THE QUASI-STATIC FRACTURE BEHAVIOR OF 7034 ALUMINUM ALLOY REINFORCED WITH SILICON CARBIDE PARTICULATES

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ABSTRACT

The quasi-static response of aluminum alloy 7034 discontinuously reinforced with particulates of silicon carbide was studied at room and elevated temperatures, in both the under-aged and peak-aged conditions, with the objective of documenting the influence of microstructure and temperature on tensile properties and intrinsic fracture behavior. Test results reveal the elastic modulus and strength of the aluminum alloy-based metal matrix composite to decrease with an increase in temperature, while the ductility, quantified in terms of elongation-to-failure and reduction-in-area, revealed significant improvement. Fractures on a microscopic scale was dictated by events that resulted in the failure of the brittle reinforcing silicon carbide particulates by cracking and decohesion at the matrix-particulate interfaces.

KEYWORDS: ***Aluminum alloy composite, microstructure, tensile properties, fracture***.

1. INTRODUCTION

Twenty-first century aerospace systems have mission requirements that will demand advanced materials, such as metal matrix composites, to have the potential to meet the demands of present and future aerospace vehicles. In the time period spanning the last two decades, metal matrix composite (MMCs) have been a promising and often-promised, structural materials solution. Reinforced metal-matrices are highly versatile engineering materials that offer the potential for improvements in efficiency, strength, stiffness coupled with good wear and corrosion resistance over the newer generation monolithic alloys of aluminum and titanium and even organic matrix composites [1-5]. Besides, they have the ability to be processed and finished using conventional metal processing. In fact the technology of discontinuously-reinforced aluminum alloy based composites has matured to the point where components are now being produced for aircraft structures, gas turbine engines, automobiles, electronics, spacecraft and even recreational goods [6].

This paper examines the influence of silicon carbide particulate (SiC_p) reinforcements and aging condition on the tensile properties and fracture behavior of 7034 aluminum alloy based MMC. The tensile properties and fracture behavior of the composite, at both room and elevated temperatures, are compared in order to rationalize microstructure and test temperature influences on deformation and fracture.

2. MATERIAL

The aluminum alloy MMC used in this research investigation was made using the spray processing technique and provided as an extruded billet by the Air Force Materials Laboratory (Dayton, Ohio, USA). The billet was obtained by extruding the consolidated sample through a standard shear-face die. The as-received billet was subject to the following heat treatment: (a) solution heat treated at 490°C for 4 hours, (b) immediately quenched in cold water, and (c) artificially aging at the following temperatures: (1) 120°C for 30 minutes to get the under-aged (UA) condition, and (2) 120°C for 24 hours to get the peak-aged condition. The composites are referred to henceforth in this manuscript as 7034/SiC/15p-UA and 7034/SiC/15p-PA.

3. EXPERIMENTAL PROCEDURES

Samples were cut from both the 7034/SiC/15p –UA and 7034/SiC/15p-PA composites and prepared by standard metallographic procedures for observation in an optical microscope. The reinforcing silicon carbide particulate morphology, their size and distribution in the aluminum alloy metal matrix and other coarse microstructural features were examined in an optical microscope and photographed using a bright-field technique.

Tensile test specimens were precision machined from rectangular blanks (l: 150 mm x w: 20 mm x t: 20 mm), using a diamond coated saw blade, with the stress axis parallel to the extrusion direction. To minimize the effects of surface irregularities and finish, final surface preparation was accomplished by mechanically polishing the entire gage section of the test specimens through 600 grit silicon carbide paper and then finish polished to remove all circumferential scratches and surface machining marks. The specimens were deformed at a constant strain rate of 0.0001 s^{-1} on a fully automated, computer controlled servohydraulic test machine equipped with a 22,000-kg load cell (INSTRON: Model 8500 Plus). The tests were performed at room temperature (27°C) and elevated temperature of 120°C. The elevated temperature tests were performed in an environmental changer (Type: INSTRON Model 3111). The temperature was controlled with the aid of a temperature controller linked to thermocouple fixed on the surface of the specimen. Maximum temperature variation along the gage section of the specimen was + 2°C. Fracture surfaces of the deformed tensile specimens were examined in a scanning electron microscope (SEM) to characterize the predominant fracture mode and the fine-scale features on the fracture surface.

