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Role of heat treatment on mechanical and wear characteristics of Al-TiC composites

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ABSTRACT

The aim of this work is to explore the mechanical and wear properties of Al-TiC composites synthesized through liquid metallurgy technique. Al6061 was the matrix material used and Titanium carbide (TiC) is the reinforcement material. The composites were fabricated by adding TiC of 3, 6, 9 and 12 wt. % to Al6061. Thermal processing was used on the produced composite specimens to accomplish solutionization at 530 °C for a period of 8 hours and quenched in three different medias like air, water and ice. The effect of heat treatment and quenching media was evaluated in the research. In order to validate the effect of heat treatment as cast samples also studies for its wear properties. Results outcomes shows the better mechanical and wear characteristics compare to composites that haven't been heat treated. Also, superior mechanical and wear characteristics of composites are produced by ice quenching compare to air and water quenching. Wear out samples are investigated through SEM to study the mechanism of wear. Microstructure study was made, and it reveals good bond between matrix and reinforcement material.

KEYWORDS

Al6061 • TiC • liquid metallurgy • SEM • wear • hardness • mechanical properties

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Introduction

Due to the enhanced performance, MMCs have recently grown in popularity and have begun to replace traditional materials in a number of engineering fields. Due to their fundamental advantages like exceptional stiffness, strength, low density, light weight, resistance to corrosion, and resistance to wear, numerous industrial applications employ MMCs, including those in the automotive, aerospace, and military sectors [1–4]. Al-based MMCs are among the kinds of MMCs that are most commonly used because of their superior mechanical and tribological characteristics. The quantity, scope, composition, and weight distribution of reinforcements are just a few of the many variables affecting the characteristics of these AMCs. Al6061 is one of the many series of aluminium that are readily available and is a popular matrix substance used in the manufacture of MMCs due to its high corrosion resistance, weldability, and machinability. Alumina, TiC, silicon carbide, Boran carbide, and other materials are frequently employed as reinforcements when Al 6061 is used to create composites that enhance a variety of mechanical qualities [3,5–8]. These particles specifically improve Al6061's mechanical and wear resistance. MMCs can be produced using a variety of methods, including the PM process, liquid phase fabrication vacuum casting, squeeze form technology, compo casting, and stir casting, and more. Because it is easy to obtain, simple to manufacture, and more affordable than other production procedures, the most common technique used to make AMCs is stir casting [8–12].

The majority of the basic materials have unusual properties. Because of some intrinsic traits and attributes that may not be suited for ordinary uses, the majority of them that are currently available may not be physically viable for many engineering purposes. As a result, materials are frequently thermally treated to increase their strength, making them physically and structurally viable for a larger range of industrial uses. The heat treatment procedure has the potential to change the microstructure of AMCs, strengthening its mechanical attributes. The solution treatment step of the thermal treatment procedure is followed by the quenching in different medias. Literature reveals that heat treatment positively affects the properties of composites. There is a wealth of information on metal alloys with an aluminium foundation that contain alumina, silicon carbide, boron carbide, and magnesia, however there aren't many experiments on titanium carbide particles. Although the type of reinforcement and the synergistic effect of heat treatment both significantly influence the ultimate mechanical properties of composites, little is known about the heat treatment of Al-based composites. As a result, using the liquid metallurgical approach, composites have been created in the current experiment by adding TiC particles to the Al6061 matrix. Analysis of the effects of heat treatment and quenching media on the performance of Al6061-TiC MMCs is the main goal of the study. TiC of 0–12 wt. % added to Al6061 in a stage of 3 wt. % were used in the testing. Mechanical and wear properties were then assessed and contrasted with the composites that hadn't been heated. On hardness and wear qualities, studies and reports on the effects of heat treatment and quenching medium were made.

Materials and Methods

Due to the accessibility and ease of use, the stir casting approach has been used to create MMCs that contain Al6061 and TiC at concentrations of 0–12 wt. %. Al6061 was the matrix material used in the current study. Properties and chemical composition of Al60631 was shown in Tables 1 and 2. TiC particles with a size range of 10–20 μm are utilised as reinforcement in the ongoing research work to produce composite. Properties of TiC was shown in Table 3. In a stage of 3 wt. %, TiC particles were blended at a rate of 0–12 wt. % to Al6061. Utilising a CNC machine, samples for various testing have been prepared using the created composites. To find the distribution of TiC particles across the matrix material and quantify wear behaviour, a microstructure investigation of produced sample specimens was done. In order to determine the configuration of composites, energy dispersive spectroscopy (EDS) and optical microscope were also used. Scanning electron microscopy (SEM) analysis is made to study the mechanism of wear. Therefore, they are contrasted with the basic alloy material in order to support the experimental results.

