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Effect of Heat Treatment on Sliding Wear Resistance of Hybrid Aluminum Matrix Composite

Mohammed Naveed *

Ghousia College of Engineering, Ramanagara, Karnataka, India; E-Mail: naveed.gce1980@gmail.com

* **Correspondence:** Mohammed Naveed; E-Mail: naveed.gce1980@gmail.com

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Abstract

Composite materials with aluminum as matrix material have a wider amplitude of large-scale applications in engineering. Some salient features of aluminum matrix composites are, low density, low thermal coefficient of performance and low weight and high strength. Among the various series of aluminum alloy, Al6061 have been widely used by researchers due to its outstanding properties particularly as they are heat treatable. Aluminum 6061 alloys have been reinforced with various particulate reinforcements such as silicon carbide, and graphite to study their friction and wear resistance properties. Adding silicon carbide particulate reinforcement improves the sliding wear resistance of composite material. However, it makes the material brittle and hard resulting in machining difficulties and rough surface finish. On the other hand, it has been found from the literature survey that the addition of graphite particulate reinforcement increases ductility and sliding wear resistance. In this context, the present article focuses on developing hybrid aluminum matrix composites by incorporating both graphite and silicon carbide. Heat treatment has been carried out to further enhance the wear resistance and strength of the composites. Vortex-stir casting was successfully utilized to fabricate Al6061-SiC-Gr hybrid composites. There was excellent bonding between the matrix and reinforcement materials as revealed by the microstructure study. The sliding wear resistance of the Al6061-SiC composite was higher than the base matrix material. Heat treatment increases the sliding wear resistance of the composite. Ice quenching results in maximum improvement. Increased content of graphite increases the sliding wear resistance of Al6061-SiC composite. Further heat treatment increases the sliding wear resistance of the hybrid composites with ice quenching resulting in maximum improvement.

Keywords

Heat treatment; sliding wear; vortex casting technique; hybrid metal matrix composites

1. Introduction

In today's life conventional aluminum alloys are substituted by aluminum matrix composites (AMCs) because of their outstanding properties such as improved wear resistance, weight-to-strength ratio, saving of energy etc. Aluminum matrix composites are those materials that are specially designed for applications in the field of aerospace and automobile engineering. It has excellent properties for example good wear resistance at a higher temperature, high stiffness, better corrosion resistance, good specific strength, excellent fatigue resistance, etc. [1]. Among various reinforcements tried silicon carbide, and aluminum oxide are generally adopted for improving the hardness of the aluminum alloy. Composites fabricated using particulate reinforcements provide the excellent capability for plastic forming resulting in a ductile type of failure compared to other reinforcements [2, 3]. In hybrid aluminum-graphite-silicon carbide composites, the existence of silicon carbide helps in improving mechanical strength in addition to improvement of wear resistance. At the same time, the presence of graphite provides self-lubrication, improves ductility, impact strength and decreases the coefficient of friction compared to that of aluminum-silicon carbide and aluminum-graphite composites [4, 5]. The presence of silicon carbide in aluminum alloy shows better load-withstanding and load-carrying capacity. The elastic properties of aluminum matrix composites have been largely influenced by the microstructural parameters such as volume fraction, shape, size, orientation, and distribution of the reinforcement materials [6-9]. As there is a demand for increasing the production of aluminum matrix composites because of their excellent properties in the present market, there is a need to understand the various processing methods of these composites [10-14]. Because of their outstanding properties, aluminum-based composites have been the most suitable alternative materials for various aerospace and industrial applications. This is also because their properties can be improved by adding hard particulate reinforcements such as silicon carbide. With this, they have shown an excellent improvement in specific strength and specific stiffness at elevated room temperatures [15-17]. Some applications of Al-6061 matrix composites are found in helicopter structures, missile & satellite structural supports & compressor blades, high-temperature structures, and superconductor restraints in fission power reactors. Since it is difficult to vary both silicon carbide and graphite, this article maintains the constant weight of silicon carbide. In contrast, graphite is added from 1wt% to 4wt% in the step of 1wt%. The effect of graphite on the wear resistance of Al 6061-SiC composite has been evaluated. Past research showed that the addition of SiC beyond 7wt% in aluminum alloy showed lesser improvement in the strength properties of the composites. In light of the above, the present article attempts to study the effect of graphite on sliding wear resistance of heat-treated Al-6061-SiC composite.

