

Aging Behaviours of 8011 Al and 8011 Al/15% SiCp Composites

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How to cite this paper: Vembu, V. (2019) Aging Behaviours of 8011 Al and 8011 Al/15% SiCp Composites. *Journal of Minerals and Materials Characterization and Engineering*, 7, 221-229.

<https://doi.org/10.4236/jmmce.2019.75017>

Received: June 26, 2019

Accepted: September 7, 2019

Published: September 10, 2019

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Abstract

In this investigation, the effect of aging on the hardness and tensile behavior of 15% SiCp/8011 Al composites has been studied. The composites were manufactured through stir casting method. Cast ingots of the composites were hot extruded at 500°C. The composite samples were solution heat-treated at 530°C for 3 h and quenched in cold water. The aging temperature was 130°C, 150°C, 170°C, 190°C, and 210°C for aging duration of 1, 3, 5, 7 and 9 hrs respectively. The mechanical properties measured included: tensile strength, yield strength and hardness values. The composites produced exhibited maximum mechanical properties at peak aged condition. These increases in mechanical properties during aging are attributed to the formation of coherent and uniform distribution SiC particles in the aluminum matrix composites. It was also observed that thermal modification plays an important role in retaining the ductility of composites. This result shows that a substantial improvement in mechanical properties has been achieved in the reinforced metal matrices produced after age-hardening.

Keywords

8011 Aluminum Matrix Composite, Extrusion, Aging Behavior, Tensile Strength, Micro Hardness, Response Surface Methodology (RSM)

1. Introduction

The 2xxx, 6xxx, 7xxx and 8xxx aluminium alloys have been used widely as matrix materials for making composites. For good bonding and strength in the composites, metal alloys are used as the matrix element instead of pure metals. Aluminium alloys containing reactive elements like Mg, Li which normally aid interfacial bonding with the dispersions, will be ideal as the matrix material. In

general, Al-Cu-Mg (2xxx) matrix system provides excellent combination of strength and damage tolerance. While Al-Zn-Mg-Cu (7xxx) matrix system can offer higher strength potential Al-Mg-Si-Cu (6xxx) system provide improved corrosion resistance for severe environments as well as improved product fabric ability. With high strength to weight ratio of (8xxx) aluminium and its alloy, based on the Al-Li-Cu-Mg system, the mechanical properties are closely related to the microstructure of these alloys, which are greatly influenced by thermo mechanical processing. The age hardening characteristics of an alloy are generally modified by the introduction of reinforcement. These modifications are due to the manufacturing process, the reactivity between the reinforcement and matrix, the size, the morphology and the volume fraction reinforcement [1]. A great deal of research has been carried out in the past to develop and improved aluminium based composites with the aim of achieving better mechanical properties. In general many techniques have been developed to fabricate the SiC particle reinforced aluminium alloy composite, including casting, powder metallurgy, molten metal methods, pressure infiltration and spray deposition. Among all the fabrication method, the stir casting technique is attractive because it offers uniform distribution reinforcement, flexibility and applicability to large quantity production [2]. These composites are the typical candidates for engineering application in aerospace, military, civil and manufacturing industry. Borrego *et al.* [3] studied the influence of extraction temperature on the aging behaviour of 6061 Al-15% SiC_w composites and reported that accelerated aging observed in composite materials with respect to the unreinforced alloy is more accentuated with increasing extraction temperature. This is described to the increasing dislocation density of the composites since fragmentation of whiskers during consolidation is reduced with extraction temperature. Qureshi *et al.* [4] developed a mathematical model to predict the mechanical model to predict the mechanical properties of aluminium alloys subjected to prediction hardening. The model, based on the experimental data, was used to predict the tensile strength and yield strength as the response of aluminium alloys subjected to age-hardening process. No much is documented on the age hardening characteristics of this alloy particularly with silicon carbide reinforcement. Hence the need for research in this area is justified. The objective of this present research therefore is to study the age hardening characteristics of 15% SiCp/8011 Al particulate composites [5].

2. Experimental Procedure

8011 aluminum alloy was used as the metal matrix and 15% SiC particles as the reinforcement. The metal matrix consists of (in weight percentage) 0.625 Si, 0.725 Fe, 0.007 Cu, 0.003 Mn, and 0.002 Mg, 0.013 Ti, 0.001 Cr, 0.002 Zn and rest being aluminum. The reinforcement size used in the composites was 23 μm . The composites were manufactured through stirring casting technique under an argon atmosphere. The melt was cast into a permanent die, to obtain ingots of 35 mm diameter and 70 mm height after the feeder head was removed. The cy-