In the beginning, known quantities of Al6061 alloy rods were put into the graphite crucible and then into the electric furnace. At 850 °C, the alloy was melted and fine vortices began to form as a result of mechanical stirring. In order to increase the degree of wetting, in a different container, preheating of the TiC particles was carried out at 700 °C. The preheated TiC was then put into a furnace containing molten Al6061 alloy after being stirred to create a fine vortex. A steady feeding rate and an electric stirrer speed of 450 rpm were used during the addition of reinforcement. By moving the molten metal from the crucible into the cavity of the mould at room temperature, the metal was given time to solidify. The same procedure was repeated for various TiC fractions, including 3, 6, 9, and 12 wt. %. Table 4 displays the configurations of the MMCs used in the ongoing research work.

Table 1. Properties of Al6061

Properties	Values
Density, g/cm^3	2.70
Melting point, °C	585.00
Tensile strength, MPa	124.00
Yields strength, MPa	55.00
Young's modulus, GPa	68.00
Poison's ratio	0.33
Thermal conductivity, W/mK	180.00
Shear strength, MPa	83.00

Table 2. Configuration of Al6061 by wt. %

Constituents	Mg	Cu	Fe	Cr	Si	Mn	Ti	Zn	Al
Percentage	1.1500	0.2750	0.1060	0.2010	0.5800	0.0014	0.1300	0.2500	Balance

Table 3. Properties of titanium carbide

Properties	Values
Formula	TiC
Density, g/cm^3	4.93
Size mesh	325
Purity, %	99.10
Melting point, °C	3155.00
Vickers hardness, VH	3200.00
UTS, MPa	240.00
Compressive strength, MPa	3700.00

Table 4. Composite configuration

Specimen	Composite
A	Al6061
B	Al6061+3 wt% TiC
C	Al6061+6 wt% TiC
D	Al6061+9 wt% TiC
E	Al6061+12 wt% TiC

To create the specimens, the designed composites were machined on a CNC machine. In order to analyse the physical and microstructural characteristics that match the test rig standards. To find the scattering of reinforcing particles in an alloy, the optical metallurgical microscope was used in the microstructural examination. The samples were polished for microstructure analysis, and the polished surface was etched using the conventional metallographic procedure. The samples were polished using the conventional metallographic method in order to examine their microstructure, and the polished surface was etched with Keller's reagent.

By using a weight of 500 g and a dwell time of 15 s, the Vickers' hardness tester was utilised to determine the microhardness of produced MMCs. For data reproducibility, three trials were conducted for each test condition in order to reduce experimental error and uncertainty. The outcome is determined using the value's arithmetic average. The average value from the dataset, a standard deviation of one on either side, is used to plot the graphs. Utilising a pin on disc device, composites have had their wear rate assessed. A force of 30 N, a velocoty of 100 rpm, and a sliding distance of 1000 m are used to measure the wear rates. The specimens were created in accordance with ASTM (G99-05) requirements for a length of 30 mm and a diameter of 8 mm. Figure 1 shows the sample that was utilised to test the wear properties. At the same time, the coefficient of friction (COF) of aluminium and its composites was also observed. SEM was used to do a morphological analysis on worn-out samples in order to investigate the wear mechanism.

Fig. 1. Wear test specimens

Heat treatment has been applied to the produced composites. The heat treatment for solutionizing was carried out in a muffle furnace. Al6061 and Al6061-TiC composites that have been cast are first given an 8-hour solutionizing treatment in a muffle furnace at a temperature of 530 °C, followed by an immediate quenching in three distinct media, like air, water and ice. In order to evaluate how heat treatment and quenching media affect composites, the microstructural and wear behaviour of both heat-treated and non-heated MMCs were examined.

Results and discussion

Examination of microstructure

In the current study, hybrid MMCs are created by combining Al6061 with micron-sized TiC particles. With the aid of an optical microscope, a morphological study has been carried out to look at the dispersion of reinforcing materials into Al6061. The corresponding optical micrographs of Al6061 with 0–12 % TiC particles are shown in Fig. 2. The accurate and uniform dispersion of TiC particles over the matrix alloy is shown in Fig. 2. A homogenous dispersion of reinforcing elements has been seen in optical micrographs. Due to the swirling effect created during the production process, this has happened. Additionally, the key factor for the homogenous dispersion of TiC in alloy is the existence of a component of magnesium in the matrix alloy [13–16].