4. RESULTS AND DISCUSSION

4.1 *Initial Microstructure*

The optical micrographs illustrating the microstructure of the 7034/SiC/15p-UA and 7034/SiC/15p-PA composites are shown in Figure 1. The SiC_p, in the 7034 metal matrix, were non-uniform in size, irregularly shaped and randomly dispersed. At regular intervals, a clustering or agglomeration of the SiC particulates, of varying sizes, was observed resulting in SiC particulate rich and SiC particulate depleted regions. An agglomerated site consisted of the smaller SiC_p intermingled with few larger SiC_p. No attempt was made to determine the particle size distribution for the two microstructures.

4.2 *Tensile Properties*

Test results reveal that at the elevated temperature of 120°C the elastic modulus of the 7034/SiC/15p-PA composite is marginally lower that at the ambient temperature (27°C), and marginally higher for the 7034/SiC/15p-UA counterpart. The yield strength, defined as the stress corresponding to a plastic strain of 0.2 percent, decreased with an increase in test temperature for both the peak-aged (PA) and under-aged (UA) test samples. The observed decrease was as high as 13% for the 7034/SiC/15p-PA microstructure and only 9% for 7034/SiC/15p-UA counterpart. For both aging conditions the ultimate tensile strength (σ_{UTS}) of the 7034/SiC/15p composite is marginally higher than the tensile yield strength (σ_{YS}) indicating that the work hardening rate past yielding is low. The ultimate tensile strength followed the same trend as the yield strength of the composite. The decrease in ultimate tensile strength with an increase in test temperature from 27°C to 120°C was around 11% for the 7034/SiC/15p-UA and 7034/SiC/15p-PA microstructures.

The ductility as measured by: (a) tensile elongation over a 12.7 mm gage length of the test specimen, and (b) reduction in cross-sectional area, increased with an increase in test temperature. The increase was as high as 40% for the PA microstructure and only 3% for the UA microstructure. The reduction-in-area increased with an increased in test temperature by as much as 110% for the 7034/SiC/15p-PA and only 25% for the 7034/SiC/15p-UA condition. The observed increase in strain-to- failure and reduction-in-area with an increase in test temperature is consistent with the degradation of strength at the higher test temperature.

4.3 *Tensile Deformation and Fracture Behavior*

At both room (27°C) and elevated (120°C) test temperatures the 7034/SiC/15p composite exhibited essentially limited ductility, on a macroscopic scale, with fracture occurring on a plane normal to the far-field tensile stress axis. However, examination of the tensile fracture surfaces at higher magnifications revealed features reminiscent of locally ductile and brittle mechanisms. Representative fractographs of the tensile fracture surface of the 7034/SiC/15p-UA and 7034/SiC/15p-PA composites are shown in Figures 2 and 3.

A: *7034/SiC/15p-UA Composite*

At both test temperatures the tensile fracture surfaces of this microstructural condition was flat and normal to the tensile stress axis when viewed on a macroscopic scale but rough when viewed on a microscopic scale (Figure 2a). The aluminum alloy metal matrix revealed combinations of tear ridges (Figure 2b), failure of the reinforcing SiC_p by cracking (Figure 2c) and decohesion at the interfaces with the matrix (Figure 2c). Following the early initiation of damage, subsequent accumulation, growth and eventual linkage in the matrix resulted in brittle failure (Figure 2c). At the higher test temperature the degree of particulate failure both through cracking and decohesion at its interfaces with the metal matrix increased (Figure 2d). The matrix of this composite was covered with pockets of shallow dimples. Multiple microscopic cracks were observed in regions of particulate agglomeration, which is responsible for the inferior ductility of the composite.

B: *7034/SiC/15p-PA Composite*

At ambient temperature (27°C) the fracture surfaces revealed the SiC particulates surrounded by ductile regions described as tear ridges (Figure 3b), particulate failure through cracking (Figure 3c) and decohesion or separation at the matrix-particulate interfaces (Figure 3d). No major difference in tensile fracture features was evident at the higher test temperature (120°C). The matrix of the composite was covered with a population of microscopic voids of varying size and isolated pockets of shallow dimples. The submicrometer-sized dimples are indicative of the improved ductility of this composite at this temperature.