2. Materials and Methods

2.1 Fabrication of Composite Material

In the present work, Al6061 is used as matrix material while reinforcements such as silicon carbide and graphite are used. The size of the reinforcements used is 10 microns and 60 microns respectively. Stir casting technology is adopted for casting composite materials. In vortex casting, superior bonding between reinforcements and the matrix phase can be achieved because of stirring action. It is also very simple, economical and commercially used by many researchers. The matrix material is heated inside the graphite crucible for about 710°C after which the reinforcements are added gradually and stirred uniformly for about 15 minutes. The molten liquid mixture of the composites is then poured inside a preheated metal mold. To remove gases and other impurities from the molten mixture, a hexachloroethane (C_2Cl_6) degassing tablet is used. Two types of composite materials are fabricated such as Al6061 + 7wt%SiC and Al6061 + 7wt%SiC + xwt%Gr. The graphite reinforcement is varied from 1wt% to 4wt% in the step of 1wt% respectively.

2.2 Heat Treatment Process

The base and composite materials are heated inside an electric furnace to a solutionizing temperature of about 550°C, for one hour. The specimens are quenched in ice, water and air media respectively. The specimens were further heated to ageing temperature of about 175°C for six hours, resulting in maximum hardness. After the heat treatment all the specimens are cooled under normal temperature.

2.3 Adhesive Wear Test

Standard pin on disc tribometer is used to study sliding wear and friction of base material and all its composites as shown in Figure 1. Specimens with a diameter of 10 mm and height 23 mm are developed. The specimens were finely grounded. The pin-on-tribometer had a counter disc of hardened steel material of Rc 60. Tests were conducted at sliding speed of 1.57 m/sec and load of 10 N with sliding distance of 5.655×10^3m.

Figure 1 Friction and wear monitor.

3. Results and Discussions

3.1 Microstructure Studies

The optical microphotographs of Al-6061 and its hybrid composites after etching are shown in Figure 2(a-f).

