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Aging Behaviour of 6061 Al-15 vol% SiC Composite in T4 and T6 Treatments

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***Abstract*—**The aging behaviour of 6061 Al-15 vol% SiC composite was investigated using Rockwell B hardness measurement. The composite was solutionized at 350°C and quenched in water. The composite was aged at room temperature (T4 treatment) and also at 140°C, 160°C, 180°C and 200°C (T6 treatment). The natural and artificial aging behaviour of composite was studied using aging curves determined at different temperatures. The aging period for peak aging for different temperatures was identified. The time required for attaining peak aging decreased with increase in the aging temperature. The peak hardness was found to increase with increase with aging temperature and the highest peak hardness was observed at 180ºC. Beyond 180ºC the peak hardness was found to be decreasing.

***Keywords*—**6061 Al-SiC composite, Aging curve, Rockwell B hardness, T4, T6 treatments.

I. Introduction

THE recent worldwide interest shown in metal matrix composite (MMC) materials has been fuelled by the fact that mechanical and physical properties of light alloys can be enhanced by incorporating reinforcing fibres, usually ceramic. The major reinforcements used in Aluminium based MMCs are Boron, Graphite, Silicon Carbide and Alumina [1]. Aluminium alloys such as 6061 Al reinforced with SiC particles have found wide range of applications in automotive, sports, aerospace, marine and in many other fields owing to their low coefficient of thermal expansion, low density, high thermal conductivity, high wear resistance, better corrosion resistance and high strength to weight ratio [2]. The strength of 6061 Al-SiC composite can be further improved by thermal treatments. These thermal treatments are similar to those ordinarily used for hardening Aluminium alloys [3]. Extensive researches have been done on the aging behaviour of these composites during these thermal treatments [4]. Widely used treatments like T4 and T6 treatments involve solution heat treatment and subsequent natural and artificial aging respectively and is the common method to increase the strength of the alloy [5], [6]. In the present investigation, the natural and artificial aging behaviour of the 6061 Al-SiC composite was studied.

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II. Experimental Work

6061 Al-SiC composite material with 15 vol% SiC particles of size 23µm and 99.9% purity is used in this study. The 6061 Al-15 vol% SiC composites were cast in the form of cylinders each of 90mm diameter and 240mm length by stir casting technique. These cylinders were extruded at 430°C - 480°C with extrusion ratio of 30:1. The experiments were performed with composite in extruded rod form. The extruded samples were cut in cylinders of 2cm length and diameter of 1.15cm. The composition of the base metal alloy in the matrix is as follows: Cu—0.15 to 0.4 weight %, Mg— 0.8 to 1.2 weight %, Si— 0.4 to 0.8 weight %, Mn— 0.15 weight %, Cr— 0.04 to 0.35 weight %, other elements— 1.25 weight % and balance is Aluminium. Microstructure of the 6061 Al-15 vol% SiC composite was obtained using JEOL made JSM 6380LA SEM and is shown in Fig. 1. It's clearly seen in the image that the reinforced SiC particles (SiC_p) are distributed uniformly.

The composite samples were polished and solution treated at a temperature of 350ºC for 30 minutes. They were then water quenched at room temperature. This was followed by aging the quenched composites at room temperature (T4 treatment) and at 140ºC, 160ºC, 180ºC and 200ºC (T6 treatment) for various durations of time. The aging behaviour of the composite was studied using Rockwell hardness measurement. Rockwell B Hardness (HRB) tests were performed immediately after aging. Each hardness value was the average of at least three measurements in two samples.

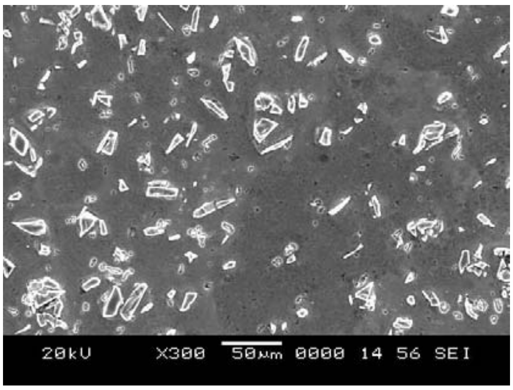

Fig. 1 SEM image of 6061 Al-15 vol% SiCp composite

III. Results and Discussion

Table I shows the Rockwell B hardness values of natural aging and the aging curve is depicted in Fig. 2.The hardness measurements for T4 treatment shows a sharp rise after the solution treatment for the first few hours. It then increases exponentially up to around 720 hours. Peak hardnessis observed at 720 hours and hardness decreases gradually after that.