lindrical ingots were machined to 30 mm diameter, and then hot extruded in four stages to obtain 16 mm diameter rod. The forming process was performed at 500°C. During the extrusion process the punch speed was 0.01 m/s and graphite based high temperature lubricant was used. The extruded rods were solution heat treated for 3 h at 530°C followed by cold water quenching to room temperature. Then the rods were artificial aging at different temperature (130°C to 210°C) over time period for (1 - 9) hours. Tensile test specimens were prepared according to ASTM-E8M standard. The length and diameter of the gage were 45 mm and 9 mm respectively. Tensile tests were conducted using a universal testing machine. The hardness measurements were performed using a microhardness tester with a load of 500 kgf. Hardness values were averaged over three measurements taken at different points on the cross-section. The variation of hardness with aging time for different aging conditions was investigated. Sample specimens for microstructural examinations were prepared following standard procedure of grinding and polishing by etching in Keller's reagent. Optical microscopy was performed to evaluate the distribution of SiC particles. The fracture surface of the composite was also examined using SEM.

3. Results and Discussion

In the following sections, the microstructure, effect of solution zing time, effect of aging temperature and time on tensile behavior of the materials examined are presented.

1) *Micro hardness of the composites as a function of aging time*

In this paper the effect of aging temperature and time on the precipitation process has been studied. The sequence of operations is involved are solutionizing at 530°C for 3 hours quenching and artificially aging at different temperatures (130°C to 210°C) over time period for 1 - 9 hours. The specimens were then tested for microhardness and the results were presented in **Figure 1**. From the results it is found that the microhardness of the specimen subject to 5 hours aging time is superior than to those subjected to 1 hour to 4 hours aging time. Moreover, it is also seen that aging time of 6 hours to 8 hours does not result in appreciable improvement in the hardness compared to hardness achieved for 5 hours aging time. Hence, aging time of 5 hours is inferred to be optimum for AA 8011-SiCp composites [6]. The increase the hardness of the composite at under aged and peak aged stage is attributed to the formation of the: G.P zone of the θ' phase, due to the higher rate of decomposition as a result of the presence of dislocation, which are considered favorable sites for nuclei formation. The more deformation, the higher dislocation density, and hence the faster the precipitation. This could explain the early appearance of the peak hardness. The decrease of the hardness of the composite at over aged condition, both discontinuous and continuous precipitates became coarser [7].

2) *Tensile properties*

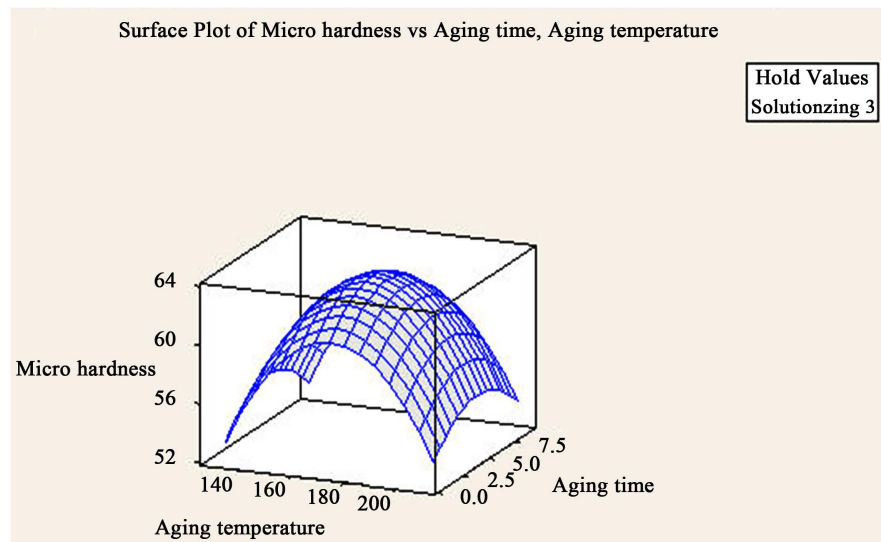


Figure 1. Effect of aging time on hardness of stir cast 8011/15% SiCp composites.

The tensile properties of the 8011 Al-15% SiCp composite material were evaluated. The results are shown in **Table 1**.

In the under aged condition 1 hour at 130°C, the tensile strength 8011 Al/15% SiCp composite is increased from 139 Mpa to 159 Mpa respectively. It is obvious that plastic deformation of the mixed soft metal matrix and non deformable reinforcement is more difficult than base metal itself [8]. The load bearing capacity of the hard particles as well as higher dislocation density of the matrix due to the thermal mismatch between the aluminum alloy and the reinforcement are response to the higher strength obtained.

In the peak aged condition 5 hour at 170°C, the tensile strength increased from 159 Mpa to 257 Mpa as shown in **Figure 2**. From this value, it is inferred that the tensile strength of the composites are greater than those of the aluminum base alloy. Because of the SiC particle provides more interface area, which serves as the nucleation site for grain formation during stir casting and as a barrier for grain growth during heat treatment therefore, it is not generally surprising that decreasing the grain size of the reinforcement, in addition to the effect of less intercept length between SiC particles (SiC particles exert more restriction on plastic flow during deformation) as well as a higher dislocation density of metal matrix, results in higher tensile strength [9].