The constraints imposed on mechanical deformation by the presence of brittle and essentially elastically deforming SiC_p in a soft, ductile and plastically deforming aluminum alloy metal matrix and the concomitant development of a local triaxial stress state, in the matrix, aids in limiting flow stress of the composite microstructure and thus favors: (a) void initiation and growth in the matrix, and (b) debonding at the matrix-SiC_p interfaces. As a direct consequence of deformation constraints induced by the hard and brittle SiC_p reinforcements, a higher applied stress is required to initiate plastic deformation in the aluminum alloy metal matrix. This translates to a higher yield strength and higher elastic modulus of the composite microstructure. Under the influence of a far-field tensile load the voids appeared to have undergone limited growth confirming a possible contribution from particulate-constraints induced triaxiality on failure of the composite matrix. The local plastic constraints are particularly important for the larger-sized SiC particulates and for SiC particulate clusters during composite fracture [7,8]. Examination of the fracture surfaces revealed damage to be highly localized at the SiC reinforcing phase through: (a) cracked particulates and (b) interfacial failure or decohesion. This suggests that plastic strain become localized during the early stages of tensile deformation. Few of the microscopic voids, generated by SiC particulate cracking, did not grow extensively in the tensile stress direction, which is generally the case for ductile fracture of unreinforced aluminum alloys [6]. The lack of extensive void growth in this particulate-reinforced aluminum alloy metal matrix also suggests that both void nucleation strain and associated linkage strain critically control the fracture strain.

5. CONCLUSIONS

The following are the essential findings of this study:

1. The microstructure of the two composites, Underaged and peaked, revealed a non-uniform dispersion of the reinforcing SiC particulates. At regular intervals, an agglomeration of the reinforcing particulates, of varying size, was observed.
2. The modulus and strength of the two composite microstructures decreased with an increase in temperature. The ductility, quantified in terms of elongation-to-failure and reduction in area decrease with an increase in temperature.

3. Fracture of the reinforcing SiC particulates coupled with decohesion at its interfaces with the matrix permits the microscopic cracks to grow and link by fracture through the matrix resulting in macroscopically brittle appearance and resultant low ductility.

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TABLE 1: THE TENSILE PROPERTIES OF THE 7034/SIC/15P COMPOSITE**

Aging Condition	Temperature (^oC)	E (GPa)	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Elongation (%)	Reduction-in-Area (%)
UA	27	90	662	709	1.8	2.4
	120	86	574	604	2.5	5.1
PA	27	91	612	683	1.9	3.3
	120	90	562	611	1.9	4.0

*** Results are the mean values based on duplicate tests.*

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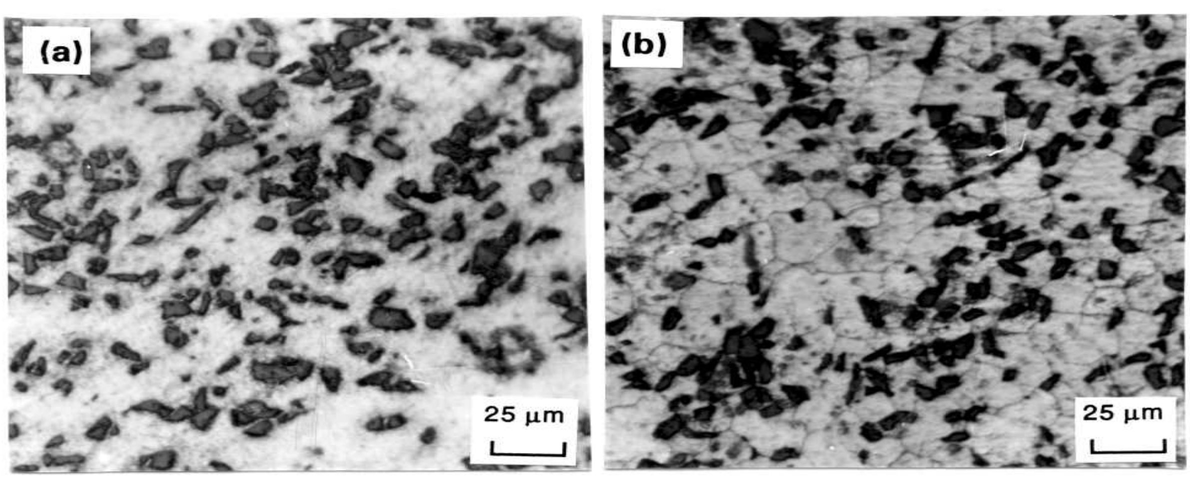

Figure 1. Optical micrographs showing the microstructure of the 7034/SiC/15p composite for: (a) under-aged (UA) and (b) peak-aged (PA).

