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Research Article

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Effect of Subsequent Aging on Wear Behaviour of SiCp Reinforced AA2124 Aluminum Metal Matrix Composite

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Abstract This study aims to investigate the effect of aging parameters on wear behaviour of **SiC_p reinforced AA2124 aluminum metal matrix composite.** Aging behaviour and microstructure characterization of AA2124/SiC/25p composite was performed under the aging temperatures of 180, 185 and 190 °C for various dwelling time ranging from 0 up to 100 hours. Wear tests were peromed on a pin-on-disc wear tester using an alloy steel pin and disc of hardness 63 HRC for 160 rpm and 10,20,30 N load. The microstructure was characterized by means of scanning electron microscopy (SEM). The hardness, energy dispersive spectroscopy analysis and X-ray diffraction (XRD) measurements were also performed to evaluate the characteristics of aged AA2124/SiC/25p composite. SEM observations of the worn surfaces cracks as the mechanism in the as aging **conditions.** The results show that the hardness and wear rate values of as-received composite were considerably improved up to two third by the aging AA2124/SiC/25p composite.

Keywords composites: metal matrix, heat treatments , Wear, microstructure , X-ray analysis

Introduction

Metal matrix composites (MMCs) are materials, which combine a tough metallic matrix with a hard ceramic reinforcement to produce composite materials with superior properties to conventional metallic alloys. The most popular reinforcements are silicon carbide and alumina. Aluminum, titanium and magnesium alloys are commonly used as the matrix phase. The density of most MMCs is approximately one third that of steel, resulting in high specifc strength and stiffness. Due to these potentially attractive properties coupled with the ability to operate at high temperatures, MMCs compete with superalloys, ceramics, plastics and re-designed steel parts in several aerospace and automotive applications [1-2]. Discontinuous fiber (short fiber, whisker or particulate) reinforced aluminum matrix composites provide many advantages in engineering applications where low density, high strength, high stiffness, and being machinable and workable are mostly considered [3]. Heat treatment of aluminium alloys are affected by means of precipitation hardening comprising the following steps: solutionizing, quenching and aging at room temperature (natural aging) or at elevated temperature (artificial aging) [4]. The reactivity between the reinforcement and the matrix during the elaboration process and during the high temperature solution treatment may lead to a modification of the composition of the matrix [5]. There are many studies carried out by several researchers such as, Kiourtsidis et al. [6], Christman and Suresh [7], Sannino and Rack [8], Abdel-Azim et al. [9], and Pal et al. [10] concerning the effects of aging on mechanical properties of the aluminum matrix composites reinforced with one kind of reinforcement, i.e., particles or whiskers [11]. However, there is no work on the aging behaviour of AA2124/SiC/25p MMCs in the current literature.

Material removal is expressed as area, volume or mass and is termed as wear amount and wear rate relates to the path or duration load. The reciprocal value of wear amount is termed the wear resistance. Economic life of many structural parts is limited by wear and wear resistance is as important as yield stress or fracture ductility values. The material removal from the sample in contact with a hard surface effect, because it is known as ductile materials [12-15]. Subsurface deformation influences the wear behaviour.

The present work was initiated in order to contribute to a better understanding of the aging behaviour in AA2124/SiC/25p MMCs. Dry sliding tests were performed in base and aged samples. Wear loss was determined all samples after wear tests. Worn surfaces of base and aged were analyzed under SEM.