In over aged condition 9 hour at 210°C, the tensile strength decreased from 257 Mpa to 189 Mpa. Then the volume fraction of the precipitates remain constant, and the interspacing of the precipitates increase if the aging time and temperature continues to increase through the growth of larger precipitates and the dissolving of the smaller precipitates. The increase in the interspacing of the precipitates will decrease strength [10].

3) Microstructure examination

The microstructure examination of the as cast composites generally revealed that SiC particles were not distributed in the matrix, regional cluster of particles

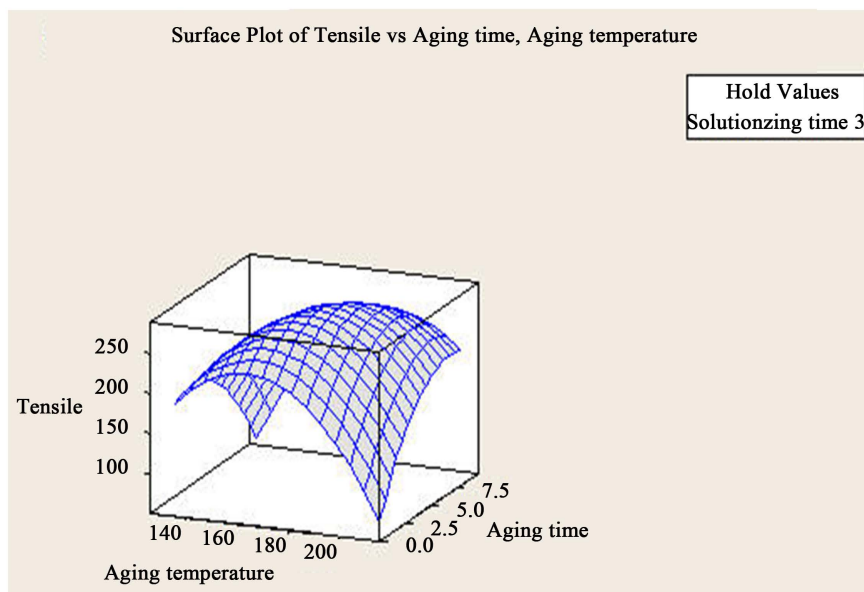


Figure 2. Tensile properties of the 8011 Al/15% SiCp composite.

Table 1. Mechanical properties of the 8011 Al/15% SiCp composite.

Sl. No	Solutionizing time (A)	Aging temperature (B)	Aging time (C)	Tensile strength (Mpa)	Yield strength (Mpa)	Micro hardness
1	4	190	7	195	181	54
2	2	190	7	216	188	59
3	4	150	7	174	161	66
4	2	150	7	164	157	49
5	4	190	3	166	143	49
6	2	190	3	174	156	66
7	4	150	3	205	172	59
8	2	150	3	180	173	53
9	5	170	5	123	113	49
10	1	170	5	124	121	50
11	3	130	1	159	137	54
12	3	130	5	150	140	55
13	3	210	9	189	161	54
14	3	170	1	200	174	60
15	3	170	5	254	225	64
16	3	170	5	257	227	63
17	3	170	5	254	224	62
18	3	170	5	257	221	63
19	3	170	5	258	225	64
20	3	170	5	257	226	65

exist and some pores are resolvable in as cast samples [11]. But after applying the extrusion process the number resolvable pores is reduced. It should be noted that extrusion generated severe plastic deformation of the matrix, which led to rearrangement of the SiC particles. The extrusion can improve the mechanical properties of the composite due to a more uniform distribution of SiC particle, the break up particles agglomerates, the improvement in the particle matrix interfacial bonding. Typical microstructure of the extruded composites states are shown in **Figure 3**.

4) *Fractography*

The fracture surface of the composite in the extruded condition is shown in **Figure 4**. The fracture surfaces of the composite after extrusion include mainly ductile dimples of the matrix and particle fracture, indicating an enhanced interfacial bonding strength and mechanical properties. The distribution of reinforcement was uniform [12]. **Figure 5** shows the SEM fractograph of 8011 Al/15% SiC composites in their under aged condition (1 hour at 130°C). The fracture surface of composites reveal two operating fracture mechanisms: micro-void formation and SiC particle cracking [13]. **Figure 6** shows the SEM fractograph of 8011 Al/15% SiC composites in their peak aged condition (5 h at 170°C). The fracture surface of composites revealed the coexistence of ductile and cleavage fracture [14]. The SEM image of 8011 Al/15% SiC composite shown shallow dimples as well as ductile shear bands indicating sufficient amount of ductility retained in the composite. It was observed that with increase in the amount of SiC particles, the depth of dimples decreases. The numerous small dimples are nucleated by large number of closely spaced particles in the SiC network in 8011 Al/15% SiC composite. The results of SEM examination of over aged (9 h at 210°C) composite also revealed the presence of fractured particulates as well as some interfacial de-bonding [15]. The increase in the interfacial de-bonding will decrease the tensile strength. A typical fractograph is shown **Figure 7**.

