Wear and Hardness Characterization of Hot Forged Tungsten Carbide reinforced Aluminium 6061 Composite Materials

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ABSTRACT

The current study intends to examine how forging under hot conditions affects wear characteristics of tungsten carbide (WC) particles reinforced aluminum alloy 6061 composites. The reduction ratios of 20%, 40%, and 60% were employed during forging, and the percentages of reinforcement used were 0, 2, 4, and 6 (weight fractions). The investigation clearly showed that the forged composites had a substantially lower wear rate than the unforged composites. It was discovered that the wear behavior of the composite improved due to the higher content of WC particles present in the matrix. Enhanced wear rate was observed as the weight and sliding distance increased.

Keywords-wear; hardness; hot forging; aluminum alloy; composites; tungsten carbide

I. INTRODUCTION

Scientists and engineers are constantly looking for lightweight materials, particularly for uses in quickly expanding industries like aerospace and automotive. Alloys made of aluminum and magnesium are good choices for lightweight applications. However, it is crucial to keep in mind that aluminum lacks the stiffness and strength that are crucial for many applications, thus there is a need to increase its qualities by employing appropriate reinforcement [1]. Composites made from aluminum alloys have poor formability as well as issues with particle breakage and matrix-reinforcement decohesion [2]. Additionally, reports indicate that the typical manufacturing techniques adopted for Metal Matrix Composites (MMCs) frequently produce reduced ductility due to the usage of highly brittle reinforcements and uneven microstructure, which lead to issues with porosity and agglomeration [3]. Using appropriate forming procedures to produce improved characteristics is a useful strategy for addressing the issues related to composites [4]. Authors in [5] reported on the performance of composite materials made of aluminum that were rolled or extruded. Only a few studies have looked at how forging operations affect the mechanical properties and wear rate of aluminum alloy-based composites [6]. Potential candidates for racing purposes have been thought of as forged pistons made of aluminum/SiC composites [7]. There are other reports available on various drive-train parts, particularly the connecting rod [8]. This study's main goal is to investigate how hot forging operations affect the wear characteristics of Al-WC composite materials made up of various amounts of WC reinforcement and forging conditions.

II. MATERIALS AND METHODS

This study aims to evaluate the impact of hot forging and reinforcing WC particles on the wear performance of composites made of 6061 aluminum alloy. Table I presents the composition of the alloy used in the present study. When creating composite samples, WC particles with sizes ranging from 10 to 25 µm were used as reinforcement.

TABLE I. COMPOSITION OF ALUMINUM ALLOY 6061

Al	Mg	Si	Cr	Mn	Ti	Cu	Fe	Zn
95.8 – 98.6	0.8 – 1.2	0.4 – 0.8	0.04 – 0.4	0.15	0.015	0.15 – 0.4	0.7	0.25

WC particle reinforced aluminum alloy composites of various compositions were created utilizing the stir casting method of liquid metallurgy. The calculated weight percent of WC particles was 2, 4, and 6. The aluminum alloy was melted in an electric furnace and the desired amount of 400 °C-preheated WC particles were added while it was still liquid. After allowing the castings enough time to cool, they were machined to the correct size and shape required for the forging process. The as-cast specimens were heated to 450 °C and hot forged at several reduction ratios of 20%, 40%, and 60%. The samples were examined for their wear behavior under dry (unlubricated) circumstances as per ASTM G99 standards by using a pin-on-disc tribometer. The counter facing disc on which the specimen was made to slide was EN 32 steel. The disc had 68 HR_C hardness. The selected loads ranged from 30 N to 50 N in steps of 10 N. The disc speed was 1000 rpm. In the test, sliding distances ranging from 1000 m to 3000 m in stages of 1000 m were used. After the tests, a Scanning Electron Microscope (SEM) was used to examine the specimens' worn surfaces. In addition to the wear tests, the specimens underwent hardness tests using a Brinell hardness tester. Ten different readings were collected for each specimen at various positions on the samples.