Experimental Procedure

AA2124/SiC/25p aluminum MMCs plates, α-SiC reinforced composite which were supplied by AMC Aerospace Metal Composite Limited (UK). Powder metallurgy processing involving mechanical powder mixing and hot isostatic pressing followed by forging was used to produce this composite. The forged composite plates were solution heat treated at about 505 °C for 1 h. and quenched in 25% polymer glycol solution. They were subsequently aged at room temperature for 100 h. (T4 temper condition). The AA2124 alloy had a composition of Al-3.86Cu-1.52Mg-0.65Mn-0.17Si which was obtained by the supplier. AA2124/SiC/25p-T4 composite plates of having 6×6×3 mm dimensions were used as aging samples. Aging procedure employed in this study as follows; samples were annealed at 530 °C for 8 hours and followed by quenching in ice-cold water and then aging was performed at 185 °C for 0, 2, 4, 6, 8, 12, 24, 48, 72 and 100 hours. SEM and energy dispersive spectroscopy (EDS) analysis were conducted by JEOL JSM-5910LV to investigate the microstructural changes of the aged composite. The specimens were prepared for microstructural analysis and hardness measurements using conventional polishing methods without etching. Hardness measurements were carried out by Rockwell-A (HRA). 18 tests were performed for each aging time and temperature on both sides (3 measurements for each side) of 3 separate aged composite to determine the hardness profiles by DIA Testor 7551 type Instron-Wolpert hardness testing unit. Phases formed during aging treatment of AA2124/SiC/25p-T4 composite were determined by Bruker AXS D8 XRD system with 40 KV and 40 mA operating voltage and Cu Kα radiation. Scanning rate of 0.02° mm-1 was employed in the range of 5°<2θ< 100°.

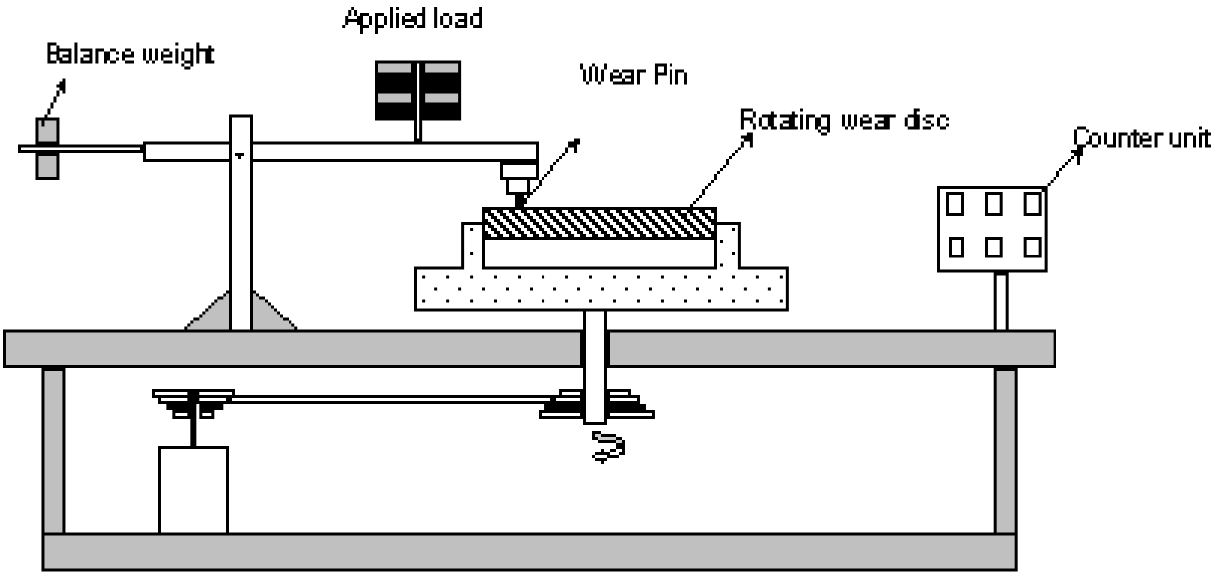

Figure 1: Schematic illustration of wear device

The wear behaviour was measured by a dry pin-on-disk test (Fig. 1). Wear tests were performed according to ASTM Standard G99-95 using the following test conditions: tool steel (63 HRC) of wear disc, pin of 3 mm diameter, 25 mm length and polished to a roughness of 0.100 µm R_a.; sliding distance 5000 m; speed 0.75 m/s; 20 N load applied; relative humidity less than 30%, and room temperature. Disc surface were ground and polished to a roughness of 0.750 µm R_a. The wear rate was calculated using the following equation:

$$W_s = \Delta m / \rho L F_N \quad (1)$$

where, W_s is wear rate, m^2/N, Δm the mass loss of test samples during wear test of N revolutions, kg, ρ the density of test materials, kg/cm^3. L is total sliding distance, m and F_N the normal force on the pin, N. The total sliding distance was monitored on an auto-recorder. The worn surfaces of all the samples were examined using SEM (JEOL JSM-5910LV). At least three samples were tested under the same conditions to guarantee the reliability of the results.

