EFFECT OF AGING CONDITION ON STRUCTURE AND THE PROPERTIES OF Al-ALLOY / SiC COMPOSITE

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Abstract: The heat treatments have been designed to vary the matrix microstructure in P/M processed SiC reinforced 7xxx Aluminum alloys to determine the effects of matrix microstructure, interface behavior on the mechanical properties. Smooth tensile, notched bend tests were performed. The results conclude that the clustered regions have been observed as preferred initiation sites in both tensile and notched bend experiments on the SiC / Al-alloy composites. Despite the relative similarity in macroscopic tensile properties between the under aged and over aged composite, quantitative fractography revealed preference for SiC fracture in the under aged composite and preference for interface or near-interface failure in the over aged composite.

Keywords: aging, Al-alloy, SIC composite, notched bend tests

I. INTRODUCTION

Metal matrix composites (MMCs) have been drawn attention in recent years owing to the need for materials with high strength and stiffness in the field of aerospace applications. The type of reinforcement (viz; particulate, whisker, fibre and filament) depends mainly on the use and requirements [1]. The discontinuous reinforced composites are fabricated by casting and powder metallurgy techniques followed by conventional metalworking processes like extrusion, rolling, etc. In most ductile matrix composites, low tensile ductility is obtained despite the use of ductile metals such as Al or Ti for the matrix. It is well accepted that changes in microstructure may change the fundamental deformation and fracture processes in both ferrous [2] and non-ferrous [3] unreinforcement materials Recent works reveal major effects of changes in matrix material, volume percent and size distribution of reinforcement on subsequent properties in monotonic loading. Few studies have focused on the role of microstructure in the deformation and fracture of MMCs.

The present work was focused on the effects of matrix microstructure and reinforcement fracture on the properties of Silicon carbide (SiC) reinforced Al-alloy composites. Heat treatments have been designed to vary the matrix microstructure and SiC/matrix interface in P/M 7XXX Aluminum alloys reinforced with 22 volume percent SiC.

II. EXPERIMENTAL PROCEDURE

The composition of matrix alloy is given in Table-I. The average size of SiC particulate before blending was 18μm. The matrix alloy was reinforced with 22% by volume SiC particulate. The as-extruded MMC specimens were solution treated, cold water quenched and aged. The solution treatment was carried out for 4 hours at 480^0C followed by water quenching. The quenched specimens were then aged: (i) at 100^0C for one hour (under aged) and (ii) at 100^0C for 24 hours (over aged). The heat treatments have been designed to vary the matrix microstructure in the composite.

TABLE I: COMPOSITION OF MATRIX ALLOY

Content	Zn	Mg	Cu	Zr	Al
%Weight	7.00	2.50	2.00	0.12	Balance

Tensile testing was carried in the longitudinal orientation on cylindrical specimens of the design shown in Fig.1. The strain rate was 1×10^{-3} /sec. The notched specimens of the design shown in Fig.2 were tested in 4-point bending to determine the effect of a stress concentration on fracture initiation.

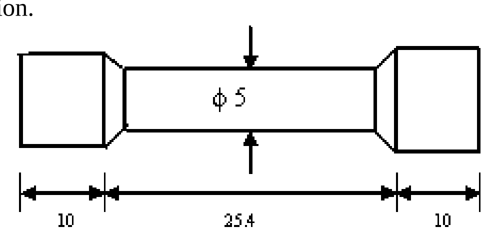

Fig.1 Tensile specimen tested. Dimensions are in mm.

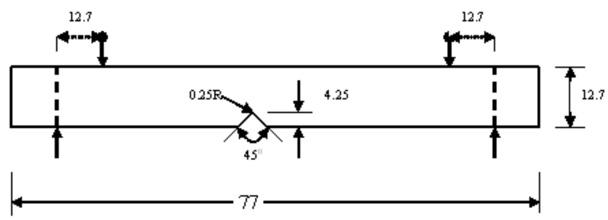

Fig.2 Notched bend bar tested. Dimensions are in mm.