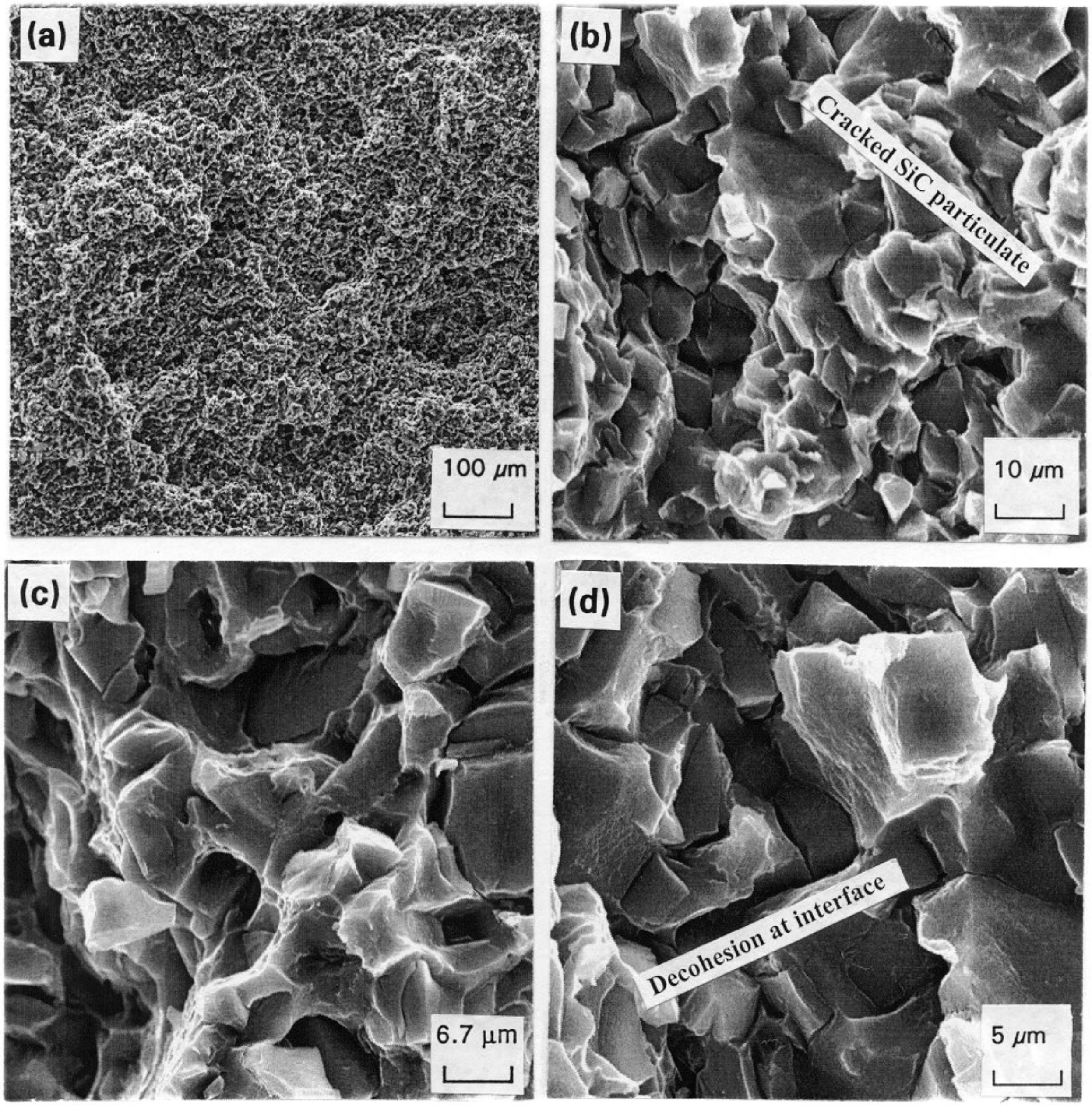

Figure 2. Scanning electron micrographs of the 7034/SiC/15p-UA composite deformed at 27°C and showing the following features: (a) overall morphology, (b) tear ridges, (c) cracked SiC particulates and decohesion at matrix-particulate interfaces, (d) microscopic features of fracture at the higher test temperature (120°C).