The Rockwell B hardness values of T6 treated 6061 Al-SiC composite at various temperatures of aging are given in Table II. Figs. 3-6 depict hardness variation with time in T6 treatment. Fig. 7 shows the peak hardness variation with aging temperature in T6 treatment. Fig. 8 shows the variation of peak-aging time with different aging temperatures.

TABLE I
ROCKWELL B HARDNESS VALUES OF T4-TREATED 6061AL- SIC COMPOSITE

Time of Aging (Hours)	Hardness (Rockwell B)	Time of Aging (hours)	Hardness (Rockwell B)
0	62	48	83
2	64	120	86
4	65	240	87
6	67	480	89
8	71	720	90
24	77	960	88

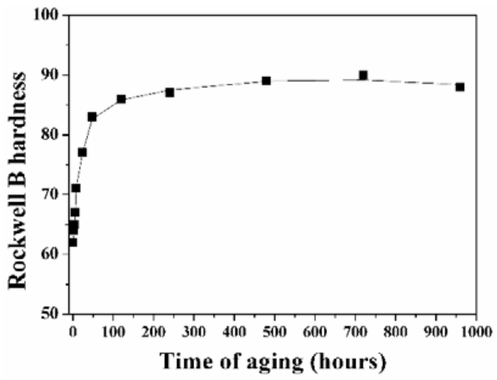

Fig. 2 Hardness variation with time in T4 treatment

In 6061 Al alloy Mg and Si are the major alloying elements. When this alloy is solutionized both these alloying elements are taken into solid solution as single α phase. Quenching the alloy results in super saturated solid solution α as the solubility for these elements at room temperature is very less. Given an opportunity, the excess solutes diffuses out of α lattice and forms intermetallic precipitates of Mg_2Si (β phase). However, formation of these precipitates occurs in successive stages. The aging sequence for 6061 Al alloy and its composite are as follows: Super-saturated solid solution → clusters of solute atoms and vacancies (Primitive Guinier-Preston [GP] zones)→ needle shaped GP zones → rod shaped, metastable, semi-coherent β' phase → stable, incoherent, Mg_2Si precipitate (β phase) [3].

TABLE II
ROCKWELL B HARDNESS VALUES OF T6-TREATED 6061 AL-SIC COMPOSITE

Time of Aging	Rockwell B hardness of the composite aged at			
(Hours)	140ºC	160ºC	180ºC	200ºC
0	62	62	62	62
1	68	79	86	70
2	73	84	91	78
3	78	87	98	85
4	88	94	93	75
5	79	85	82	72

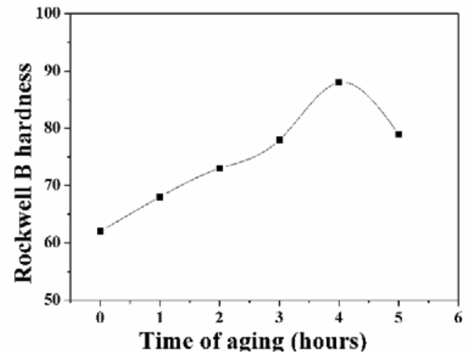

Fig. 3 Hardness variation with time in T6 treatment at 140ºC

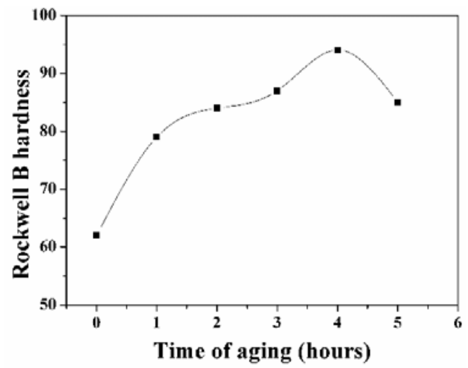

Fig. 4 Hardness variation with time in T6 treatment at 160ºC

If aging is done at room temperature, it is called natural aging (T4 treatment) and if it occurs at higher temperatures it is called artificial aging (T6 Treatment) [7]. Guinier Preston or GP zones have been recognized as microstructural elements in Al alloy. These zones are formed by natural aging at room temperature and in the early stages of the industrially important artificial aging at temperatures in a range of 100-180°C [8]. In 1972 Jacobs proposed that the equilibrium β phase has an fcc structure with a= 0.642nm and the β' phase was observed to be hexagonal with a=0.705nm and c=0.405nm [9].