Quantitative metallographic techniques were utilized to characterize the material with respect to average particle size and size distribution using micrographs obtained from scanning electron microscope (SEM). Fracture surfaces of both the tensile and 4-point bend test specimens were examined under SEM and the quantitative analysis was performed to calculate area fraction and particle size distribution of SIC present on the fracture surfaces.

III. RESULTS AND DISCUSSION

The size distribution of SiC particulate before blending and extrusion is shown in Fig.3. The average size of SiC particulate was 18μm at 22 volume percent. The particle size was measured along the transverse section. As shown in Fig.4, the extrusion of composites causes fracture of the SiC, thus reducing the average particle size to 5μm. There is a doubt on; either a crack growing in the composite refractures the SiC - fractured during the extrusion process in addition to fracturing 'new' SiC or some SiC particles are consolidating into larger SiC particle during the extrusion process.

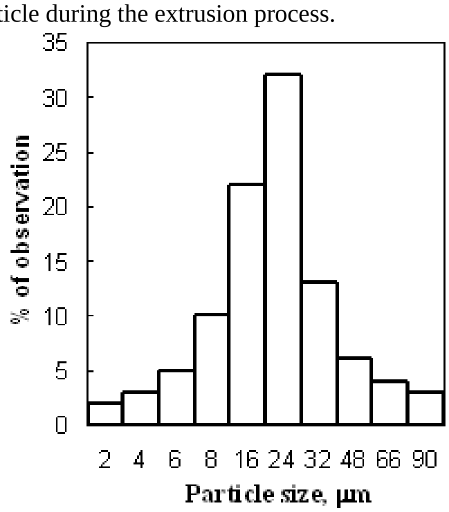

Fig.3 Size distribution of SiC prior to extrusion

The fractographs in Fig.5 illustrates the differences in the fracture morphology in the under aged and over aged tensile specimens. In the under aged composite, SiC is clearly present on the both halves of the fracture surface indicating presence of fractured SiC. In contrast, evidence of failure near the interface of the SiC and matrix is revealed in the over aged composite. In materials processed via super-solidus consolidation, coarse intermetallic particles have often been found to initiate failure in smooth tensile specimens, while material processed using sub-solidus consolidation have revealed that fracture preferentially initiates in regions of clustered SiC both in tensile specimens and in notched test bars [4]. In the present work on 7XXX alloys, the materials were consolidated below the solidus temperature. Therefore, the fracture was initiated preferentially in the regions of clustered SiC in both the smooth tensile specimens and notched test bars.