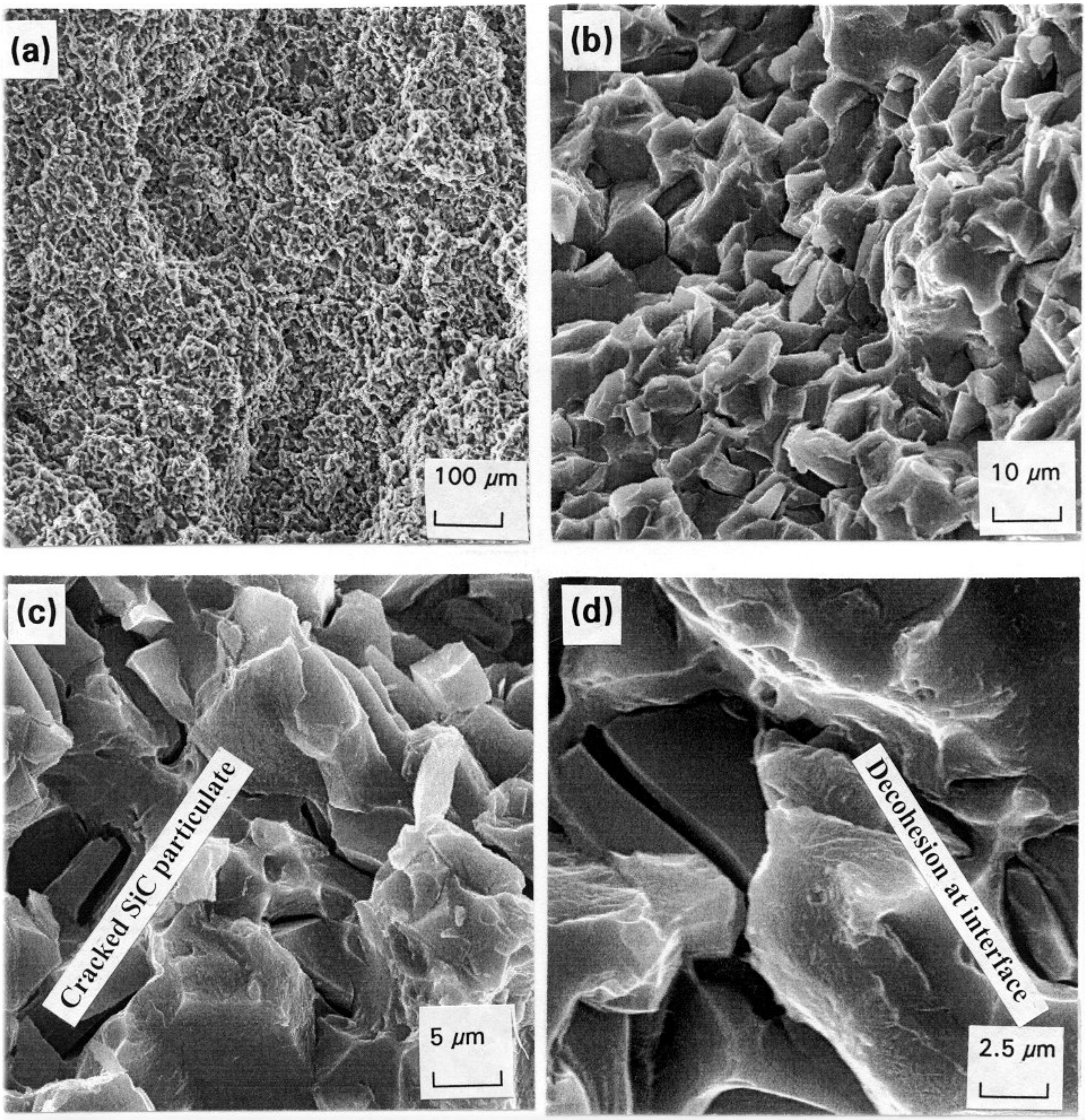

Figure 3. Scanning electron micrographs of the 7034/SiC/15p-PA composite deformed at 27°C and showing the following features: (a) overall morphology, (b) tear ridges, (c) cracked SiC particulates, and (d) decohesion at matrix-particulate interfaces.