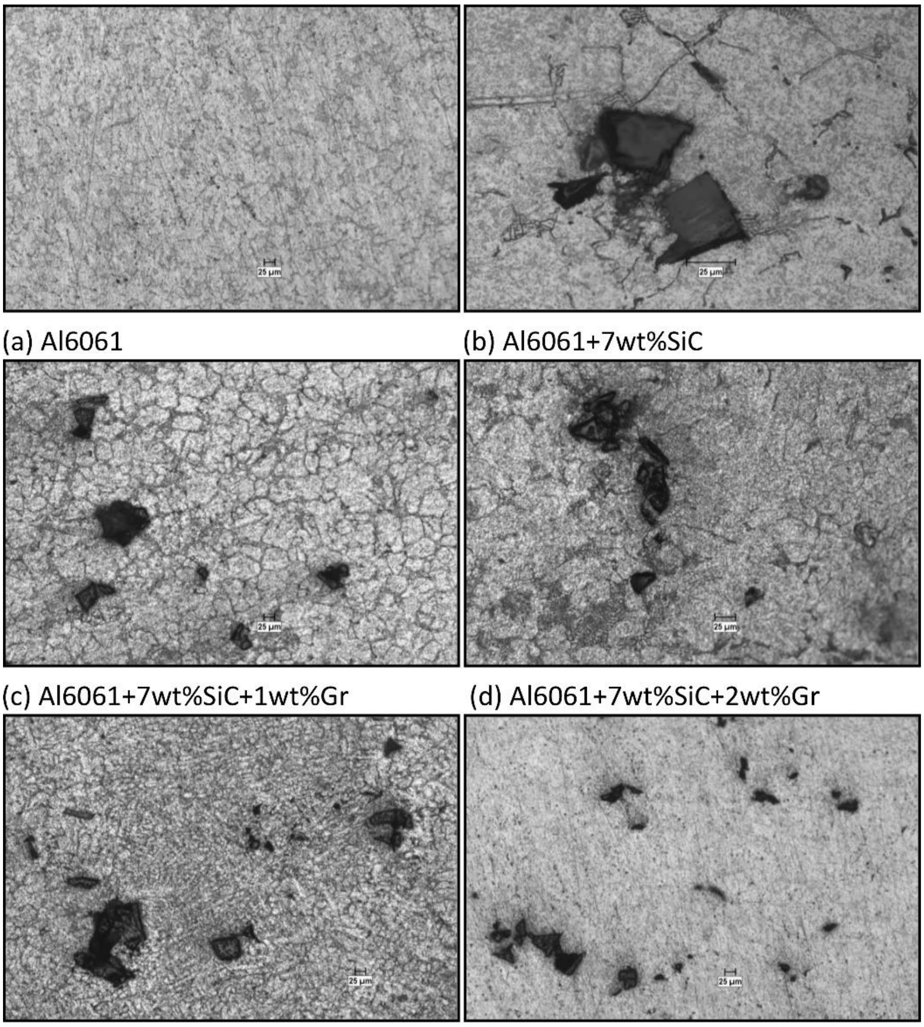


Figure 2 (a-f) Optical microphotographs of Al6061 and its hybrid composites.

It can be seen in Figure 2 that the reinforcements are distributed in the matrix material uniformly. Also the grain structure has low porosity. It can be seen that the reinforcements are homogeneously distributed, but clear identification of both the Gr and SiC is difficult and can be detected with the help of some other test such as XRD.

3.2 Wear Test

3.2.1 Impact of Gr-Sic Reinforcements on Wear Property of Al6061 Alloy

The impact of graphite and silicon carbide reinforcements on the sliding wear property of Al6061 alloy is shown in Figure 3 and Table 1.

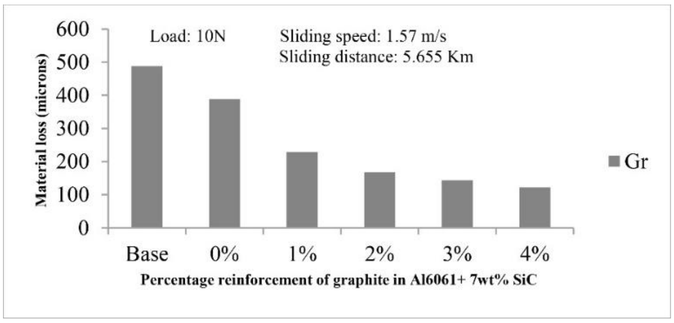


Figure 3 Impact of Gr-SiC reinforcements on sliding wear property of Al6061 alloy.

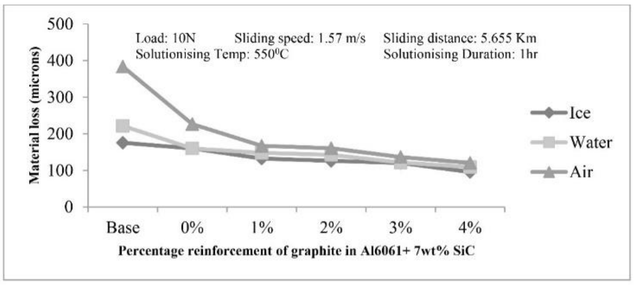
Table 1 Impact of Gr-Sic reinforcements on sliding wear property of Al6061 alloy.

Material Type	Base	0	1%	2%	3%	4%
Material loss (micron)	488	388.5	228.5	168	144	122

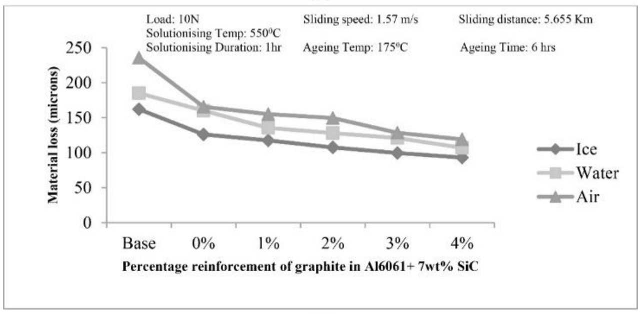
It can be seen in Figure 3 that the material loss due to sliding wear of Al-6061 alloy is higher compared to that of composite material. This is due to hard SiC reinforcement which increased the strength property of Al-6061 composites. Also it can be seen that with the addition of Gr reinforcement further there is a gradual drop in material loss. This can be reasoned due to the self-lubricating capacity of Gr reinforcement as seen in the SEM of the composites.

3.2.2 Effect of Reinforcements and Quenching Media

The material loss due to sliding wear of heat-treated matrix material and its composites is shown in Figure 4(a-b) and Table 2.



