to increase the mechanical properties of aluminium hybrid composites.

3.2 Hardness of Al6061/SiC/WC Composites

The Micro-Vickers hardness test on polished composite samples has been performed with a load of 20 N to evaluate the hardness. The average of five readings has been taken at different locations of synthesized aluminium hybrid composites are reported in the Table 3. It has been inferred that increase in weight percentage of two different hard ceramic particulates in to the matrix alloy can significantly increase the hardness of aluminium hybrid matrix composites as shown in Fig. 3. This can be attributed due to the fact that the addition of stiffer and stronger reinforcement (SiC, WC) in the matrix alloy considerably improves hardness comparatively with monolithic aluminium alloy.

3.3 Tensile Strength of Al6061/SiC/WC Composites

Tensile tests have been carried out at room temperature using universal testing machine (UTM) in accordance

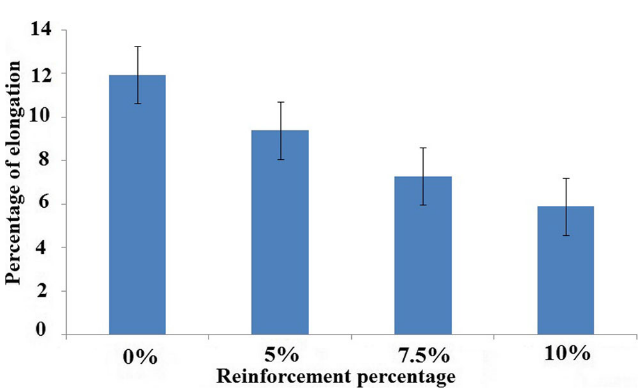

Fig. 5 Percentage elongation of Al6061 hybrid composites

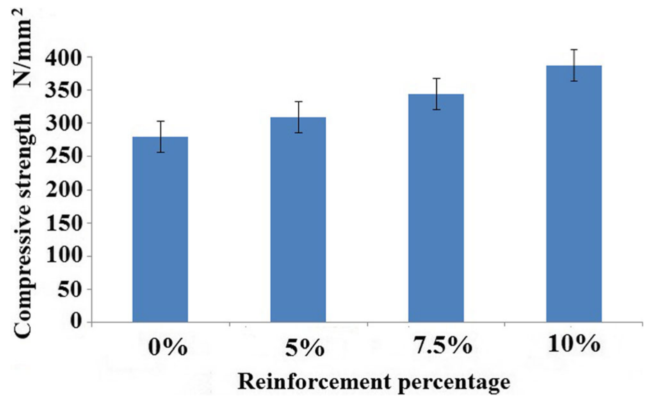

Fig. 6 Compressive Strength of Aluminium Hybrid Composites

with ASTM Standard B557M. The dimension of 80 mm × 6 mm with the thickness of 12.5 mm has been fabricated. Three set of tests has been performed and the average value has been computed to calculate the tensile strength of the hybrid composites for reducing the possibilities of measurement error. The influence of reinforcement particles such as tungsten carbide and SiC particles on yield strength and Ultimate Tensile Strength (UTS) of aluminium hybrid composite has shown in Fig. 4. It can be observed that the strength of aluminum hybrid composites increased with increase in reinforcement. The increment of UTS and yield strength is due to the interfacial bonding between the soft aluminium matrix and the hard reinforcement particles. The structure and mechanical properties of the reinforcement particles can control the mechanical properties of the hybrid composites owing to the strong interface. This effect can transfer and distribute the load from the matrix to the reinforcement which exhibits high elastic modulus and strength [20]. It has been observed that the ultimate tensile strength of hybrid composites has been increased up to 38% as that of yield strength increases 30.76% when compared with monolithic Al6061 alloy. Simultaneously, the percentage elongation of hybrid metal matrix composites has been decreased up to 86% with increase in percentage of SiC and WC reinforcement in the matrix alloy as shown in Fig. 5. This is due to the addition ceramic reinforcement such as SiC and WC particles which reduces the elastic deformation and enhances the plastic deformation of hybrid composites [21]. Nevertheless the presence of WC reinforcement in the matrix has higher tensile strength comparatively with Al6061 alloy. This forms a crack and de bonding in the composites which enhances the plastic deformation while increase in load of hybrid composites.

