

Effect of heat treatment on strength and abrasive wear behaviour of Al6061–SiC_p composites

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MS received 15 November 2008; revised 22 January 2009

Abstract. In recent years, aluminum alloy based metal matrix composites (MMC) are gaining importance in several aerospace and automobile applications. Aluminum 6061 has been used as matrix material owing to its excellent mechanical properties coupled with good formability and its wide applications in industrial sector. Addition of SiC_p as reinforcement in Al6061 alloy system improves its hardness, tensile strength and wear resistance. In the present investigation Al6061–SiC_p composites was fabricated by liquid metallurgy route with percentages of SiC_p varying from 4 wt% to 10 wt% in steps of 2 wt%. The cast matrix alloy and its composites have been subjected to solutionizing treatment at a temperature of 530°C for 1 h followed by quenching in different media such as air, water and ice. The quenched samples are then subjected to both natural and artificial ageing. Microstructural studies have been carried out to understand the nature of structure. Mechanical properties such as microhardness, tensile strength, and abrasive wear tests have been conducted both on matrix Al6061 and Al6061–SiC_p composites before and after heat treatment. However, under identical heat treatment conditions, adopted Al6061–SiC_p composites exhibited better microhardness and tensile strength reduced wear loss when compared with Al matrix alloy.

Keywords. Metal matrix composite; solutionizing; artificial aging; microhardness; tensile strength; abrasive wear.

1. Introduction

Metal matrix composites (MMCs) are gaining wide spread popularity in several technological fields owing to its improved mechanical properties when compared with conventional metals/alloys (Ramesh 1988; Ray 1993; Surappa 2003). Among the several categories of MMCs, Al based composites are finding wide spread acceptance especially in applications where weight and strength are of prime concern. Presently, Al alloy based metal matrix composites are being used as candidate materials in several applications such as pistons, pushrods, cylinder liners and brake discs etc. (Anwar Khan *et al* 2002; Surappa 2003). In recent years, among all the Al alloys, Al6061 is gaining much popularity as a matrix material to prepare MMCs owing to its excellent mechanical properties and good corrosion resistance (Ramesh *et al* 2005). In addition, Al6061 alloy is heat treatable, and as a result further increase in strength can be expected (Appendino *et al* 1991; Salvo and Surey 1994; Gupta and Surappa 1995; Anwar Khan *et al* 2002). However, the major focus is on processing and characterization of Al based composites (Appendino *et al* 1991; Pramila Bai *et al* 1992; Doel and

Bowen 1996; Gui *et al* 2000). Although the synergetic effect of heat treatment and the type of reinforcement plays a dominant role in dictating the final mechanical properties of composites, meager information is available, pertaining to the heat treatment of Al based composites. In light of the above, the present investigation is aimed at studying in detail the effect of quenching media and the ageing duration on the mechanical properties of heat treatable cast Al6061–SiC_p composites.

2. Experimental

A liquid metallurgy route has been adopted to fabricate the cast composites. Al6061 has been chosen as matrix alloy. Preheated SiC_p of size 10–20 µm was introduced into the vortex of the effectively degassed Al6061 molten alloy. The molten alloy was stirred for a duration of 10 min using a mechanical stirrer possessing ceramic coated steel impeller. The speed of the stirrer was maintained at 400 rpm. The melt at 710°C was poured into the cast iron molds. The addition of the silicon carbide particles in the matrix alloy was varied from 4–10 wt% in steps of 2 wt%.

The cast composites and the base Al6061 alloy were subjected to solutionizing at a temperature of 530°C for a duration of 1 h and then quenched in three different