III. RESULTS AND DISCUSSIONS

Figures 1-4 show the wear rate of the specimens in relation to the reinforcement content for different sliding distances and loads (30, 40, and 50 N) and forging conditions (20%, 40%, and 60% forging) at a constant speed of 1000 rpm. The wear rate of unforged composites under different sliding distances and loads are shown with reference to the weight % of WC particles in Figure 1. Additionally, it was discovered that regardless of the sliding distances and reinforcing content, the wear rate rises as the load increases. Figure 2 which depicts the wear behavior with respect to the content of WC for various sliding distances for a 20% forged composite under various loads. In all situations, a similar wear performance is seen in the 40% forged condition, despite the fact that the wear resistance continues to increase, as illustrated in Figure 3. The outcome showed that the composite materials' wear resistance differs significantly after forging at a higher percentage than 40%. The wear rate rises as the applied load rises for 60% forging conditions. The graphs shown in Figure 4 show the behavior of wear rate of 60% forged composites under various load conditions. When evaluated at 30, 40, and 50 N loads in contrast to the unreinforced alloy, it could be observed that the unforged composite samples containing 6% reinforcement particles revealed a lower wear by 29.17%, 26.92%, and 21.43%, respectively. Similarly, the reduction in the wear rate for the forged composites with 6% reinforcement compared to the unreinforced and unforged samples was 44.41%, 40.82%, and 36.45%, respectively, when examined at 30, 40, and 50.