Results and Discussion

The hardness distributions of aged AA2124/SiC/25p-T4 composite with various aging time and temperature are shown in Fig. 2.

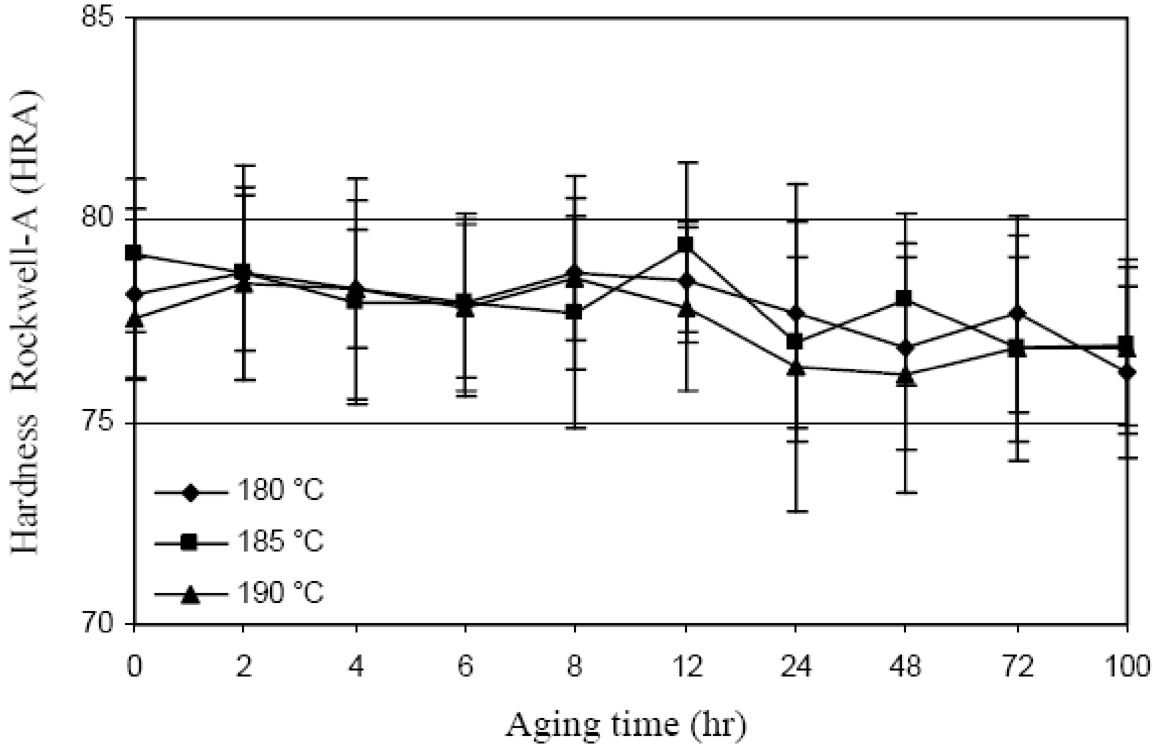

Figure 2: Hardness profile of AA2124/SiC/25p-T4 composite with various aging time and temperature