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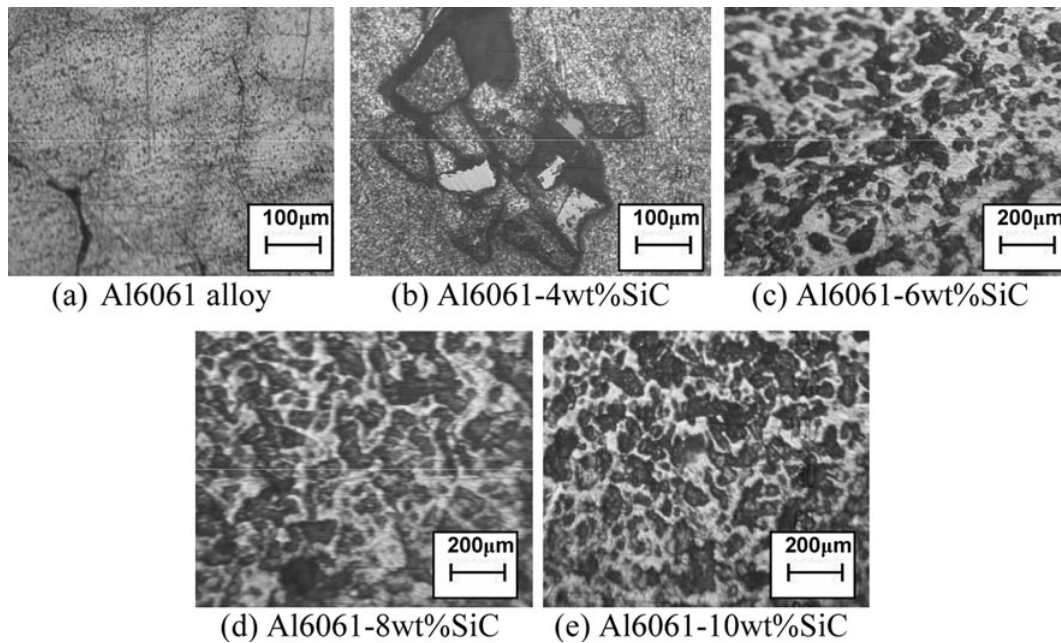


Figure 1. Optical microphotographs of base Al6061 alloy and Al6061-SiC_p composites at 4, 6, 8 and 10 wt% SiC_p.

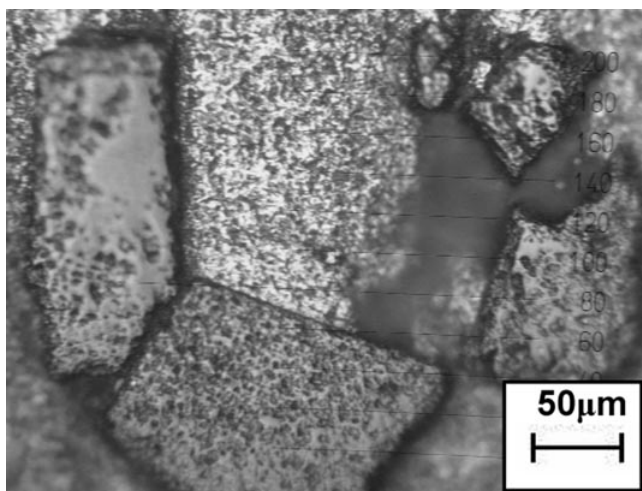


Figure 2. Optical micrograph of Al6061-4 wt% SiC indicating good bond between the matrix alloy and SiC_p.

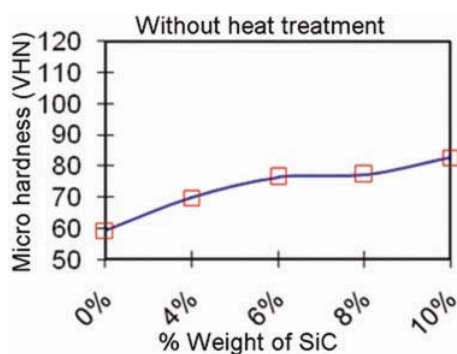


Figure 3. Variation of microhardness of Al6061-SiC_p composites with increase of SiC_p content before heat treatment.

quenching media viz. air, water and ice. Artificial ageing was carried out at 175°C for a duration of 4–10 h in steps of 2 h. Metallographic, hardness, tensile strength and wear tests were carried out on both unheat treated and heat treated samples. Hardness measurements were carried out on the castings using Shimadzu Microhardness tester using a load of 1 N for a period of 10 s. Tensile tests were conducted on both base Al6061 alloy and its composites for samples heat treated with water and ice medium. The abrasive wear test was conducted for a duration of 15 min for three grades of silicon carbide wheels viz. coarser, medium and fine wheel for varying loads from 5 N to 20 N in steps of 5 N.