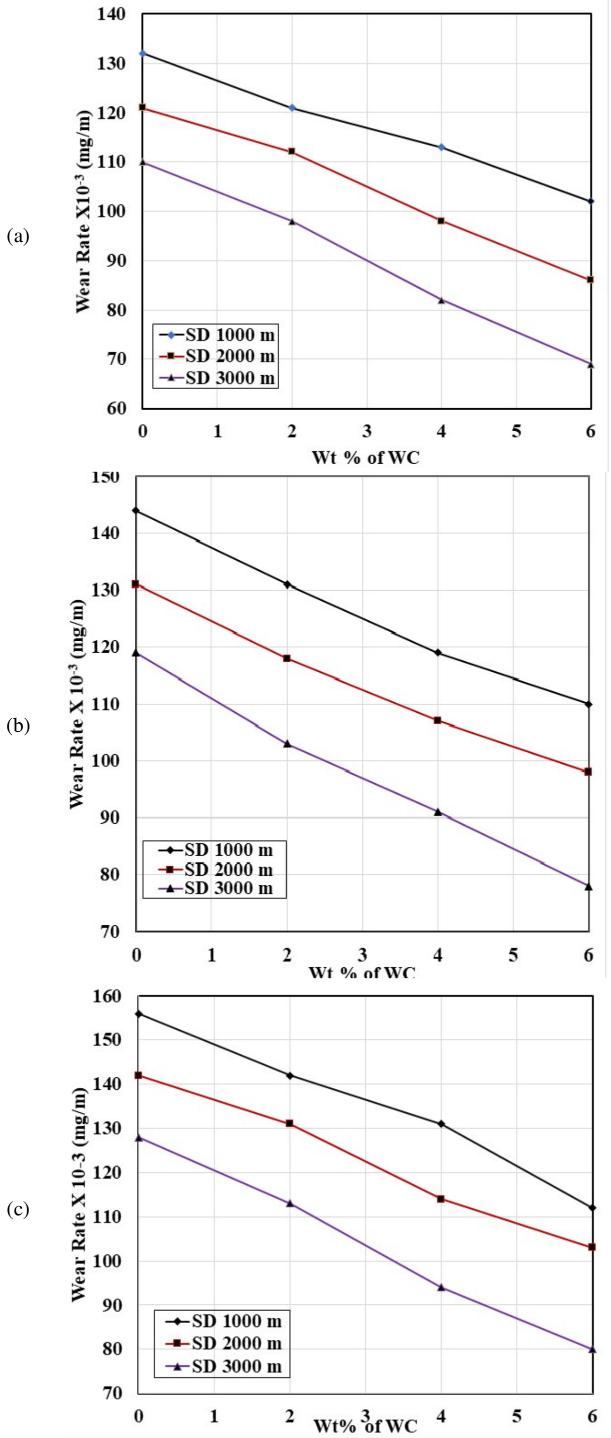


Fig. 1. Effect of WC on wear rate of unforged composites at constant load of (a) 30 N, (b) 40 N, (c) 50 N, under various sliding distances.

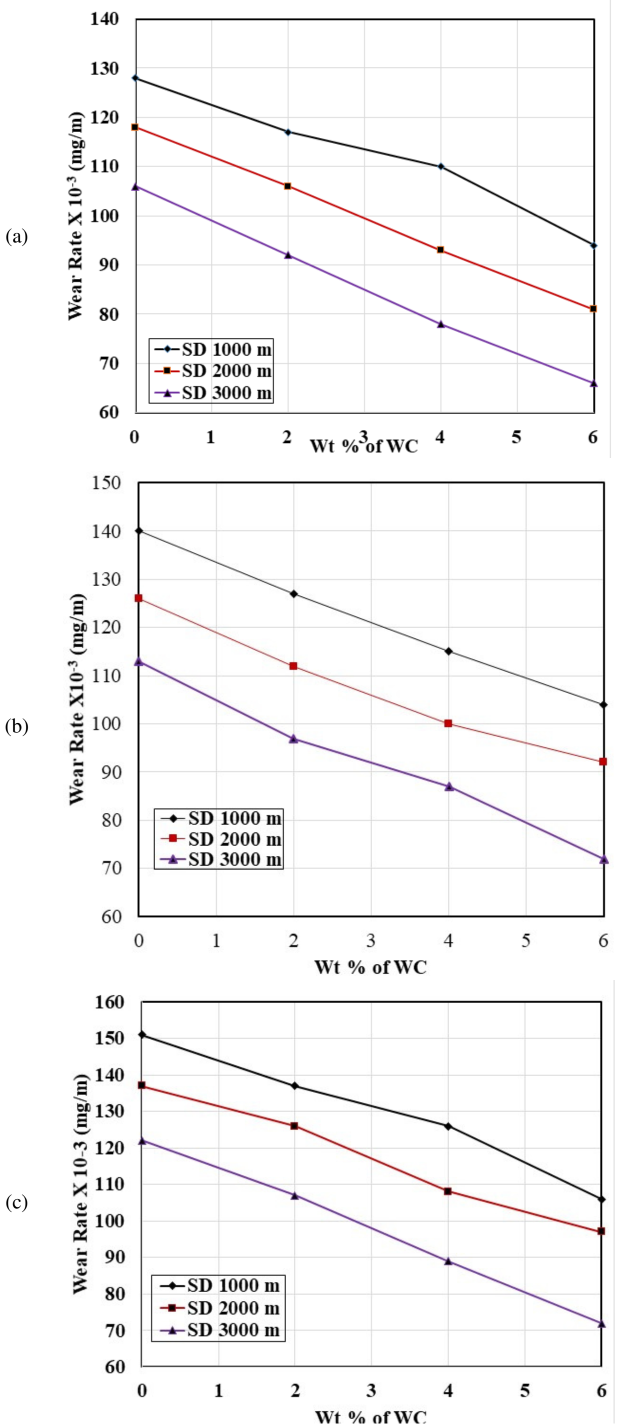


Fig. 2. Effect of WC on wear rate of of 20% forged composites at constant load of (a) 30 N, (b) 40 N, (c) 50 N, under various sliding distances.