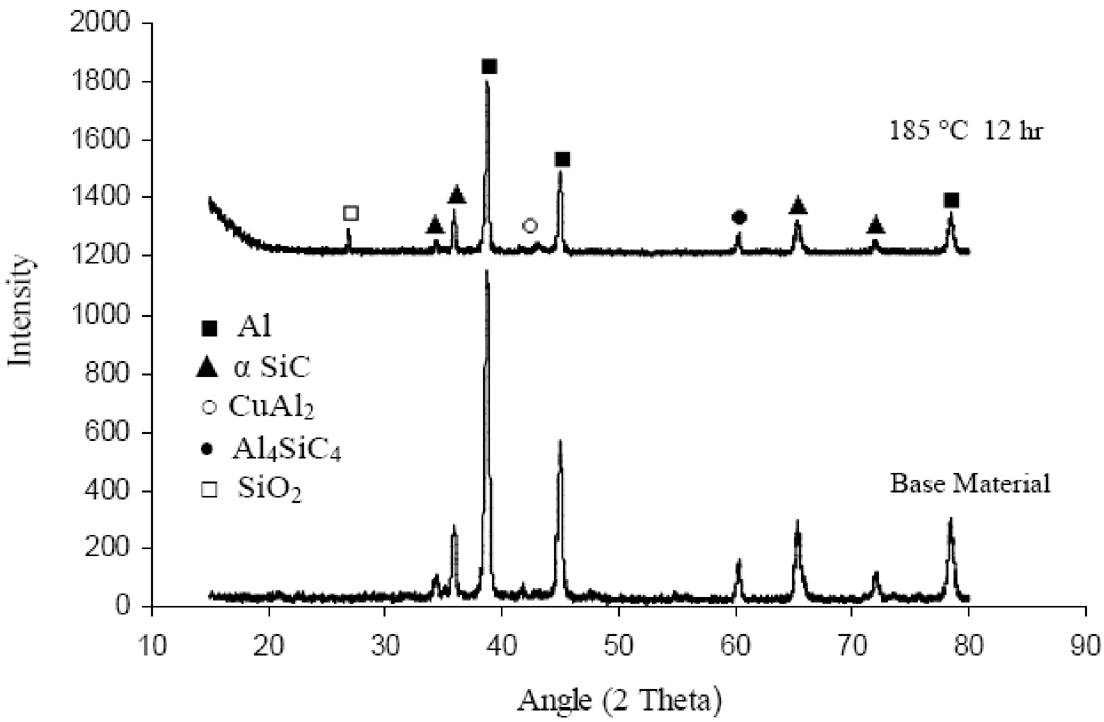

Figure 3: XRD pattern of AA2124/SiC/25p-T4 composite as received and after aging at 185 °C for 12h.

The hardness values of aged AA2124/SiC/25p-T4 composite was remarkably improved when compared with as received composites having 47 HRA before aging. It was found that the hardness were increasing up to 12 h then decreasing with prolonged aging treatment. There was no study found about aging behaviour of AA2124/SiC/25p-T4 composite in the literature, therefore direct comparison of our study with others was not attempted. This is because of the fact that there are some studies in the reference [6] with very similar composite composition, totally different processing conditions, different type of SiC, particle sizes and volume fractions.

Standard deviation of hardness values was in the range of 1.467 -2.947 which are reasonable and acceptable for average 18 hardness measurements for each composite. The optimum value for all series of experimental studies was obtained at 185 °C for 12 hours. The similar trend was observed in a previous study carried out by Bozkurt el al [13]. In this study, it was employed AA2124/SiC/25p-T4 friction stir welded composite with a thickness of 6 mm, which was solutionized at 510 °C and followed by an artificial aging at 160 °C for 8 h. It was found that the hardness value of AA2124/SiC/25p-T4 base material was risen up to 7.5 % by subsequent aging. In this study, the hardness value increased up to 67 % by subsequent aging. This remarkable increase in hardness, when compared to Bozkurt's previous study [13], could be attributed to the difference in solutionizing temperature, time and quenching media which were ice water respectively. Therefore ice water quenching can provide severe quenching media resulting in high hardness.

