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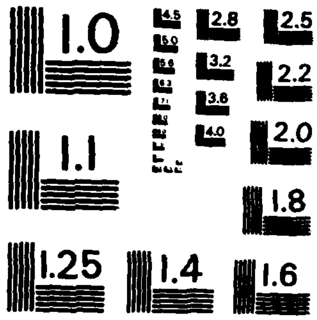

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Report EW-20-83

BENDING FATIGUE OF A PARTICULATE SiC/ Al 6061 METAL MATRIX COMPOSITE

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Fatigue, bending fatigue, metal matrix composite, SiC particulate

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The bending fatigue behavior of 20 volume percent SiC particulate reinforced Al 6061-T6 sheet was investigated. Improved mechanical properties and ductility in the material, as compared to past results and Al 6061-T6 sheet, provided higher fatigue resistance. Low cycle fatigue specimens failed immediately after crack initiation. High cycle fatigue specimens exhibited a coarse step morphology, but classic striations were not observed. The existence of crack propagation at lower stresses was not verified. Preliminary results suggest

that the fatigue resistance of particulate SiC reinforced/Al6061 composite exhibits orientation dependence. Also particulate SiC reinforced/ Al 6061 composite has less fatigue resistance than whisker reinforced material. Improvement in surface finish also needs to be made over presently available material.

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INTRODUCTION

In the past fifteen years, attention has been focused on developing silicon carbide reinforced aluminum composites. These composites generally have increased Young's modulus, increased ultimate and yield strengths, and decreased ductility with respect to the aluminum alloy from which they are compacted. Crowe and Hasson[1] published a study in which the corrosion fatigue behavior of silicon carbide particulate (SiCp)/Al 6061-T6 composite examined. Crowe and Hasson tested both lab air and salt ladenend moist air corrosive environments. They also tested the Al 6061-T6 aluminum alloy. However, even in lab air, the SiCp/Al 6061-T6 particulate composite did not show an significant improvement in fatigue resistance over Al 6061-T6 aluminum alloy.

This paper will examine the lab air fatigue behavior of more recent SiCp particulate/Al 6061-T6 composite. It will also compare this composite with the results of the previous study.

EXPERIMENTAL DETAILS

Materials.

The material tested in this study was manufactured by DWA Specialities, Inc., of Chatsworth, California. The material was a 6061-T6 aluminum with approximately 20 v/o SiC particulate. The SiC volume percent was determined from the ASTM B311[2] density method to be 23 v/o. The measured density was 2.81 gm/cc. The density values for SiC and Al 6061 which were used in a law of mixtures equation were 3.17[3] and 2.70[4] gm/cc, respectively. A SiC volume percent of 18.5 was also determined from the area fraction of micrographs, such as, in figure 1. The particulates were of irregular shape and ranged from 20μ long by 10μ thick to 5-10μ long by 3-4μ thick. The SiC was "blended" with -325 mesh commercially available inert gas atomized 6061 aluminum powders. It was formed by cold compaction, followed by hot pressing at temperatures above the solidus of the matrix alloy to form "as pressed" material. It was then warm rolled to form a 3.18 mm sheet. Typical microstructure is shown in figure 1. The mechanical properties are given in table 1 for the three plates from which the specimens were cut. Also the modulus of elasticity and ultimate tensile strength of the composite material reported by Crowe and Hasson are given.

Al 6061 is an aluminum alloy that contains in weight percent 0.6 Si, 0.28 Cu, 1.0 Mg and 0.2 Cr[5]. At 75°F the nominal 0.2% yield stress, ultimate tensile stress and percent elongation are 40 ksi, 45 ksi and 17, respectively[6]. For the material tested the Rockwell-B hardness was R_B 92.

The surface finish of the SiCp particulate/Al 6061 sheet is not as uniform as that of wrought Al 6061 sheet as shown in figure 2. Also opposite sides of the SiCp/Al particulate sheet differed as depicted in figures 2(b) and (c). These irregularities in the surface could lead to poor fatigue resistance.

Procedures.

The L-S orientation[7] specimens were tested in completely reversed bending at 30 Hz. Alternating stress levels of 1/3, 1/2, and 2/3 UTS were selected for each of the three plate materials. The lab air environment was 74°F and 52% relative humidity.

In order to compare the present and past data[1] the linear regression method was selected. Slope, intercept and correlation coefficients were calculated for the alternating stress in ksi versus Log N (number of cycles to failure) plots.

Scanning electron microscope (SEM) fractography was performed on selected specimens.

RESULTS AND DISCUSSION

Fatigue Properties

The alternating stress versus number of cycles to failure data for the three SiCp/Al particulate composite plates from the present study are given in table 2. Also given are the correlation coefficient, r; the intercept, v; and the slope. The data for the lower UTS plate from Crowe and Hasson[1] are given in table 3. Also from reference 1, the data for Al 6061-T6 sheet are given in table 4. All these results are plotted in figure 3.

The data show that the improved mechanical properties of the present composite sheets give superior fatigue resistance compared to the plate tested by Crowe and Hasson[1] and Al 6061-T6 sheet. The mechanical properties of the present materials also have higher ductility as indicated in table 1. High mechanical properties along with improved ductility, therefore, are required to obtain improved fatigue resistance in the SiCp/Al particulate composites.