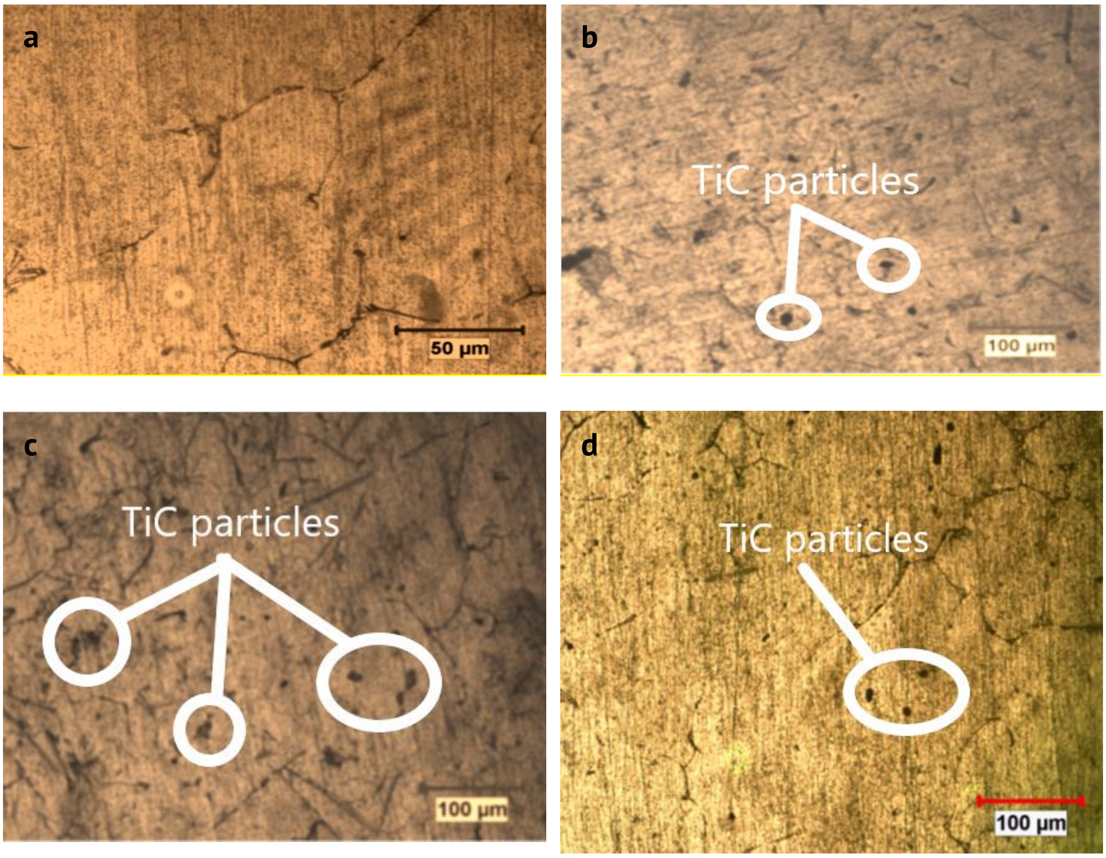

Fig. 2. Microstructure of composites (a) Al6061, (b) Al6061+3 % TiC, (c) Al6061+6 % TiC, (d) Al6061+9 % TiC

The EDS spectrum of generated MMCs, which is shown in Fig. 3, identifies the presence of the elements used in the current investigation to create composites. The incorporation of TiC reinforcements has been noticed in the EDS spectrum's Ti and C elements. The presence of all the components predicted in the paper was confirmed by the Al6061's high intensity peak that was also seen in the spectrum.