The observations show that the reinforcing particles significantly contribute to the composites' better wear resistance through a decrease in wear rate. This observation is unmistakably caused by the composite specimens' release of WC particles onto the mating surface during the tests, thereby providing wear resistance. The WC particles are sheared during the sliding contact wear process, and those layers adhere to the metal surfaces and align in the sliding direction to form a thin film sandwiched between the mating surfaces. Additionally, under low load conditions, the rigid film of WC has very little plastic deformation potential and may endure stress without breaking.

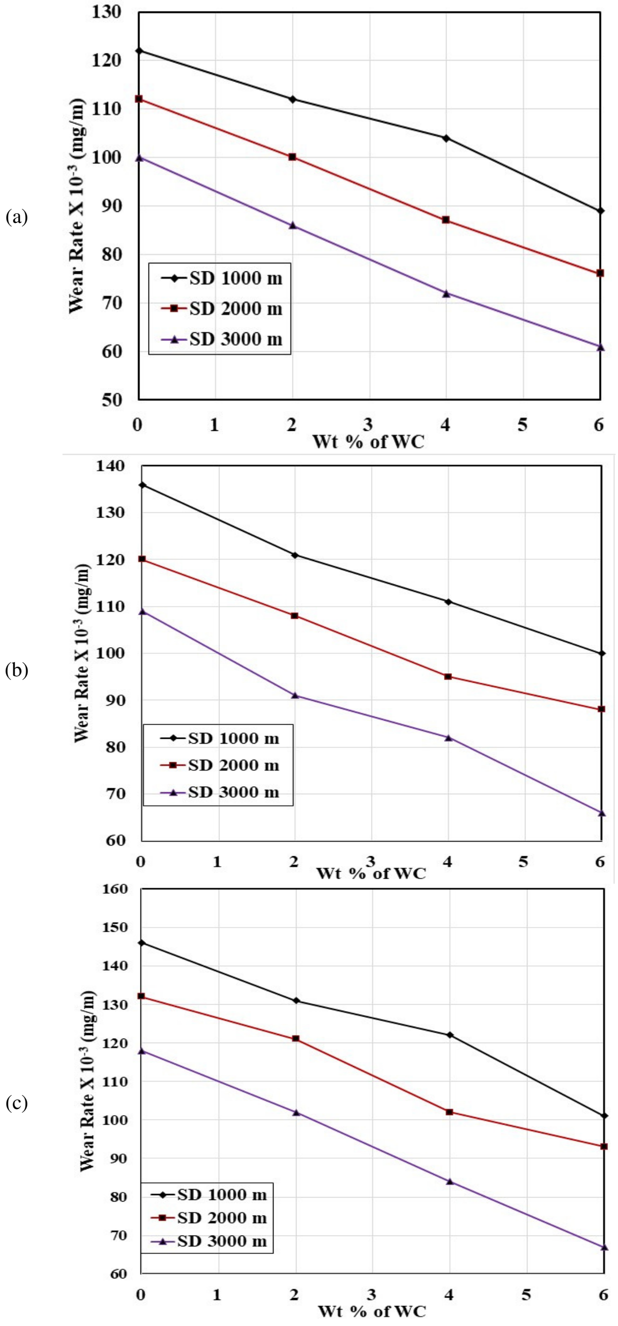


Fig. 3. Effect of WC on wear rate of of 40% forged composites at constant load of (a) 30 N, (b) 40 N, (c) 50 N, under various sliding distances.

This observation may be the result of an increase in temperature caused due to enhanced friction between the contact surfaces. It should be noted that higher temperatures cause significant surface plastic deformation. Subsurface delamination followed by asperity fracture and fragmentation were the results of this. Therefore, it follows that the reinforcing WC particles help the composites' composites have better wear resistance. During the first rubbing action, the reinforcing WC particles serve as a load-bearing material and extremely effectively reduce wear. Additionally, the reinforcing WC particulates function as inhibitors preventing plastic deformation, and also adhering of the aluminum alloy to the wear disc surface [9].