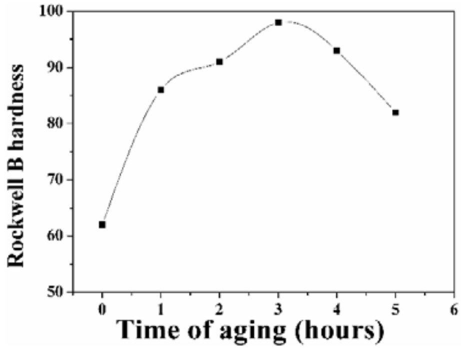

Fig. 5 Hardness variation with time in T6 treatment at 180ºC

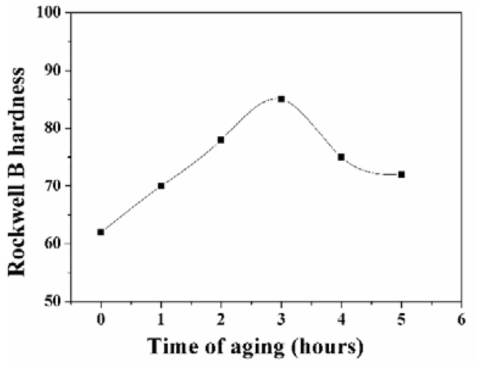

Fig. 6 Hardness variation with time in T6 treatment at 200ºC

Since natural aging is carried out at room temperature, the diffusion rate is very low and therefore it is expected that the alloy takes very long period to get aged. In artificial aging, we can expect higher rates of diffusion resulting in faster attainment of aging effect. Since the aging phenomenon is diffusion controlled, both time and temperature play vital roles in the process.

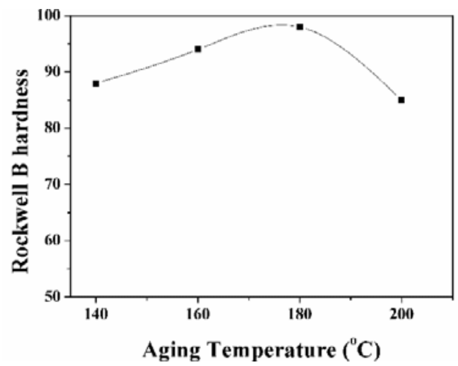

Fig. 7 Peak hardness variation with aging temperature in T6 treatment

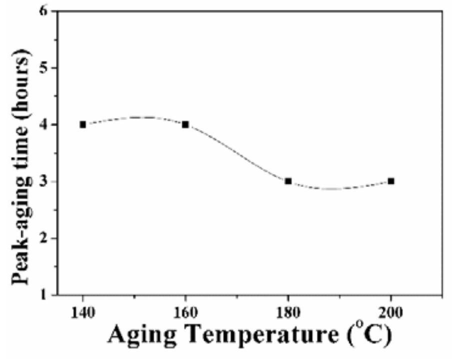

Fig. 8 Peak aging time variation with aging time in T6 treatment

The effects of reinforcing material on the age-hardening behaviour have not been reported consistently. But it was found that the age-hardening is accelerated since the times to reach the peak hardness were considerably shortened by the presence of reinforcement in SiC_p/ 6061 Al alloy composites. For this reason, the diffusion of alloy elements is required in order to produce precipitation during the artificial aging treatment, and many dislocations were introduced by serious deformations at the interface of the SiC_p/ matrix. These high density dislocations offer not only a heterogeneous site for the precipitation, but also a high diffusivity path for the diffusion of alloying elements; accelerating the age-hardening behaviour of composites [10]-[12]. On the contrary, dislocations do not affect the kinetics of natural aging; the driving force for this process only depends on the concentration of alloying elements in the super-saturated solid solution [3], [13].

From Figs. 3-6 variation in the hardness with time is clear. Based on the hardness profile the aged specimens are categorized into three groups namely a) under aged b) peak aged and c) over aged. The variation in hardness is associated with the microstructural evolution. The formation of Mg and Si clusters takes place initially. These contribute marginally to the increase in hardness. Peak-aging is associated with a dense population of β needle-shaped precipitates. Only a part of these precipitates remain in the microstructure during over-aging as the metastable phases like β' form which results in the lowering of hardness values [5], [14]. In natural aging treatment, the peak hardness of 90 HR_B was observed after 720°C and in artificial aging treatment peak hardness of 98 HR_B was achieved after 3 hours at 180°C. The peak-aging time decreased with the increase of aging temperature as shown in Fig. 8, which suggests age-hardening kinetics became faster as the aging temperature was increased [4].

IV. Conclusions

The peak hardness in T4 treatment is 90 HR_B which was obtained at 720 hours of aging at room temperature. In T6 treatments, the temperature for under-aging, peak-aging and over-aging was determined using aging curves. The composite was under- aged at 140°C and 160°C, Peak-aged at 180°C and over-aged at 200°C. Maximum Peak hardness value of 98

HR_B was obtained when the composite was aged at 180°C for 3hours. The peak-aging time was decreased to 3 hours when the aging temperature was increased.

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