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EFFECT OF AGING ON MECHANICAL PROPERTIES OF Al-8Si-8Fe-1.4V/SiCp COMPOSITES

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Preliminary Note – Prethodno priopćenje

In this study, Al-8Fe-8Si-1.4V/SiC_p composites fabricated by squeeze casting process were age-hardened to study the influence of heat treatment on mechanical properties, such as hardness, bending strength and modulus of elasticity. The cast samples were solid soluted at 540 °C for one hour, then quenched in water to room temperature, and finally aged at 190 °C for 2, 4, 6, 8 and 10 hours for hardness test and at 195 °C for 2, 6 and 10 hours for bending strength determination.

Key words: Al alloy, die custing, heat treatment, mechanical properties, harness test, bending test

INTRODUCTION

Cast aluminum alloys are used extensively for making various engineering products due to their light weight and high strength to weight ratio. The principle alloying elements in Al based cast alloys are Si, Cu, Zn, Mn, Cr and Ti. These alloys are used up to the temperature 453 K. Beyond this temperature the mechanical properties deteriorate due to coarsening of precipitates. An Al transition metal system has the potential to withstand relatively high temperatures and is likely to be suitable for use in the aerospace and automobile sectors. In particular, Al-Fe-Si-V alloys have attracted considerable interest since they maintain strength at temperatures higher than other Al-Fe-X system alloys. Excellent high temperature mechanical properties of Al-Fe-Si-V alloys are attributed to the high volume fractions of ultrafine cubic silicon intermetallic phase, $Al_{12}(Fe,V)_3Si$, and its slow coarsening rate [1]. As the percentage of ceramic increases, composite displays more and more properties of ceramic, like improved stiffness and decreased ductility.

As the volume of ceramic increases, the amount of matrix between particles decreases. The ability of matrix to deform is the basis of ductility of composite. Ductility of the unreinforced matrix in the case of aluminum can be over 10 %, as measured by strain to failure of test samples, [2]. As the percentage of reinforcement increases to 40 %, the elongation decreases to less than 2 %, [3]. The objective of this study is to evaluate the influence of heat treatment on some mechanical properties of SiC particulate reinforced aluminum alloy. Hardness and three-point bending tests were conducted on metal matrix composites with SiC particles of different amounts. Results were compared with the non-reinforced aluminum matrix alloy.

EXPERIMENTAL PROCEDURE
Materials and production processes

The nominal chemical composition of the matrix was approximately Al-8Fe-8Si-1.4V by wt %. The composites produced contained 4 % and 7 % SiCp. The volume fraction of SiC_p in the composites was determined experimentally by the image analyzer. Particles of SiC having diameter 2 9 ± 1,5 µm, were produced by KLA Exalon, Norway.

The alloys were modified by adding nearly 1,5 % Mg, and melted in an induction furnace using master alloys of Al–Si and Fe-V. After melting, sufficient time was given for homogenization of the melt. The molten alloy was degassed, and then SiC particles were added into the alloy at its mushy state. Molten Al alloys were poured into a mold specially designed for vertical filling squeeze-casting machine (Figure 1).

Bending and tensile test specimens were produced simultaneously in this mold. During squeeze casting the applied pressure was 80 MPa. The alloys were heat-treated to T6 condition that is solid saluted at 540 °C for

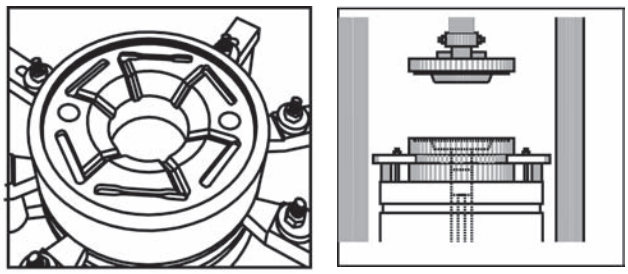

Figure 1 Squeeze/Pressure casting die

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1 h / water quench + aging up to 10 h. Aging temperature was 190 °C ± 5 °C.

Bending Test

Bending strength of cast composite specimens, produced by squeeze/pressure die casting machine, was evaluated by the three point bending test. The number of tested specimens was three samples for each case. Dimensions and shape of three point bending test specimen were: Span length = 50 mm, width = 10 mm, height= 5 mm. The three point bending fixture of the tensometer device was used for these tests.

Brinell Hardness Test

Hardness measurements were carried out according to ASTM standard E10-84, standard test method for Brinell hardness. All tests were performed with 2,5 mm diameter ball using31,25 kg loads. On each sample average of eight measurements were taken.