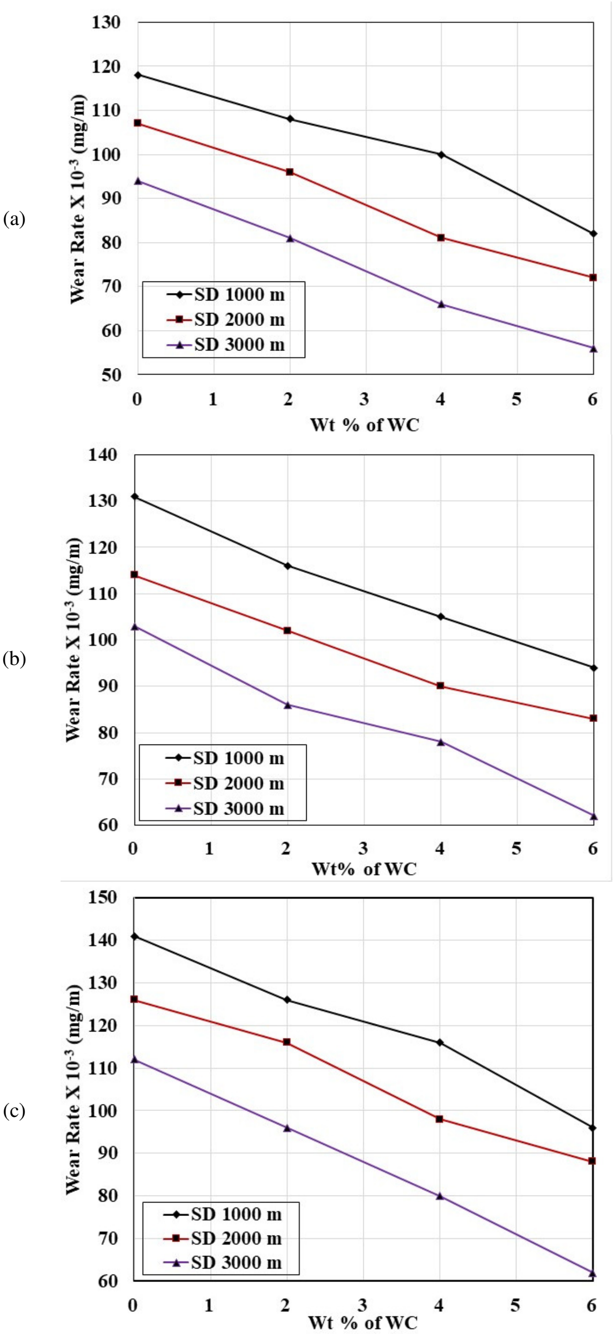


Fig. 4. Effect of WC on wear rate of of 60% forged composites at constant load of (a) 30 N, (b) 40 N, (c) 50 N, under various sliding distances.

The study also included hardness tests with the intention of ascertaining the influence of the WC reinforcement. The results for the forged and unforged samples are shown in Table II. Hard WC particles were added to the composites to increase their hardness, which can be linked to the composites' enhanced resistance to wear. Additionally, the composite material's porosity dramatically decreases, increasing its resistance to crack propagation. The results clearly show that the matrix and reinforcement have a strong link even after forging, which has a significant impact on wear behavior, improves the ability of the matrix to transfer load to the reinforcement, and increases the wear behavior of the composite. Such observations are in line with those made in [10].