The phases detected by XRD analysis were given in Fig. 3. In addition, as the Fig. 3 depicted, there is an evidence of SiO_2 formation which is probably the result of oxidation of α-SiC during heat treatment. Some evidence of SiC oxidation was found as SiO_2 peaks in samples aged at 185 °C for 12 hours. Whereas $CuAl_2$, Al_4SiC_4 and phase intensities both were increased by the increase with aging time from 0 h to 12 hours suggesting an increase in the ratio of reaction products formation between Al-Cu and Al-SiC.

SEM micrograph of as received composite before aging was depicted in Fig. 4a. The SEM microstructure examination revealed non uniform distribution of SiC particles in the matrix. Backscatter electron image (BEI) micrograph of AA2124/SiC/25p-T4 composite shown in Fig. 4b, which was annealed at 530 °C for 8 hours and followed by quenching in ice-cold water and then aging was performed at 185 °C for 12 hours. In SEM microstructure evaluation before and after aging, SiC particles were found to be non uniformly distributed throughout the matrix with a grain size distribution ranging from (0.05-0.4 micron) and also with a coarser grain size between 1-6 micron. Evidence of white ultra fine precipitates was found by SEM, BEI examination and XRD results were also revealed secondary phase intermetallics confirming some secondary reaction products which is in very good agreement with reference [10].

These reaction products and precipitation phases were occurred between Al-Cu and Al matrix - SiC particles system. It was identified CuAl2, Al4SiC4phases in AA2124/SiC/25p-T4 composite after aging by XRD as depicted in Fig. 3. The precipitation phases can contribute to overall strength and hardness of composite. It is a very well known fact that these precipitates such as $CuAl_2$, Al_4SiC_4 phases behave as hard secondary phases blocking movement of dislocations and increasing mechanical properties and hardness. The same secondary reaction products and precipitation phases were also detected by EDS analysis, occurred between Al-Cu and Al matrix - SiC particles system after aging. These precipitates were identified as $CuAl_2$ and Al_4SiC_4 phases as depicted in Figs. 3 and 5.

EDS analysis of composite which was aged at 185°C for 12 hours and variation of elements in different regions of the same BEI image were given in Fig. 5 and Table 1, respectively. In EDS analysis of BEI image only Al-Cu peaks were detected in the region 1 (represented in Fig. 4b) of EDS analysis revealing matrix structure.

In region 2 (Fig. 4b) of BEI micrograph's EDS analysis revealing precipitate phase (Fig. 5) Al-Cu-Si-Mn-Mg-C-O peaks were determined and the existence of SiC phase was clearly observed. Besides a little oxygen peak was detected showing the presence of SiO_2 phase suggesting an evidence of oxidation of SiC [14]. In region 3 (Fig. 4b) of BEI micrograph's revealing precipitate phase EDS analysis the presence of Al peak, which was effected by being a base material in the composite, Si and C peaks were observed as main elements confrming the existence of SiC and Cu-Mg-O peaks were also detected. Cu and Mg elements are alloying elements of the composites and the oxygen presence could be referred to oxidation of SiC.

Table 1: Variation of elements in different regions of BEI image after aging.

Number in BEI	**Element (%)**					
	C	**O**	**Mg**	**Al**	**Si**	**Cu**
1	-	-	-	94.92	-	5.08
2	10.38	2.37	0.98	64.80	14.22	3.24
3	16.80	4.20	0.71	48.72	27.66	2.01

Since α-SiC is quite unstable it reacts with aluminum alloy matrix or other alloy elements in high temperatures. This may explain the absence of Al_2CuMg as aging precipitate or any spinel or oxidation products like MgO in an Al-Cu-Mg alloy such as AA2124 and the limited presence of $CuAl_2$ as XRD pattern of Fig. 3 indicates. In addition, as the Fig. 3 and Fig. 5 depicted, there is an evidence of SiO_2 formation which is probably the result of oxidation of α-SiC during heat treatment. Since SiO_2 formation was only observed in precursor composite and no trace of SiO_2 was observed which was inherited by the production stage. Hence it is quite possible for aluminum alloy / α-SiC composites to spontaneously oxidize, therefore they should be surface protected at high temperature applications in open air.