(a)



(b)

Figure 4 (a-b) Material loss due to sliding wear of heat treated matrix material and its composites.

Table 2 Material loss due to sliding wear of heat treated matrix material and its composites.

(a)

Material Type		Base	0	1%	2%	3%	4%
Material loss (micron)	Air	383.5	226.5	167	160.5	136.5	120.5
	Water	221.5	160	148	142.5	121.5	109
	Ice	175.5	160	132.5	126	120.5	95.5

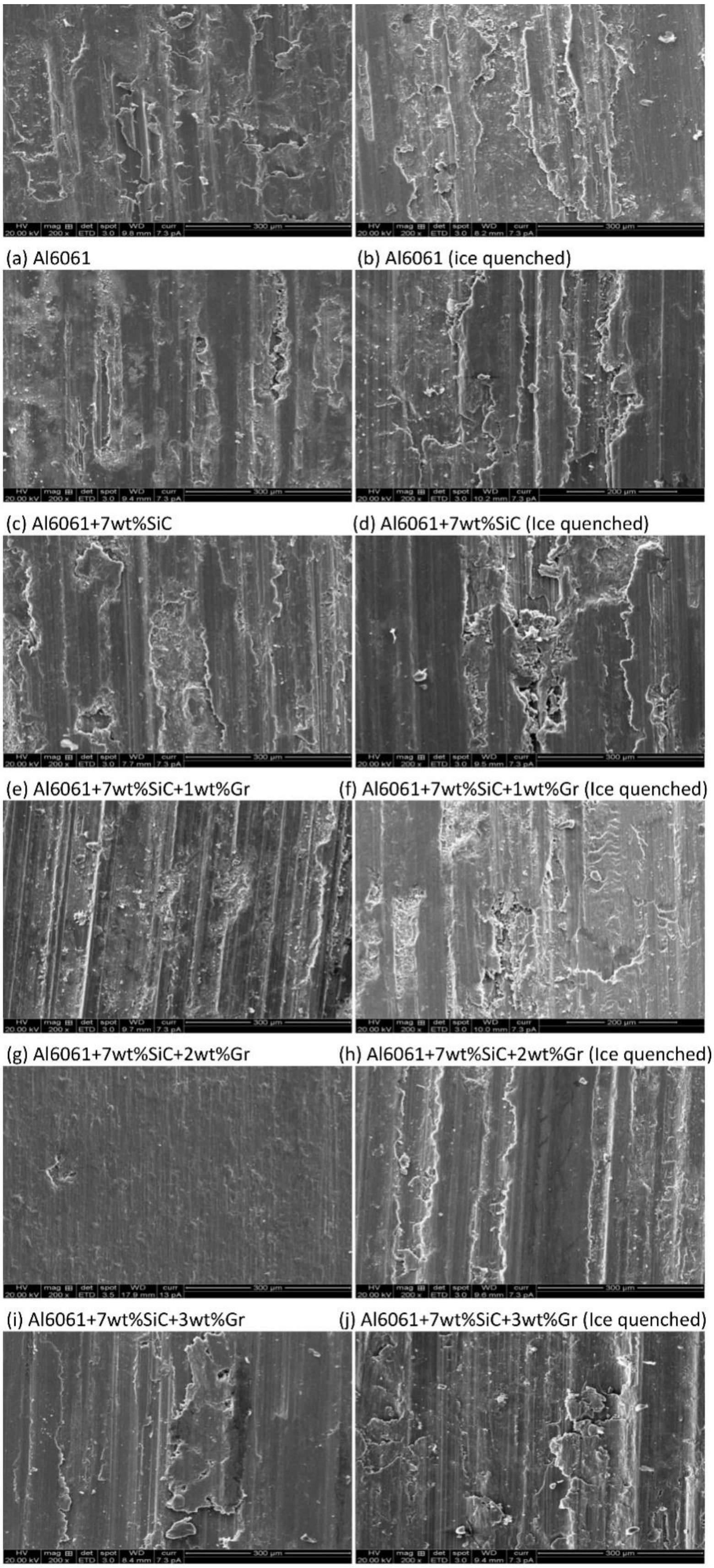
(b)