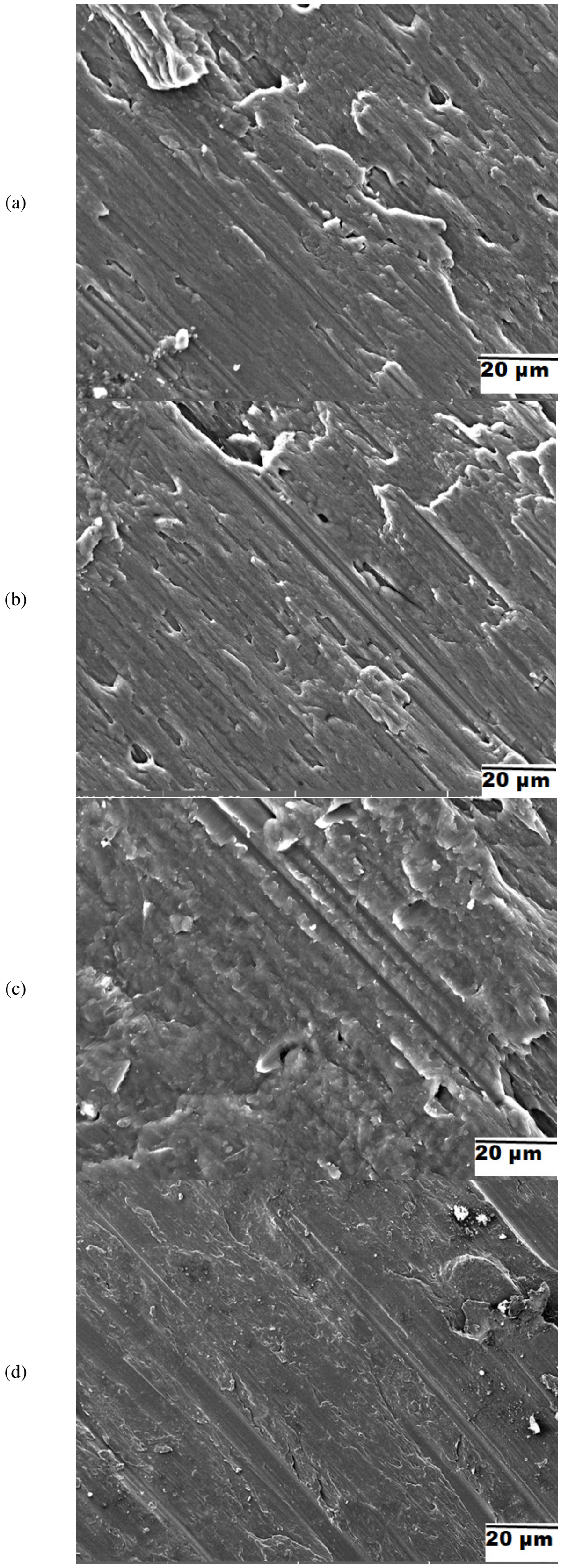
The analysis revealed that the specimen exposed to the 40% forging condition, offered the composites the most excellent wear resistance, which can be ascribed to the forging process because the composites' strength and hardness were greatly improved. It is clear that the layer of oxides that forms on the surface causes the adhesive metal wear to decrease at higher temperatures. The model proposed in [9] can be used to describe the several phases that contribute to the creation of an oxide layer which is resistant to wear.

TABLE II. HARDNESS RESULTS (BHN) OF TESTED SAMPLES

Reinforcement % (WC)	**Unforged composites**	**Forged composites**
0	72	78
2	81	89
4	88	97
6	96	104

The concentrated huge wear product particles disintegrate into smaller particles, go through oxidation process backed by sintering process, and then cover the entire wear surface. Therefore, it follows that at high temperatures, the rate of wear decreases due to the production of an oxide layer, which causes the change from an adhesive to an oxidative wear. Figure 5 displays the SEM images of the worn surfaces of the unreinforced alloy and the composite with 6% WC at test condition of 50 N load and 2000 m sliding distance. Figure parts 5(a)-(c) pertain to worn surfaces of unreinforced alloy, while 5(d)-(f) pertain to composite samples containing 6% WC reinforcement. Figure parts 5(a),(d) relate to worn samples tested under 20% forging conditions, while 5(b),(e) pertain to those with 40% forging conditions, and 5(c),(f) are for 60% forging conditions.