The number of tested specimens was 4-6 samples for each case (different aging times and different SiCp content).Hardness levels for materials obtained by HB tests are given in Table 1 and Figure 2.

Table 1 **Average Brinell hardness values / HB**

Aging time / h	Matrix	Matrix + 1,5 % Mg + 0 % SiC	Matrix + 1,5 % Mg + 4% SiC	Matrix + 1,5 % Mg + 7% SiC
0	66	83	99	97
2	62	87	126	107
4	58	100	129	127
6	70	119	131	125
8	67	122	128	130
10	59	119	128	128

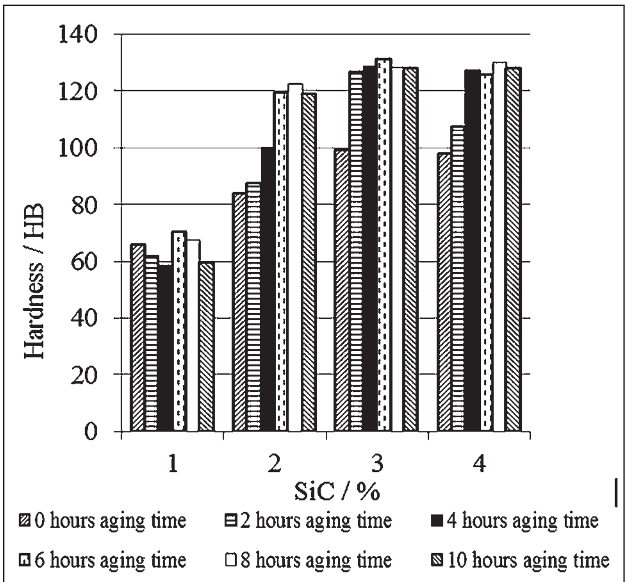

Figure 2 Effect of aging time and SiC content on the hardness behaviour (1) Matrix, (2) Matrix with 1,5% Mg, (3) Matrix with 1,5 % Mg and 4 % SiC, (4) Matrix with 1,5 % Mg and 7 % SiC

For instance, the 6 hr aging matrix without Mg showed an average hardness value of 70 HB. With Mg addition, hardness improved to 119 HB which is 70 % increase. However, with 4 % SiC addition, for the same aging time, hardness increased to 131 HB corresponding to approximately 10 % increase compared to the matrix with Mg. It seems that Mg addition to the matrix is more effective factor than SiC. One should also notice a small decrease in hardness (125 HB) as SiC content is increased to 7 %.

Figure 2 shows that effect of SiC content and aging time on hardness values. For unreinforced and unmodified matrix there was no significant change in the hardness level with increasing aging time because the amount of hard phases and precipitates present were not significant to improve the hardness. The hardness of Mg modified matrix, significantly increased with increasing of aging time because of the nucleation of new hard phases like Mg_2Si and increase in dislocation density. Hardness increased for 2, 4, 6 and 8 h of aging time because of the increase in dislocation density, and then decreased at over aging (OA). This reduction in hardness is attributed to the increased size (coarsening) of precipitates which led to the decreased dislocation density, and increase in incoherency between matrix and particles. To investigate the effective hardness of the composite by means of the rule of mixtures (ROM), following relations are used:

$$\bar{H}_{up} = H_h f_h + H_s f_s \tag{1}$$

$$\bar{H}_{low} = (f_h / H_h + f_s / H_s)^{-1} \tag{2}$$

where H_h and H_s are the hardness values of hard and soft phases, and f_h and f_s are the volume fraction of hard and soft phases, respectively. The subscripts "up" and "low" represent the upper bound and lower bound of hardness.

In Figure 3, the calculated results are compared with the measured results, indicating reasonable values since most of the measured points lie between the upper and lower bounds.