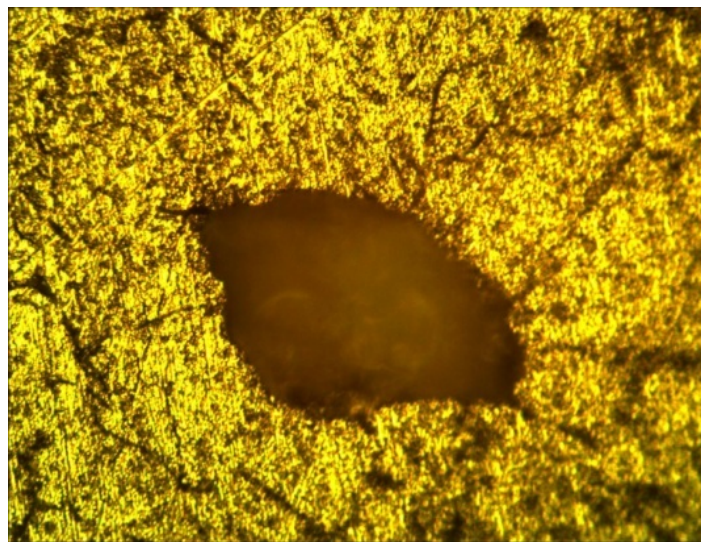


Figure 3. Microstructure of 8011 Al/15% SiCp composite in the extruded condition.

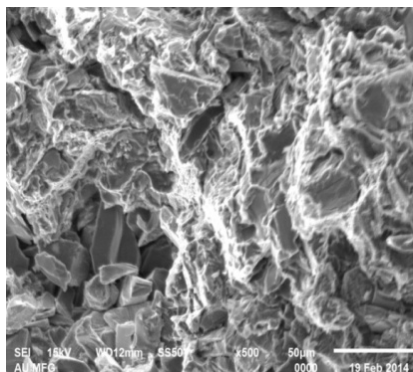


Figure 4. Fracture surface for the composite in the extruded condition.

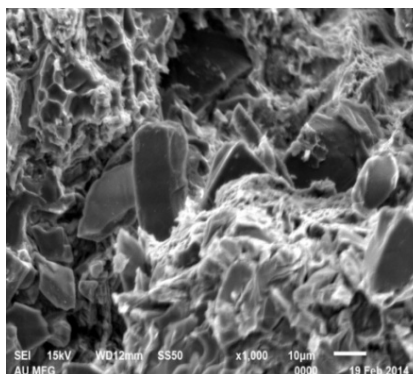


Figure 5. Fracture surface for the composite Underaged 1 h at 130°C.

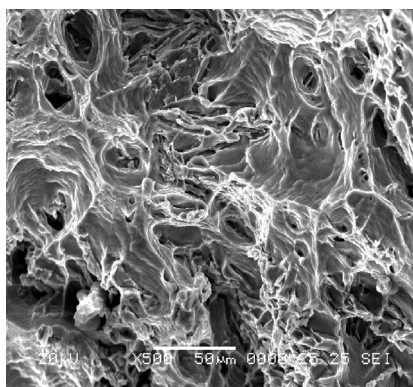


Figure 6. Fracture surface for the composite peak-aged 5 h at 190°C.

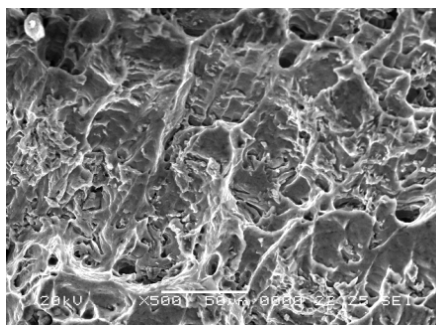


Figure 7. Fracture surface for the composite over-aged 9 h at 210°C.

4. Conclusion

In the peak aged condition 5 hours at 170°C, the tensile strength increased from 159 Mpa to 257 Mpa. From this value, it is inferred that the tensile strength of the composites is greater than those of the aluminum base alloys. Because of the SiC particle provides more interface area, which serves as the nucleation site for grain formation during stir casting and as a barrier for grain growth during heat treatment; therefore, it is not generally surprising that decreasing the grain size of the reinforcement, in addition to the effect of less intercept length between SiC particles (SiC particles exert more restriction on plastic flow during deformation) as well as a higher dislocation density of metal matrix, results in higher tensile strength.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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