Abrasion, delamination, and oxidation are the three main types of wear mechanisms. The main type of wear is abrasion, which is seen in all the specimens as scratches, grooves, and other debris. The wear asperities on the steel counter-face or hard particles between the pin and the disc that cut into the samples and wear it by removing minute pieces are the distinguishing features of abrasive wear [11]. It is immediately obvious that deeper grooves are indicated by a greater extent of impregnation by harsh counter-face asperities. The asperities of the steel disc deform the asperities of the sample's soft surface, and as a result, shear deformation causes microcracks to occur close to the subsurface area of the pin's softer material.



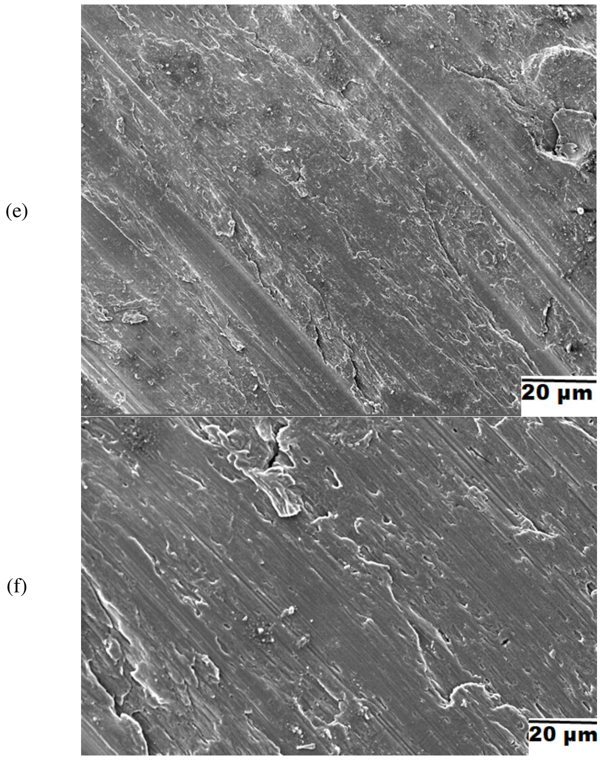


Fig. 5. SEM micrographs showing worn out surfaces of unreinforced alloy (a, b, and c) and composite samples with 6% WC (d, e, and f) at load of 50N and sliding distance of 2000m under 20% forging condition (a and d), 40% forging condition (b and e) and 60% forging condition (c and f).

Later, the pieces separate from the pin surface and become wear debris. Delamination wear is the term used to describe this tendency [12]. The formation of a fracture was seen around the hard particles during the sliding activity between the pin and the disc, and delamination clearly was visible in the SEM microstructures when the pin was made to slide on the steel disc.

IV. DISCUSSION

The current study presents very interesting and significant results which are likely to have relevance to the practical world. The literature shows that not much work has been conducted regarding the influence of metal forming operations on wear behavior of composites. However, the results obtained in the present study are in agreement with the results obtained by several other studies [2, 5, 8, 10]. The novelty of the present work lies in the fact that hot forging as a process can significantly reduce the wear rate of composites thereby contributing to enhanced wear resistance. Several components that are prone to wear in the practical world such as bearings, couplings, pulleys, gears, shafts, etc., can be made this way, thus acquiring an extended life cycle.

V. CONCLUSIONS

This paper deals with the effect of hot forging and WC particles on the wear behavior of composites. The results are of great significance since the effect of forging and reinforcement is found to be very profound in improving the wear behavior. It was found that the wear behavior of the composites improved due to the presence of higher content of WC particles in the matrix. It was observed that the wear behavior of the composites subjected to forging operation was better than that of the unforged counterpart. Further, the wear rate of the reinforced composites was observed to improve with the addition of reinforcing WC particles. Also, the wear rate was indirectly proportional to the content of reinforcement in the composites. This observation was found to be true for all the sliding distances taken into consideration. It was also evident that the wear rate had a direct relation with the load applied up to 40% reduction, which subsequently decreased due to the acute plastic deformation of the composite samples.

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