3. Results and discussion

3.1 Microstructure

The optical micrograph of the cast Al6061 and Al6061-SiC_p composites are shown in figure 1. The micrographs clearly indicate the evidence of minimal porosity in both the Al alloy and the Al6061-SiC_p composites. The distribution of SiC_p in a matrix alloy is fairly uniform. Further the microphotographs reveal an excellent bond between the matrix alloy and the reinforcement particles (figure 2).

3.2 Hardness

The variation of microhardness with increased content of SiC_p in the matrix Al6061 in as cast condition without heat treatment is shown in figure 3. It is observed that

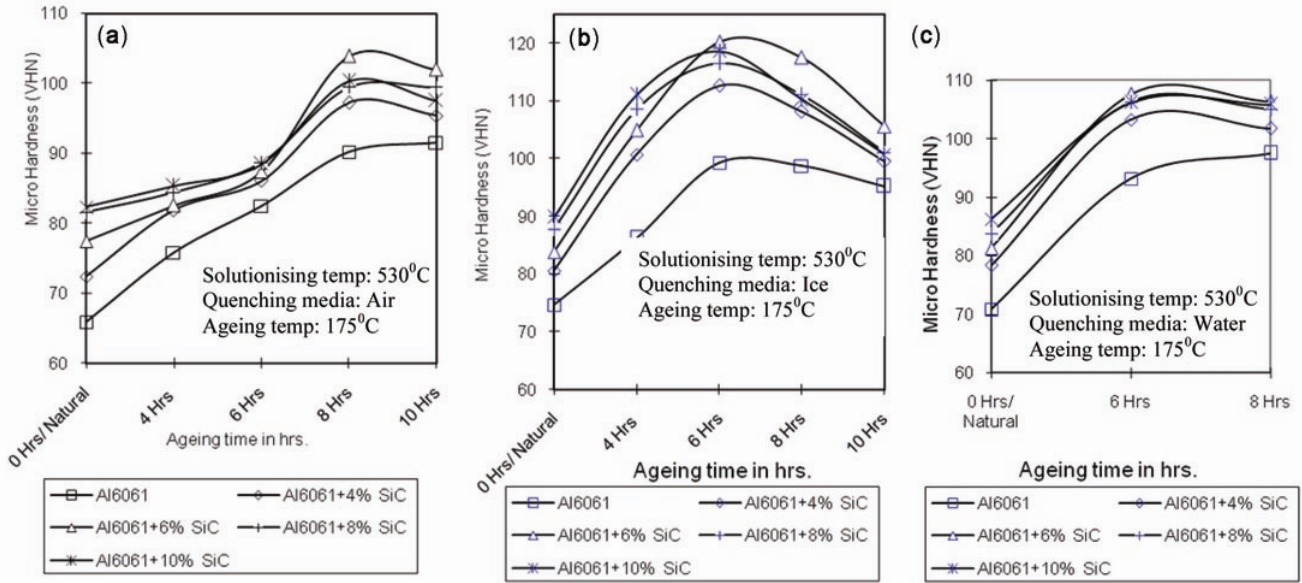


Figure 4. Variation of microhardness with increase in ageing time for Al6061 and Al6061-SiC_p composites under different heat treatment conditions.