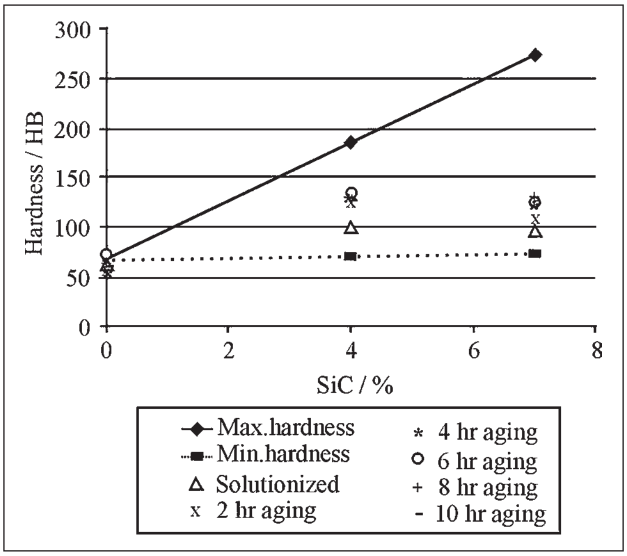

Figure 3 Comparison of measured and calculated hardness values

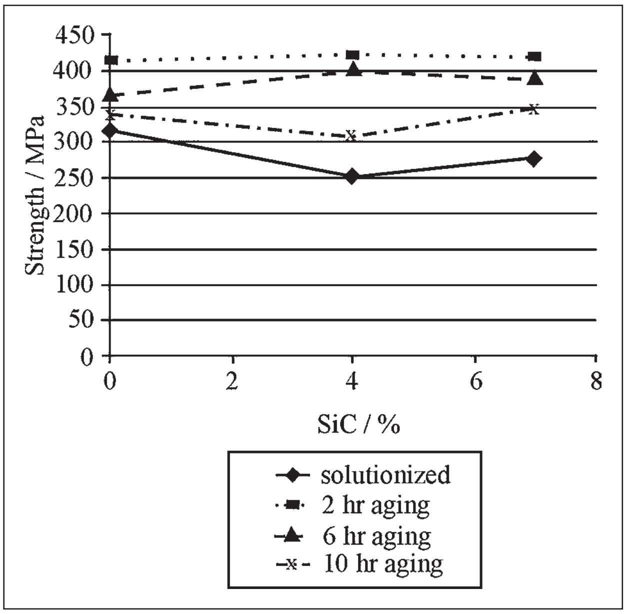

Figure 4 Relationship between strength and SiC content with increasing in aging time

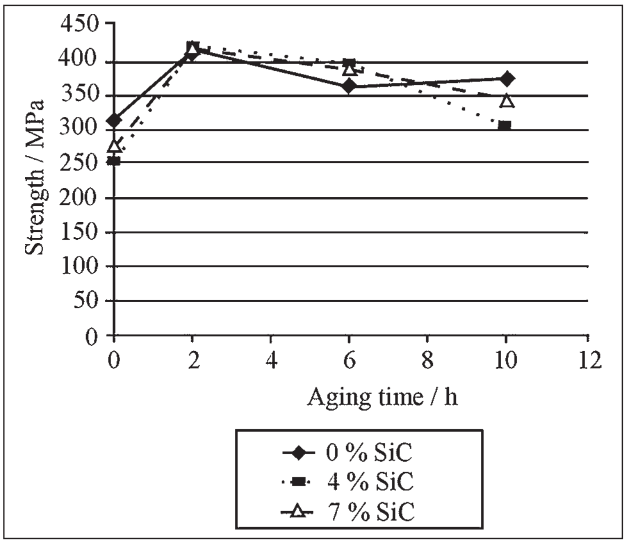

Figure 5 Flexure strength related to aging time with different SiC contents

Bending strength

The average of bending strength values, measured by three point bending tests, are given in Figure 4, indicating that there is no significant change, as SiC content increases from 0 to 7 %. Peak strength is observed at two hours aging (also shown in Figure 5), since the strength increased sharply within first two hours, and then decreased gradually as a result of over aging phenomenon. The early peak strength due to aging may be attributed to the relatively high aging temperature which accelerates the dislocations, and nucleation of hard phases.

Modulus of elasticity:

The modulus of elasticity, E, was determined using the force deflection equations formulated for three point bending conditions as follows:

$$E = \frac{PL^3}{4ybt^3} \tag{3}$$

where P is load / N;L span / mm; y mid-point deflection / mm; b width / mm; and t height / mm.

Measured values are shown in Table 2, for different content of SiC (in Volume percent – Vp) and different aging times.

Table 2 **Modulus of elasticity / GPa – measured values for matrix with 1,5 % Mg**

	Aging time / hr			
SiC Vp / %	0	2	6	10
0	48,2	52,8	51,7	49,3
4	58,0	60,2	59,1	50,3
7	41,7	44,8	37,9	43.6

The modulus of elasticity of Al/SiCp composites increased as the volume fraction of SiC increased. The Hashin - Shtrikman model (H-S model) was used to predict the modulus of Al/SiCp composites, [3]. In this model, the modulus is expressed as:

$$E_c = E_m \frac{E_m V_m + E_p (V_p + 1)}{E_p V_m + E_m (V_p + 1)} \tag{4}$$

where index "m" stands for matrix, "p" for particle, and "c" for composite.