Material Type		Base	0	1%	2%	3%	4%
Material loss (micron)	Air-8hrs	235.5	165.5	155	149.5	128.5	119
	Water-6hrs	185	160	135.5	128	121	107
	Ice-6hrs	162	126	117.5	107.5	99.5	93

It can be found in Figure 4 (a-b) that with heat treatment there is a significant improvement in the sliding wear resistance of both the matrix material and its composites. However the material loss due to sliding wear was lower in Al-SiC-Gr composites. This may be due to improvement in the strength properties of Al-SiC-Gr composites Also with the increase in Gr reinforcement, material loss is decreased due to wearing. This may be due to the self-lubricating property of Gr reinforcement [18]. Among all the quenching media studied, ice-quenched specimens showed the best results followed by water and air.

3.2.3 Fractography

The scanning electron micrographs of a fractured surface of specimen subjected to sliding wear test are shown in Figure 5 (a-l).



(a) Al6061 (b) Al6061 (ice quenched)

(c) Al6061+7wt%SiC (d) Al6061+7wt%SiC (Ice quenched)

(e) Al6061+7wt%SiC+1wt%Gr (f) Al6061+7wt%SiC+1wt%Gr (Ice quenched)

(g) Al6061+7wt%SiC+2wt%Gr (h) Al6061+7wt%SiC+2wt%Gr (Ice quenched)

(i) Al6061+7wt%SiC+3wt%Gr (j) Al6061+7wt%SiC+3wt%Gr (Ice quenched)

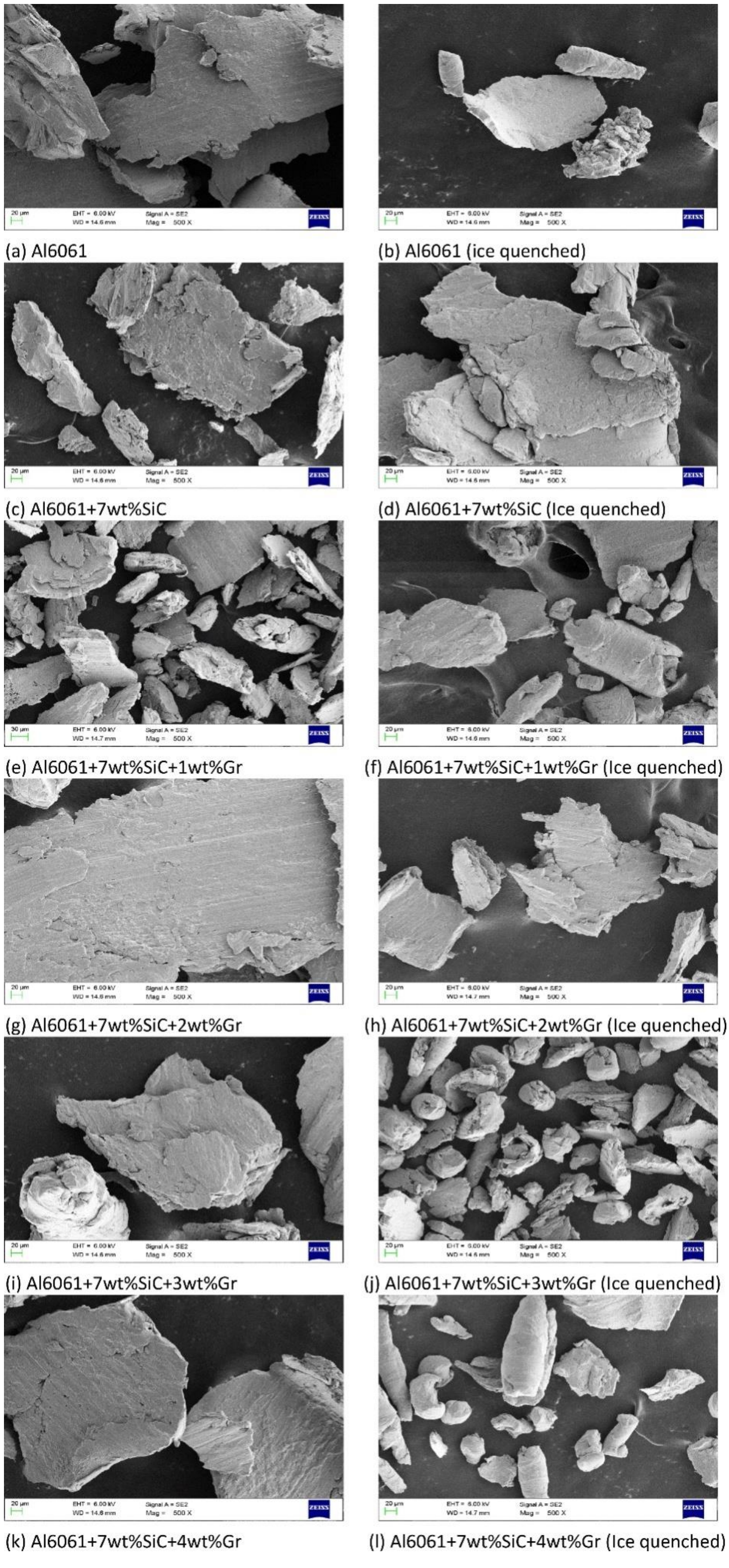
(k) Al6061+7wt%SiC+4wt%Gr (l) Al6061+7wt%SiC+4wt%Gr (Ice quenched)