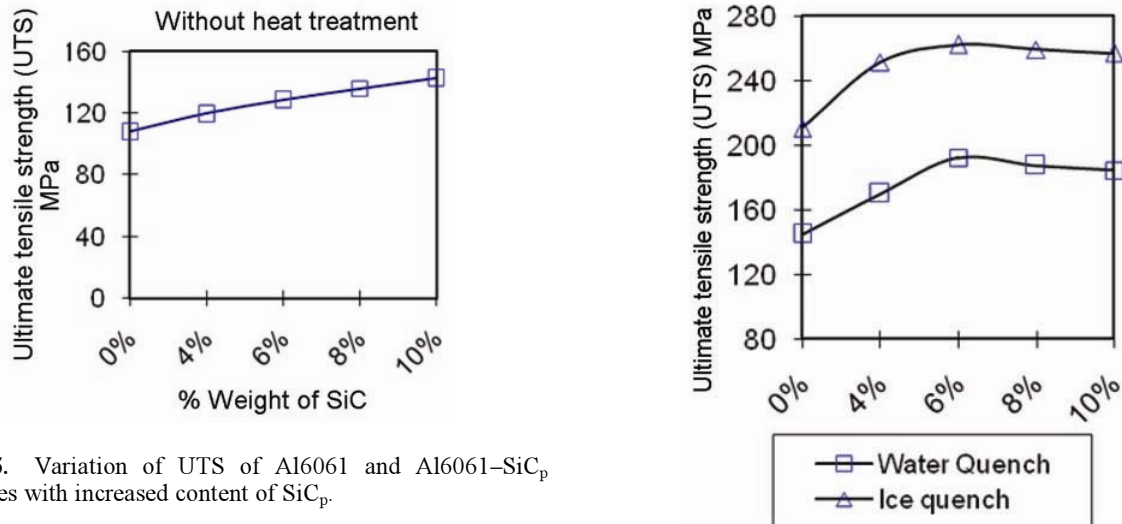


Figure 5. Variation of UTS of Al6061 and Al6061-SiC_p composites with increased content of SiC_p.

with increased content of SiC_p in the matrix alloy, there is a significant improvement in the microhardness of the composites. An improvement of around 39% is observed in Al6061-10wt%SiC_p composites when compared with the unreinforced Al6061 matrix alloy. This trend is similar to the result of other researchers (Sahin and Acilar 2003).

The variation of microhardness under heat treatment conditions are shown in figure 4. Heat treatment has a profound influence on the hardness of the matrix alloy as well as its composites. For a solutionizing temperature of 530°C, solutionizing duration of 1 h, ageing temperature of 175°C, quenching media and ageing duration significantly alters the microhardness of both the matrix alloy and its composites. The maximum hardness was observed

Figure 6. Variation of UTS with increased content of SiC_p in Al6061 alloy under different heat treatment conditions.

for both the matrix alloy and the studied composites for ageing duration of 6 h when the quenching media was ice and water, while the maximum hardness for the matrix alloy and its composites was achieved only after 8 h of ageing on air quenching. In all the quenching media, and under all ageing times studied, composites exhibited higher hardness when compared with the matrix alloy.

Ageing of matrix alloy and its composites for a duration of 6 h at a temperature of 175°C upon ice quench after solutionizing results in obtaining maximum hardness of the matrix alloy and its composites. Ice quenching and ageing for 6 h, the matrix Al6061 alloy exhibited a

maximum improvement in hardness of around 67%, while Al6061–10 wt%SiC composites exhibited a maximum improvement in hardness of around 44%. On water quenching and ageing for 6 h, the matrix Al6061 alloy exhibited a maximum improvement of microhardness of around 57%, while Al6061–10wt%SiC composites exhibited a maximum improvement in hardness of around 28%. On air quenching and ageing for 8 h, the matrix Al6061 alloy exhibited a maximum improvement in hardness of around 52%, while Al6061–10wt%SiC composites exhibited a maximum improvement in hardness of around 21%.

3.3 Tensile strength

The variation of ultimate tensile strength (UTS) with increased % of SiC_p in matrix alloy Al6061 is shown in figure 5. This trend is similar to observation made by other researchers (Robi *et al* 1996). Al6061–10 wt% SiC composites exhibited the highest UTS of 143 MPa, while the matrix alloy Al6061 exhibited an UTS value of 108 MPa in as cast unheat treated condition. The improved UTS of composites can be attributed to the fact that increased content of SiC_p increases the hardness of the composites, which in turn enhances the tensile strength of the composites. The good bond exhibited as discussed in the previous section also promotes the improvement of tensile strength of composites.