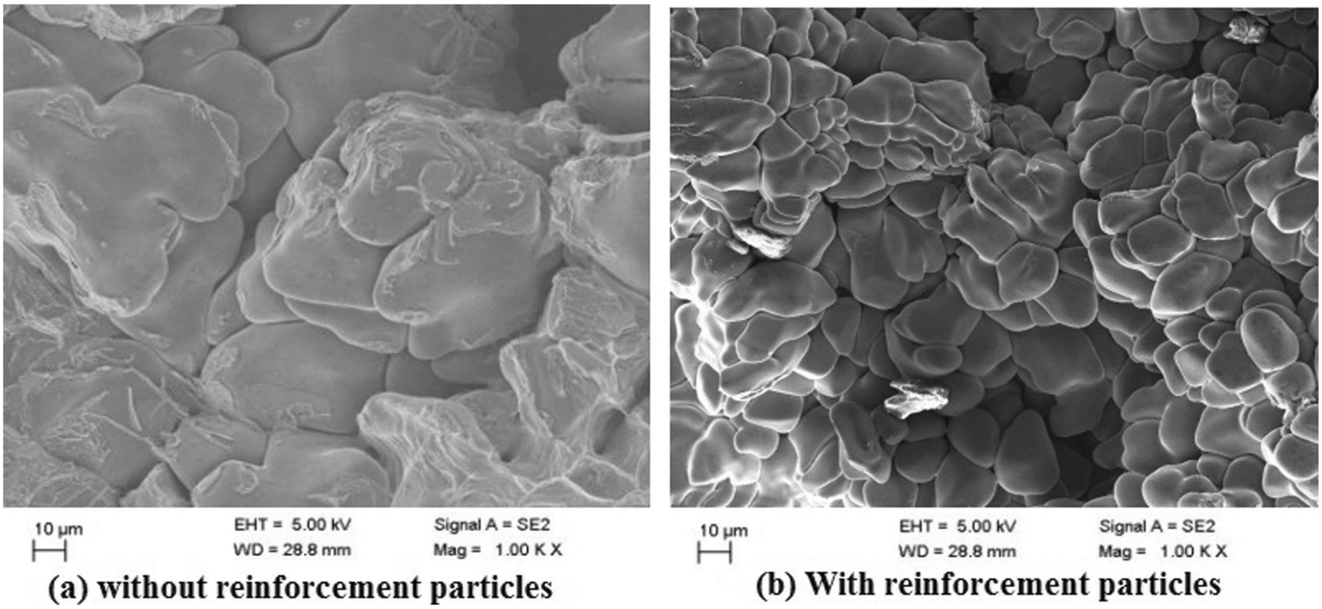

Fig. 7 Fracture surface of Aluminium hybrid composites

3.4 Compressive Strength of Al6061/SiC/WC Composites

The compression tests have been performed using UTM E8M in accordance with ASTM Standard at room temperature as shown in Fig. 6. It has been observed that the compressive strength has been increased with higher weight percentage of reinforcement particles in the matrix alloy. However the presence of SiC has higher compressive strength comparatively with monolithic alloy. It can be observed that the compressive strength compared with tensile strength has been increased linearly owing to the interface between the uniformly distributed reinforcement and the matrix alloy. The addition of stiffer reinforcement particles in the matrix alloy acts as obstacles which restricts the motion of dislocations and plastic flow in matrix alloy [22]. The surface morphology of fracture surface of synthesized composites due to compressive load is shown in Fig. 7. The crack propagation for producing fracture can be reduced with the presence of the reinforcement particles in aluminium composites owing to the restricted material flow. Nevertheless the compressive strength of hybrid composites is comparatively higher than monolithic alloy owing to the homogenous distribution of reinforcement particles in Al6061 alloy, the presence of lower residual pore and the grain refinement in the microstructure.