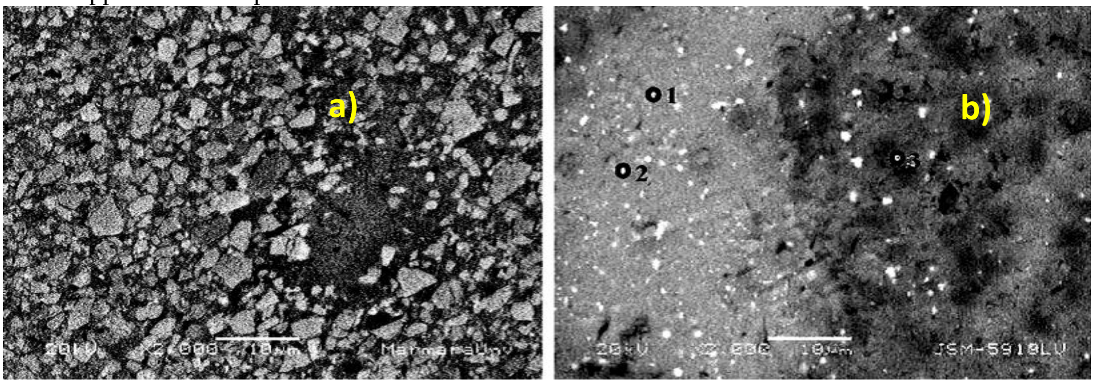

Figure 4: SEM micrograph of as received AA2124/SiC/25p-T4 composite before aging (a) and BEI image after aging at 185 °C for 12 hours (b).

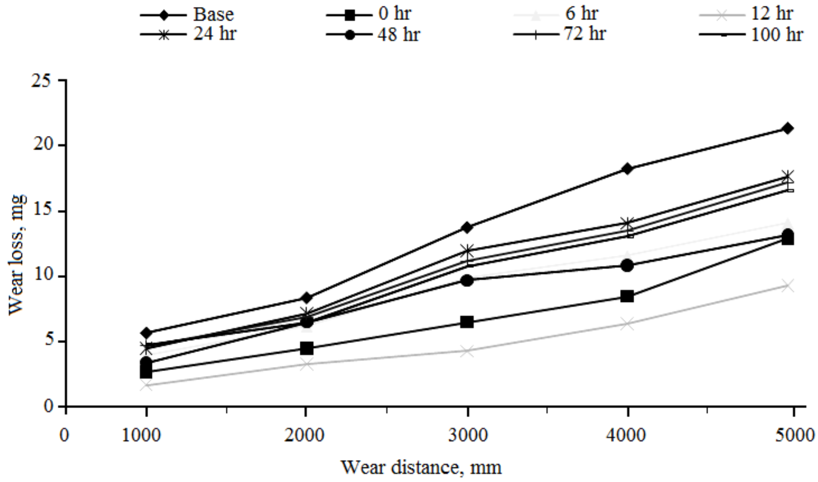

Figure 6: Variation of weight loss with wear distance and aged times for base and aged samples

The variation of weight loss and wear rate with wear distance and aging times for base and aged samples are shown in Fig. 6 and Fig. 7., respectively. The wear loss was increased with increase in wear distance and the wear rate was decreased with increase in wear distance. Agigng time were decreased wear loss and wear rate up to 12 hr. More agigng time than 12 hr. Wear loss and wear ratewas increased. It is very clear from these observations that the hardness had a significant effect on the wear behaviour in the particle reinforced composite materials.