The variation of UTS under different heat treatment conditions is shown in figure 6. Heat treatment has a significant effect on the UTS of matrix alloy and its composites. For a solutionizing temperature of 525°C, solutionizing duration of 1 h, ageing temperature of 175°C, ageing duration of 6 h, the quenching media significantly alters the UTS of both the matrix alloy and its composites. As evidenced in figure 6 the maximum UTS was observed, for both the matrix alloy and the composites when the quenching media was ice.

The maximum UTS of 210 MPa for the matrix alloy and the value of 257 MPa for the Al6061–10 wt%SiC has been observed on ice quenching. An improvement of around 79% in UTS values has been observed for Al6061–10 wt%SiC, while the matrix alloy exhibited nearly 94% improvement in UTS on heat treatment. This marked improvement in tensile strength of both Al6061 alloy and its composites studied on heat treatment can be attributed to larger extent of formation of intermetallic precipitates which act as the points of obstacles for pinning down the dislocations. This phenomena of multiplication of dislocations curtails the mobility of dislocations, thereby reducing the extent of plastic deformation. This leads to significant improvement in UTS.

3.4 Abrasive wear

The variation of abrasive wear loss of both the unreinforced Al6061 and Al6061–SiC composites under different loads and different grades of abrasive for unheat treated condition is shown in figure 7. It is observed that the amount of reinforcement in the matrix alloy and the grades of the abrasive wheels have profound influence on the abrasive wear behaviour of matrix alloy and its composites at a given load. Increased content of SiC_p in the matrix alloy enhances the abrasive wear resistance of composites which can be attributed to the fact that SiC itself being hard can combat the abrasion, thereby resulting in lower material removal. Higher the hardness of composites, better will be its abrasion resistance. For a given load, the abrasive wear tends to be higher for both the matrix alloy and its composites while rubbing against a coarser abrasive silicon carbide wheel. This increased material removal can be attributed to the fact that coarser silicon carbide grains of the abrasive wheel will tend to dig in and plough out the material sideways. This phenomena results in huge material removal. The lowest wear loss for the matrix alloy and the composites have been observed when fine grades of abrasive wheel have been used. This can be explained on the grounds that the fine grade wheel having a closed type of structure results in more of scratching rather than ploughing out the material. This phenomena leads to a very marginal material removal. Under identical test conditions, composites possess better abrasive wear resistance when compared with matrix alloy.

The heat treatment of matrix alloy and its composites has a significant effect on the abrasive wear behaviour of matrix alloy and its composites as shown in figure 8. For a given load and grades of abrasive wheel used, ice as quenching media has resulted in the least abrasive wear loss when compared to without heat treated matrix alloy and its composites. However, composites possessed the lowest abrasive loss when compared to matrix alloy. The improved abrasion wear resistance after heat treatment

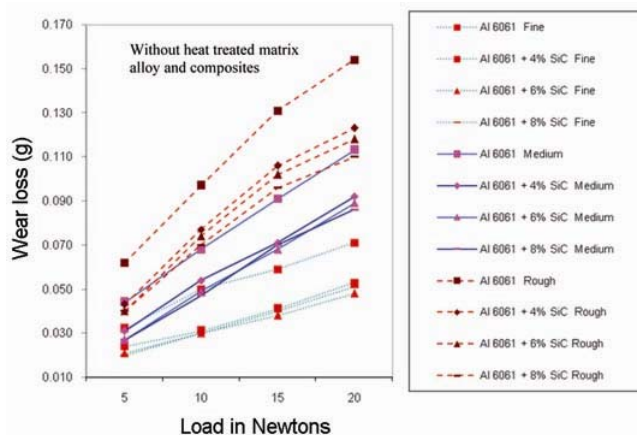


Figure 7. Variation of abrasive wear loss with increase in loads for different grades of abrasive wheels.