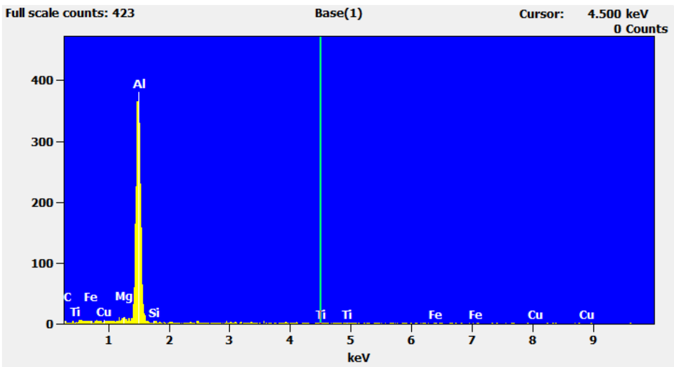

Fig. 3. EDS spectrum of composites

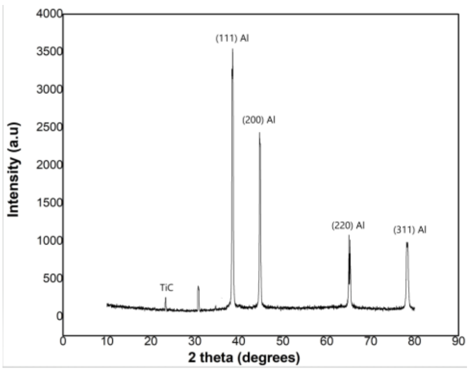

Fig. 4. XRD pattern of composites

An appropriate sample was created in accordance with the guidelines in order to perform the X-ray diffraction study. Figure 4 depicts an X-ray diffraction (XRD) pattern for the provided material to illustrate its quality and attest to the presence of the constituent elements used to construct the present composite material. Figure 4 displays multiple peaks for Al6061 and TiC particulates at the same time as well as peaks at (111), (200), and (220). Due to Al's low sterility and TiC's higher purity, this occurs. This is likewise a result of the Al and TiC particulates samples being oriented in the (111), (200), and (220) planes. After comparing the experimental peaks attained and the standard peaks, components such as Al and TiC were found. TiC reinforcement is present in the ongoing study, according to the X-ray diffraction results.

Hardness

The hardness of the produced composites is assessed using the Vickers' hardness tester. The microhardness of composites without and with heat treatment condition is shown in Fig. 5. Studies demonstrate that hardness is significantly increased when TiC is added to Al alloy. Up to 9 weight percent, adding TiC to Al6061 results in an increase in hardness; after that, it decreases. Composites lose hardness as a result of reinforcement agglomeration caused by increased TiC buildup in the matrix alloy. Similar outcomes were attained for all of the case studies involving both heat-untreated and heat-treated composites. Additionally, studies are conducted to determine how heat treatment and quenching media affect the hardness of produced composites. By solutionizing heat treating composites and immediately quenching them in air, water, or ice, the hardness of the material is significantly increased. This is because Al and its composites have been solutionized, allowing the highest concentration of the hardening solute to dissolve into solution. Additionally, quenching media influences how hard composites are. For Al+9%TiC composites that were ice quenched, a higher hardness was achieved. The hardness and mechanical qualities of composites can be increased through quick quenching, which produces a saturated solution. Because of this, ice-quenched composites have superior mechanical properties compare to air and water quenched composites. When compared to unheated Al alloy, ice-quenched Al+9%TiC composites show a hardness improvement of about 43 %. Similar kind of outcomes is seen in [17-23].

Wear

The wear rate of composites was investigated using a pin on the disc wear tester with a load of 30 N, a velocity of 100 rpm, and a sliding length of 1000 m. Figure 6 illustrates how quickly composite materials wear down with and without heat treatment. The findings indicate that the volume loss per unit distance decreases as TiC reinforcement are added to the Al6061 alloy. Increasing the weight fraction of TiC in Al alloy reduces the rate at which composites wear out. This decrease in composite wear rate is seen up until the inclusion of 9 wt. % TiC; however, TiC concentration above 9 wt. % causes an increase in wear rate. This is due to the fact that an agglomeration with a greater TiC concentration in Al alloy can be seen in the microstructure. It has been discovered that the wear rate of composite materials can be decreased by mixing hard TiC particles with Al6061.

Additionally, it is evident that heat treatment has a favourable impact on composites capacity to resist abrasion. Wear resistance of composites is improved by solutionizing heat treatment at 530 °C for 8 hours, followed by rapid quenching in three distinct mediums. In all the examples that were examined, it was found that the addition of TiC particles decreased the composites' rate of wear up to 9 wt. % of TiC. The solutionizing process causes the intermetallic phase of Mg and Si to develop, which is harder than Al and exhibits better wear resistance compare to un heat treated composites. The impact of the quenching medium on the composites' wear rate was also researched. For all quenching media examined, such as air, water, and ice, the wear rate of aluminium alloy and its composites reduces.