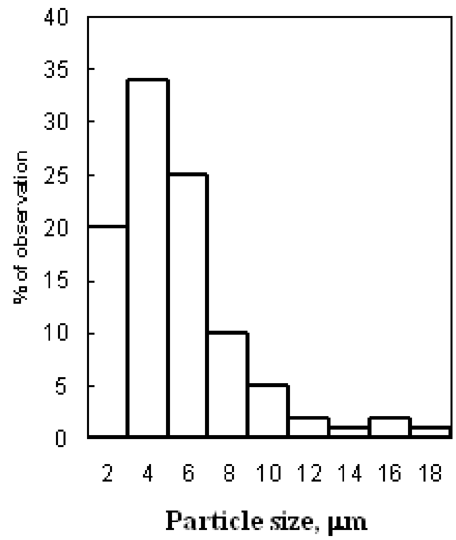

Fig.4 Size distribution of SiC after extrusion

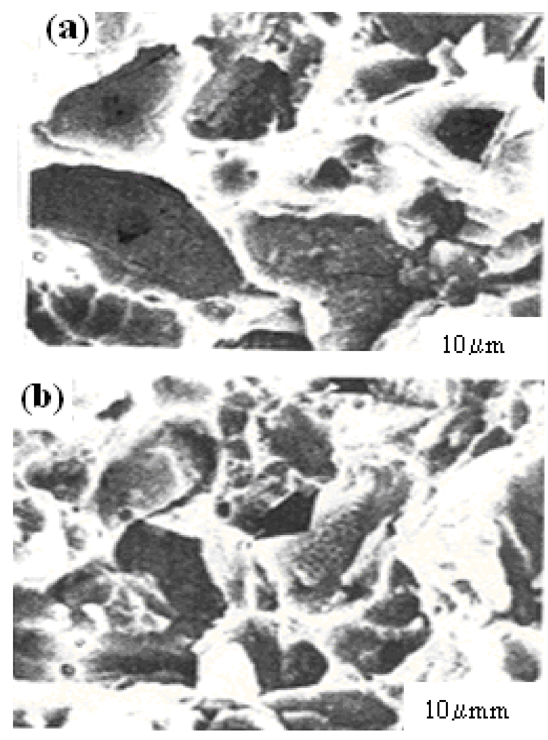

Fig.5 Surface fractographs of tempered composites of tensile tested specimen (a) under aged (b) over aged

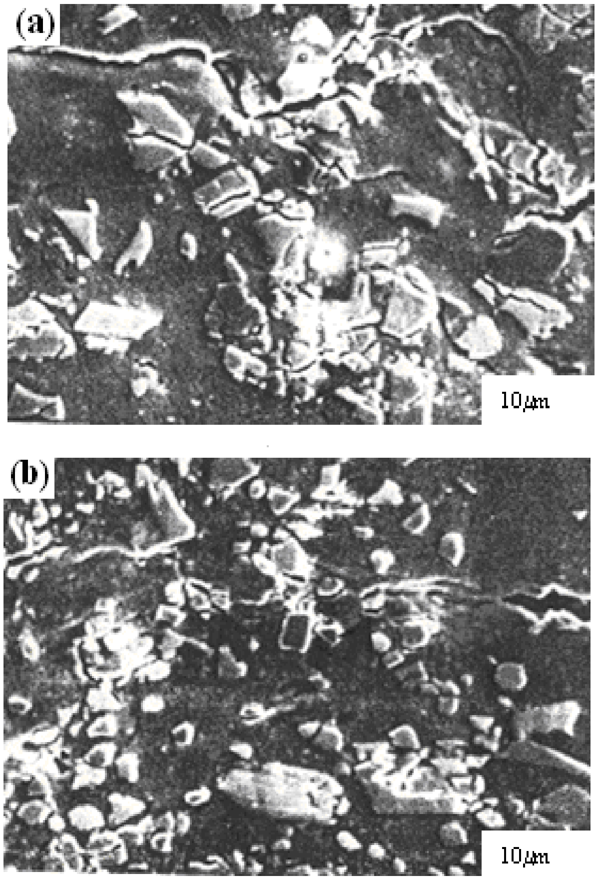

Fig.6 Crack tip regions. (a) under aged (b) over aged composites of notch bend tested specimen

Representative SEM micrographs of the crack tip regions are shown in Fig.6 for under aged and over aged composite. The under aged composite exhibited crack propagation, which occurred via SiC fracture ahead of the crack tip, with subsequent linkage of the cracks in the matrix. In addition, the under aged composite exhibited crack bridging in the wake of the crack. In contrast, fracture in the over aged composite was observed to occur at the interface of SiC particulates and matrix or near- interface. The planar crack profile was observed in the over aged composite. The under aged composite exhibited high dislocation density, while the SiC/matrix interface was free of precipitates. In contrast, the over aged composite exhibited extensive precipitation in the matrix as well as at the SiC/matrix interface. Precipitate free zones were not observed at the SiC/matrix interface in the over aged composite, although they were observed at grain boundaries in the matrix of the over aged composite. The precipitates might be $MgZn_2$.