Another equation was proposed by Halpain and Tsai (H-T), [3]:

$$E_c = E_m \frac{1 + 2sqV_p}{1 - qV_p} \tag{5}$$

$$q = \frac{\dfrac{E_p}{E_m - 1}}{\dfrac{E_p}{E_m + 2s}} \tag{6}$$

where s is the aspect ratio of SiC particles. The average value, s = 1,72, was measured from Figure 6, $s = c/a$, where c is longer axis and a is shorter axis.

Applying the isostress condition of ROM for modulus of elasticity:

$$E_c = \frac{E_m E_p}{E_p V_m + E_m V_p} \tag{7}$$

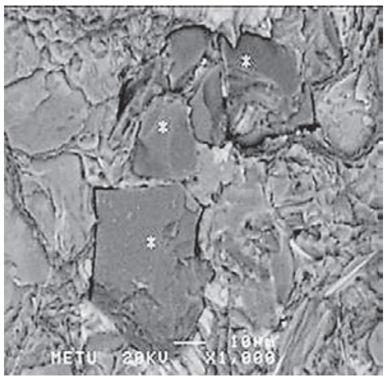

Figure 6 SEM photograph of SiC particles (Magnification 1 000 X)

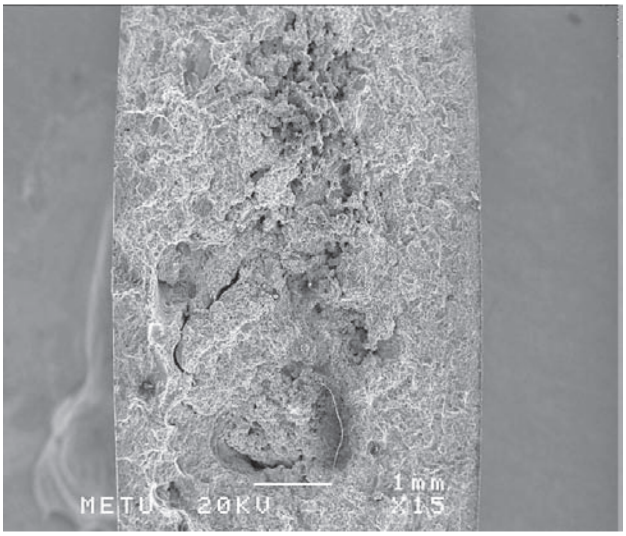

Figure 7 Fracture surface of tested specimen with high porosity and cavities

All three models are used to calculate the modulus of elasticity, as shown in Table 3, together with the measured results. Table 3 indicates that ROM is the nearest model to the measured values. For 7 % SiC content the modulus decreased in an unexpected way to reach 59,5 % of its value by ROM. This trend may be attributed to data scatter or increased porosity of specimens with higher SiC content Figure 7. The H-S and H-T models overestimate the modulus of elasticity of composites compared to ROM.

Table 3 **Modulus of elasticity values with respect to SiCp content (Vp) and aging time**

Vp / %	H-S / GPa	H&T / GPa	ROM / GPa	Measured /GPa	Measured / ROM
0	69	69	69	51,2	74,30 %
4	73,2	82,7	71,4	56,6	79,20 %
7	76,5	93,7	73,4	43,6	59,50 %

Figure 7 shows one of the tested specimens with high porosity. Existence of some cavities is also observed. These cavities may have formed as a result of entrapped gases during casting process.

CONCLUSIONS

Appreciable improvement in hardness levels was achieved by age hardening in modified and reinforced matrix. This improvement increased with addition of Mg and also with increased SiC content in the matrix. By comparison of measured values with calculated data by ROM, the experimental results were found reasonable.

Bending strength improved significantly by applying heat treatment to the modified and reinforced matrix, but no obvious trend between bending strengthand SiC content was observed.

For modulus of elasticity, the comparison of the measured results and the calculated data, using three different models, indicates that the closest model for this case is ROM. The obtained results were satisfied for matrix with 0 % and 4 % SiCp, but for matrix with 7 % SiCp the modulus decreased, as a result of high porosity.

The effect of aging obviously appeared on the average of modulus at peak aging and decreased at over aging. In other words, it follows the same trend of bending strength.

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Note: Responsible person for English translation is prof. Martina Šuto (J.J. Strossmayer University of Osijek) and prof. Marina Karšić