It was discovered that Al6061 and its composites wear down at the least rate when the composites are ice quenched compare to air and water. Compared to air and water quenching, the ice quenching procedure produces composites with superior wear resistance since the composites cool down more quickly following solutionizing treatment. Intermetallic precipitations from the extremely saturated solid solution will not be able to form during the quenching process due to the fast cooling. Minimum wear rate is observed for Al+9 % TiC for all cases tested. When compared to unheated Al6061 alloy, wear resistance for ice quenched Al+9 % TiC composites was found to be improved by about 62 %. Results are familiar in the work [24–26].

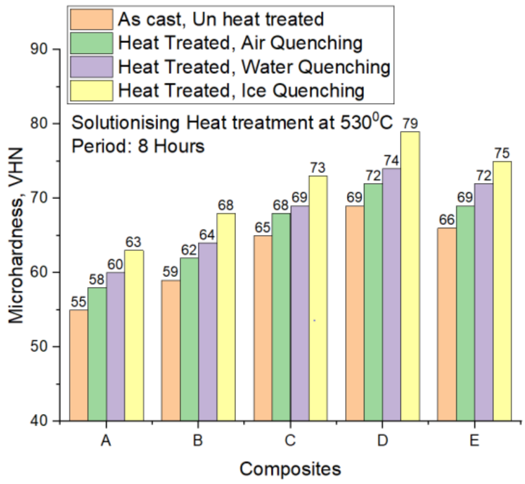

Fig. 5. Microhardness of composites

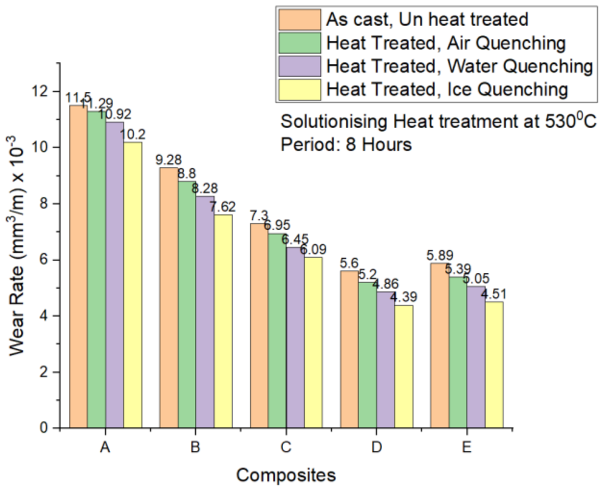

Fig. 6. Wear rate of composites

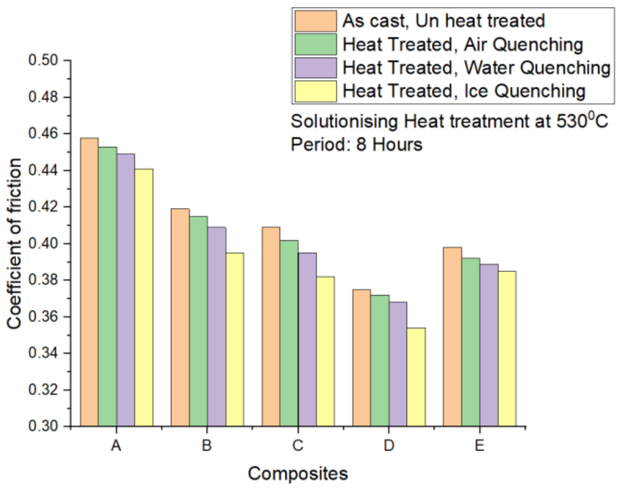

Fig. 7. Coefficient of friction of composites

Coefficient of friction

The typical coefficient of friction for composites is shown in Fig. 7. It is amply demonstrated that adding TiC lowers the coefficient of friction. When compared to unreinforced Al6061 alloy, the coefficient of friction (COF) of composites is lower. For Al6061 alloy, a high COF was seen, while reinforced composites showed a low COF. COF was found minimum for Al+9 % TiC. As a result of the harder TiC reinforcement sharing its strength with the Al alloy, the addition of TiC boosts the COF of the alloy. Additionally, solutionizing heat treatment is seen to significantly improve composites' COF. For all evaluated examples of heat treatment Al+9 % TiC composites, COF is shown to be low. It was also looked at how quenching mediums affected COF and discovered that COF of composites decreased across the board. When Al6061 and its composites are ice quenched, the COF of the composites decreases at the least rate when compared to air and water, it was found. Comparing ice quenched Al+9 % TiC to unheated Al alloy, COF drops by about 23 %.