Quantitative fractography performed on the fracture surfaces of smooth tensile specimens indicated that the fractured SiC present were coarse particle (Fig.7). Similar results were obtained from the surfaces of the notched bend specimens.

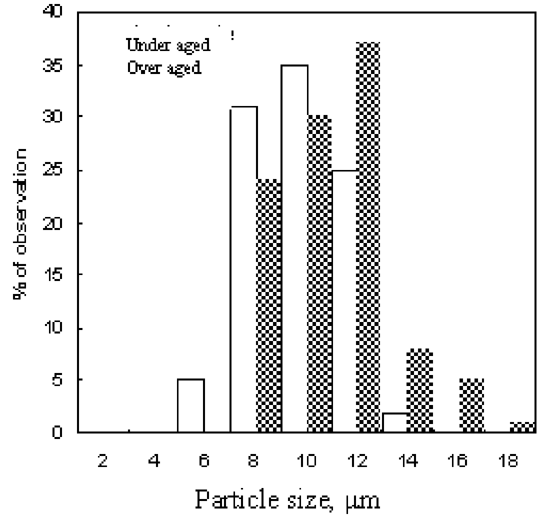

Fig.7 Size distribution of SiC present on the fractured surface of tensile tested specimen

TABLE II: TENSILE PROPERTIES

Condition	σ_y (MPa)	%Reduction area	UTS (MPa)	% Area fraction on fracture surface
Under aged	375	8.10	488	20
Over aged	400	7.60	526	11

TABLE III: NOTCHED BEND PROPERTIES

Condition	σ_{Nom} / σ_y	Max. Stress (MPa)
Under aged	1.40	883
Over aged	0.94	700

The tensile properties for under aged and over aged composites are given in Table-2. It can be seen that yield strength and ductility were nearly the same for the two treatments; but there is a large difference in the amount of fractured SiC present on the fracture surfaces between the two treatments. The reason might be owing to the use of smooth tensile specimens. Under aged composite had large fractured SiC. Table-3 summarizes the results of the notched bend tests. It can be revealed that over aged composite failed at lower nominal bending stress than did the under aged composite. Although the tensile properties did not reveal a substantial effect of matrix microstructure on yield strength or ductility, the notched bend tests revealed the status of failure in the under aged and over aged composites.

The present results indicate interfacial regions may play a dominant role in the toughness of particulate reinforced metal matrix composites. It is shown that interface and near-interface failure in over aged composite accompanies a large drop in notch bend toughness, although the macroscopic tensile properties are relatively unaffected by the aging treatments employed. Furthermore, a particle size effect has been observed whereby large SiC fracture during testing in preference to small SiC. It is also noticed that cracks in under aged composite propagate via SiC fracture in the process zone ahead of the crack with subsequent linkage in the matrix producing bifurcated crack. Bridged ligaments were further observed in the wake of the crack in the under aged composite. Planar crack fronts were observed in the over aged composite with fracture at or near SiC/matrix interface. Fracture initiation was observed to occur in regions of clustered SiC.

IV CONCLUSIONS

Tensile properties of under aged and over aged composites were nearly same. Notched bend experiments indicated that under aged fracture composite at higher nominal bending stresses than did the over aged composite. Despite the relative similarity in macroscopic tensile properties and ductility between the under aged and over aged composite, fractography revealed preference for SiC fracture in under aged composite and preference for interface or near-interface failure in the over aged composite. Fracture in under aged composite occurs via SiC fracture ahead of the crack tip with subsequent linkage via failure in the matrix. Both crack branching and crack bridging were observed in the under aged composite, while the over aged composite exhibited a planar crack front with a preference for failure at or near the SiC/matrix interface. Interfacial regions in SiC reinforced composites may exert substantial effects on the toughening mechanisms operating in discontinuously reinforced composites. Work is continuing to evaluate the importance of crack branching and bridging on increasing the toughness of the under aged composite.

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