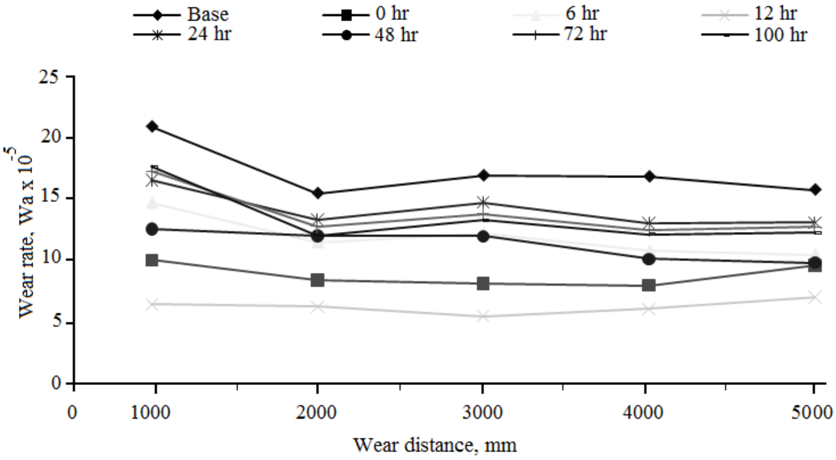

Figure 7: Variation of wear rate with wear distance and aged times for base and aged samples

SEM of worn surface for base and aged samples are shown in Fig. 8. Demonstration the mechanism of the delamination, deformed layers and tracks along the direction of sliding during wear were shown in Fig. 8. The localized plastic deformation leads to the formation of subsurface cracks resulting in the delamination of surface layer.

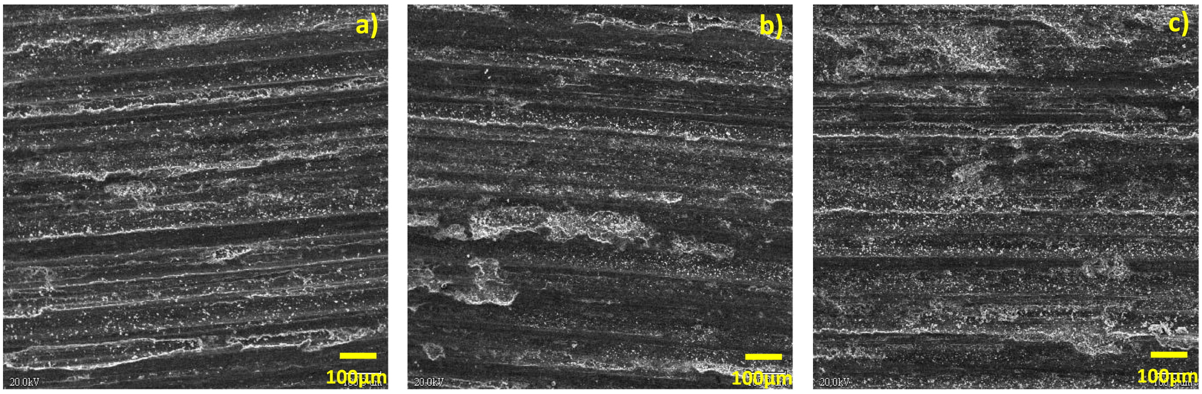

Figure 8: SEM of worn surface of base (a), 12 hr. aged samples (b) and 100 hr. aged samples (c), wear distance 5000 m.

Conclusion

In this study, the subsequent aging behavior of the AA2124/SiC/25p-T4 composite was investigated. The hardness values were generally decreasing by increasing dwelling time and aging temperature. The difference in age-hardening behaviour based on the time and temperature of solution treatment has been attributed to volume fraction of precipitates. It was identified $CuAl_2$, Al_4SiC_4 phases in AA2124/SiC/25p-T4 composite after aging by XRD. These reaction products and precipitation phases were occurred between Al-Cu and Al matrix - SiC particles system. Some evidence of SiC oxidation was found as SiO_2 peaks in samples aged at 185 °C for 12 hours which might be due to originated from production stage. Whereas $CuAl_2$ and Al_4SiC_4 phase intensities both were increased with the increase in aging time from 0 h to 12 hours. The optimum aging temperature for the composite material was found to be 185 °C for 12 h. Wear loss of composite materials increased with wear distance and decreased with aging times.

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