Figure 8 displays the SEM micrographs of the worn-out surfaces acquired under a load of 30 N at a speed of 100 rpm. The composites wear down more quickly as a result of the accumulation of harder TiC particles and an oxide layer between the pin and the disc. The samples' surfaces are all marked with scratches and grooves, as seen in the figure. Furthermore, the particles separate from the outer layer of the samples as a result of plastic deformation, which shows that the composites' surface adhesive has worn down. Researchers [27–30] have made similar observations. According to the research, the presence of hard ceramic particles enhances the wear properties of composites, increasing the wear resistance of MMCs.

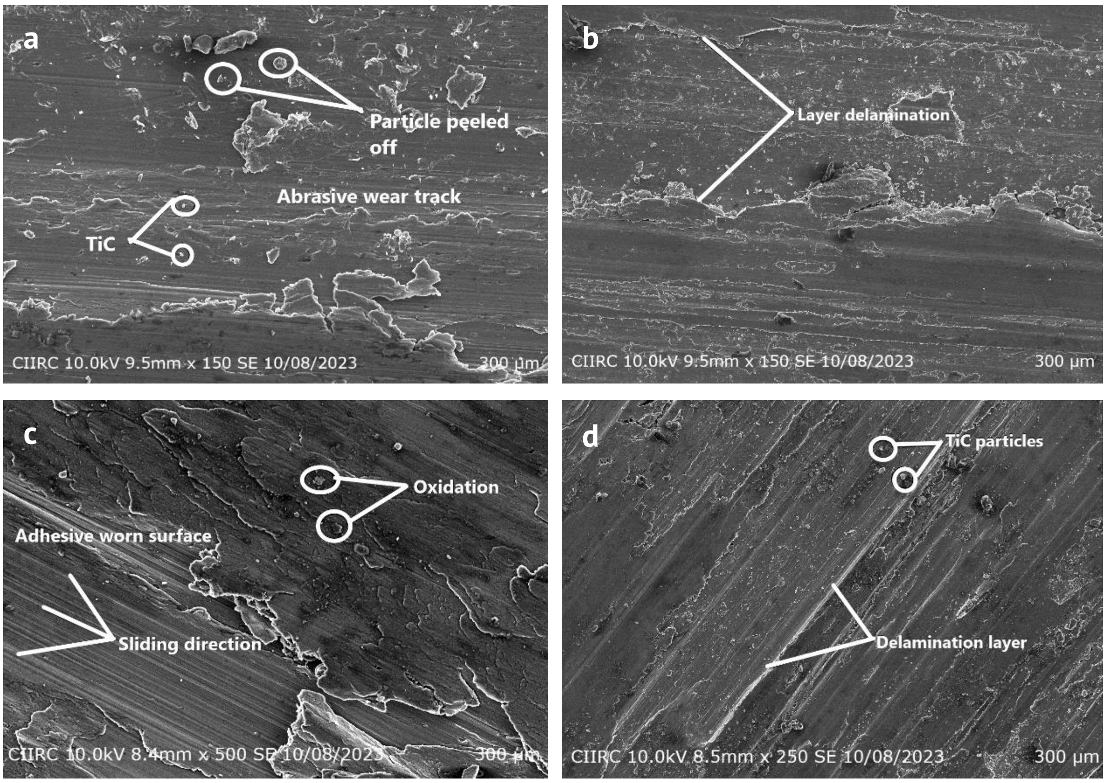

Fig. 8. SEM worn out surfaces of composites (a) Al6061+3%TiC, (b) Al6061+6%TiC, (c) Al6061+9%TiC, and (d) Al6061+12%TiC

Conclusions

1. Analysis of the role of thermal treatment and quenching media for Al6061 mixed with TiC MMCs is the main goal. To create composites, the stir casting technique was used, and the microstructure examination revealed a uniform distribution of reinforcements.
2. The EDS spectrum further supports the existence of study-related reinforcements.
3. The microhardness of composite materials increases up to a TiC content of 9 wt. % in an Al alloy; after that, it declines.
4. The hardness of composites is also influenced by heat treatment and the quenching media. The composites that have undergone ice quenching and contain 9 wt. % TiC are the toughest.
5. The addition of TiC to the Al alloy significantly reduces the wear rate of composite materials. For all of the evaluated scenarios, Al+9 % TiC composites showed the lowest wear rate.
6. The heat treatment and quenching medium has a considerable impact on the alloy and its composites' wear behaviour.
7. Ice quenched composites exhibits superior wear resistance compare to air and water quenched composites.

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