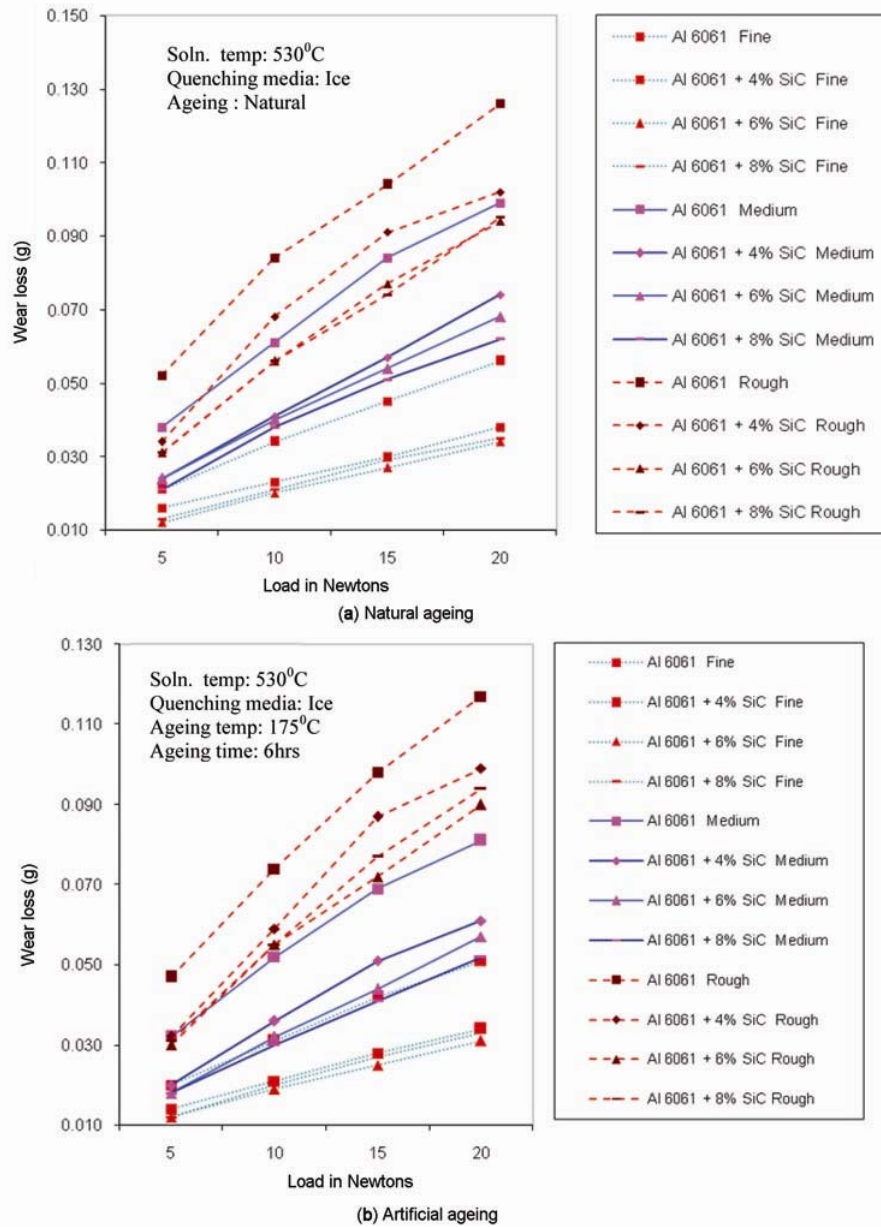


Figure 8. Effect of different ageing conditions on abrasive wear loss of matrix alloy and its composites for different grades of abrasive wheels.

can be attributed to further enhancement of hardness on heat treatment.

4. Conclusions

Microstructural studies clearly reveal a uniform distribution of SiC_p in the matrix alloy with an excellent bond between the matrix alloy and reinforcement.

Microhardness of composites increased significantly with increased content of SiC_p. Heat treatment has a significant effect on microhardness of Al6061 matrix alloy and its composites. Ice quenching followed by artificial

ageing for 6 h resulted in maximum hardness of matrix alloy and its composites.

Tensile strength of composites increased significantly with increased content of SiC_p. Heat treatment has a significant effect on UTS of matrix alloy and its composites. Ice quenching followed by artificial ageing for 6 h resulted in maximum UTS of Al6061 matrix alloy and Al6061-SiC_p composites.

Adhesive wear loss of composites decreases, with the increase in content of SiC_p in matrix alloy under identical test condition. Heat treatment has a profound effect on adhesive wear behaviour of matrix alloy and its composites.

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