Figure 5 (a-l) SEM of fractured surface of specimen subjected to wear test.

From Figure 5 (a, b), excess plastic deformation can be seen on the surface of the casted specimen. It can be observed that a normal metal matrix possesses a rough surface with grooves along the sliding direction indicating higher material loss while heat treated specimen has the least damage to the surface which are relatively smooth indicating lesser material loss. From Figure 5 (c, d) formation of grooves by hard reinforcement particles of SiC in heat-treated composites can be observed. Due to the adhesive wear, pits of irregular shapes and depths are formed on the surfaces. From Figure 5 (e-l) formation of the lubricant layer by the Gr resulting in the smooth running of the projected material can be observed. The worn-out surface of the specimen shows the presence of smeared Gr particles. These Gr particles have formed a thintribofilm between the disc and specimen surfaces, thereby preventing direct metal-to-metal surface contact. Maybe because of this, the material loss in Al-SiC-Gr was much less than in the Al-SiC composite.

3.2.4 SEM of Wear Debris Particles

The scanning electron micrographs of wear debris particles of the specimen subjected to the sliding wear test are as shown in Figure 6 (a-l).



(a) Al6061
(b) Al6061 (ice quenched)
(c) Al6061+7wt%SiC
(d) Al6061+7wt%SiC (Ice quenched)
(e) Al6061+7wt%SiC+1wt%Gr
(f) Al6061+7wt%SiC+1wt%Gr (Ice quenched)
(g) Al6061+7wt%SiC+2wt%Gr
(h) Al6061+7wt%SiC+2wt%Gr (Ice quenched)
(i) Al6061+7wt%SiC+3wt%Gr
(j) Al6061+7wt%SiC+3wt%Gr (Ice quenched)
(k) Al6061+7wt%SiC+4wt%Gr
(l) Al6061+7wt%SiC+4wt%Gr (Ice quenched)

Figure 6 (a-l) SEM of wear debris particles of specimen subjected to wear test.

From Figure 6 (a, b) it can be seen that the shape of the wear debris is highly flaky and chunky in the case of a normal metal matrix compared to that of an ice-quenched specimen which is small and not flaky indicating lower material loss. It is a finer and rounded form. From Figure 6(c, d) it can be seen that with addition of SiC, the wear debris particles' size is less compared to that of the matrix alloy. Lesser the size lower the material loss. From Figure 6 (e-l) it can be observed that with the addition of Gr, there is a further reduction in the size of the wear debris particles and also the surface of these particles is seen to be smooth which may be due to the lubricating film formed by the Gr.

4. Conclusions

- Vortex-stir casting was successfully utilized to fabricate Al6061-SiC-Gr hybrid composites. There was excellent bonding between the matrix and reinforcement materials as revealed by the microstructure study.
- The sliding wear resistance of the Al6061-SiC composite was higher than the base matrix material.
- Heat treatment increases the sliding wear resistance of the composite.
- Ice quenching results in maximum improvement.
- Increased content of graphite increases the sliding wear resistance of Al6061-SiC composite.

Further heat treatment increases the sliding wear resistance of the hybrid composites with ice quenching resulting in maximum improvement.

Author Contributions

The author did all the research work of this study.

Competing Interests

The author has declared that no competing interests exist.

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