3.5 Wear Analysis of Al6061/SiC/WC Composites

The wear resistance has been computed using pin-on disc wear testing machine as per ASTM – G99 standard. The wear rate of specimen has been found by weight loss method. The sliding distance has been found by dividing the weight lost for known distance. The wear testing has been carried out at different sliding velocities with a 10 and 20 N of load. The temperature of sliding surface has been increased by high sliding distance of hybrid composites. The wear analysis results of synthesized hybrid composites are shown in Table 4. It has been observed that variation of wear with respect to time has been increased under higher load over the specimens. Since there is possibility of producing higher friction with higher load at the contact, it leads to increase in wear of material as shown in Fig. 8.

Table 4 Wear analysis of Al6061/SiC/WC Composites

Sample	Apply load (N)	Initial weight in "g"	Final weight in "g"
Al6061 + 5%SiC+5%WC	20	3.905	3.786
	10	4.322	4.302
Al6061 + 7.5%SiC+7.5%WC	20	3.856	3.645
	10	4.234	4.105
Al6061 + 10%SiC+10%WC	20	3.756	3.648
	10	4.120	4.082

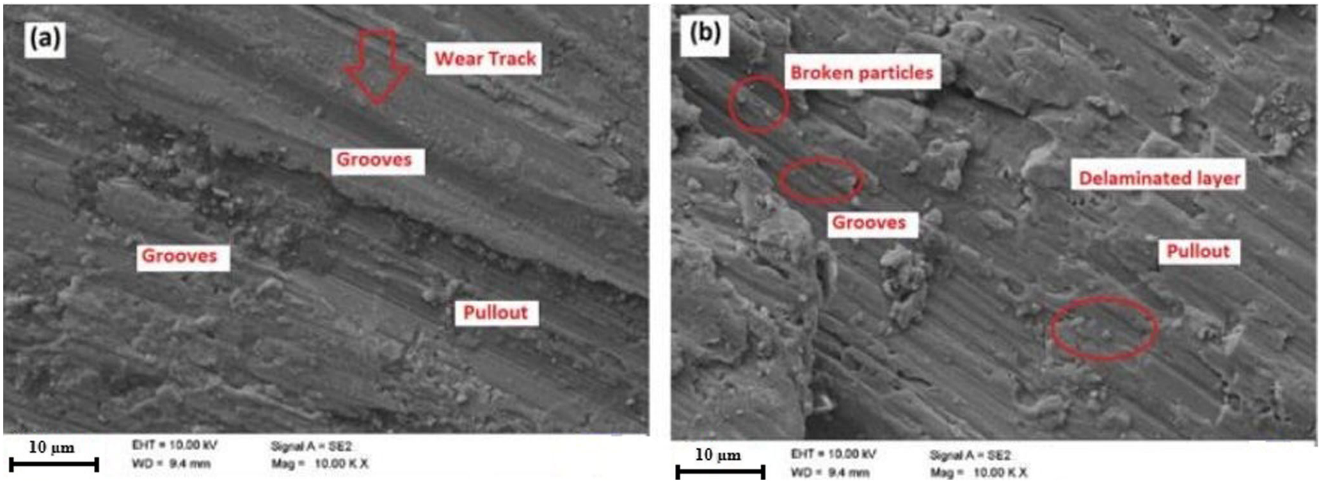

Fig. 8 Surface morphology of Aluminium Hybrid Composites

4 Conclusion

In the present study Al6061/SiC/WC hybrid aluminium composites has been synthesized with dissimilar mass percentage of reinforcement under stir casting method and its mechanical properties has been characterized. From the experimental results, the following conclusions have been made.

- The addition of stiffer and stronger reinforcement of SiC and WC presence in the matrix alloy can significantly improves hardness of hybrid composites comparatively with monolithic aluminium alloy.
- The compressive strength of hybrid composites is comparatively higher than monolithic alloy owing to the addition of stiffer reinforcement particles in the matrix alloy.
- The microstructure confirms that the presence of precipitate of Mg_2Si and un-dissolved Al6(Fe, Mn) in aluminium solid solution.

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