Some tests on T-S orientation specimens at an alternating stresses of 30,28.7 and 19.9 ksi gave values of 0.08, 0.05 and 2.75 x 10^5 cycles to failure,resspectively. These transverse orientation results indicate a significant decrease in fatigue resistance compared to the L-S orientation. These results suggest that the material is orientation dependent.

Comparison of the present data for particulate SiC reinforced composite with SiC whisker reinforced composite data from reference 1 indicates that the particulate composite has less fatigue resistance. The less favorable fatigue properties of the particulate reinforced composite could be due to the coarseness and non-uniform size distribution of the SiC particles as compared to the finer and more uniform distributed whiskers. Surface finish variations, as shown in figure 2, could also contribute to this difference.

Fractography

The SEM fractography for low and high cycle fatigue specimens are given in figures 4 and 5, respectively. The fracture morphology for the low cycle fatigue specimen shown in figure 4, shows microvoid coalescence near the surface and at the interior of the specimen. There were no striations. The cycles to failure, therefore, represent primarily crack initiation.

The fracture morphology for the high cycle fatigue specimen, shown in figure 5, reveals a coarse stepped structure. This type of structure was previously observed by Crowe and Hasson[1]. These steps are certainly not classic striations[8]. Striations were not imageable on or between these steps. As to whether there was crack propagation in the high cycle fatigue samples still has not been determined.

CONCLUSIONS

The following observations were made:

1. Improved mechanical properties and ductility in SiCp/Al 6061-T6 composite material yields higher fatigue resistance than Al 6061-T6 sheet.

2. Low cycle fatigue specimens failed immediately after crack initiation.

3. High cycle fatigue specimens exhibited a coarse step morphology, but classic striations were not observed. The existence of crack propagation at lower stresses was not verified.

4. Preliminiary results suggests that the fatigue resistance of particulate SiC reinforced/Al 6061 composite exhibits orientation dependence.

5. Particulate SiC reinforced Al 6061 composite has less fatigue resistance than whisker reinforced material.

6. Improvement in surface finish needs to be made over presently available material.

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Table 1. Mechanical Properties of Al 6061-T6/SiC Particulate Composite Materials

Composite	E(msi)	UTS(ksi)	0.2% YP(ksi)	% Elong	R_B
Plate 1	14.58	60	51.3	3.9	78.8
Plate 2	14.79	59.6	52.1	2.3	--
Plate 3	14.50	57.4	50.9	1.7	74.4
Reference 1	13.28	41.5	--	-	--

Table 2. Alternating Stress (σ_a) Verus Number of Cycles to Failure for Al 6061-T6/SiC Particulate Composite

Specimen #	σ_a(ksi)	%UTS	N(k cycles)	Log N	Composite
74	40	2/3	24	4.3802112	
77	40	2/3	23	4.3617278	
76	30	1/2	145	5.161368	
79	30	1/2	142	5.1522883	
75	20	1/3	2554.5	6.4073059	plate #1
78**	20	1/3	23321.5	7.3677565	
80	20	1/3	22748***	7.3569432	
81	38.81	.65	21	4.3222193	
84	39.73	2/3	17	4.2304489	
82	29.8	1/2	186	5.2695129	
85	29.8	1/2	150	5.1760913	plate #2
86	19.87	1/3	24837***	7.1713461	
83	19.87	1/3	23857***	7.3776158	
89	38.27	2/3	32	4.50515	
88	38.27	2/3	29	4.462398	
87	28.7	1/2	369	5.5670264	
90	28.7	1/2	189	5.2764618	plate #3
91	19.13	1/3	23292***	7.3672068	
92	19.13	1/3	23274***	7.366871	

r = 0.9662301 y-intercept = 65.261688 slope = 6.3713741

*Alternating stress $(\sigma_{max} - \sigma_{min})/2$
**Specimen failed at specimen grip
***Indicates no fracture. Still in runout.

Table 3. Alternating (σ_a) Versus Number of Cycles to Failue for Al 6061-T6/SiC Composite Data from Crowe and Hasson[1]

σ_a(ksi)	%UTS	N(k cycles)	Log N
27.708	2/3	18	4.2552725
27.708	2/3	16	4.20412
27.708	2/3	22	4.3424227
20.781	1/2	465	5.667453
20.781	1/2	389	5.5899496
20.781	1/2	334	5.5237465
13.854	1/3	20572	7.3132765
13.854	1/3	15481	7.189799

r = .9963446 y-intercept = 47.261818 slope = -4.648173

Table 4. Alternating Stress (σ_a) Versus Number of Cycles to Failure for Al 6061-T6 Sheet from Crowe and Hasson[1]

σ_a(ksi)	%UTS	N(k cycles)	Log N
30	2/3	66	4.8195439
30	2/3	80	4.90309
30	2/3	47.5	4.6766936
30	2/3	58	4.763428
30	2/3	47	4.6720979
30	2/3	48	4.6812412
22.5	1/2	334	5.5237465
22.5	1/2	288	4.4593925
30	2/3	49	4.6901961
22.5	1/2	139	5.1430148
22.5	1/2	207	5.3159703
22.5	1/2	235	5.3710679
15	1/3	1.949×10^3	6.2898118
15	1/3	7799	6.8920389

r = -.951994 y-intercept = 67.132172 slope = -8.027027

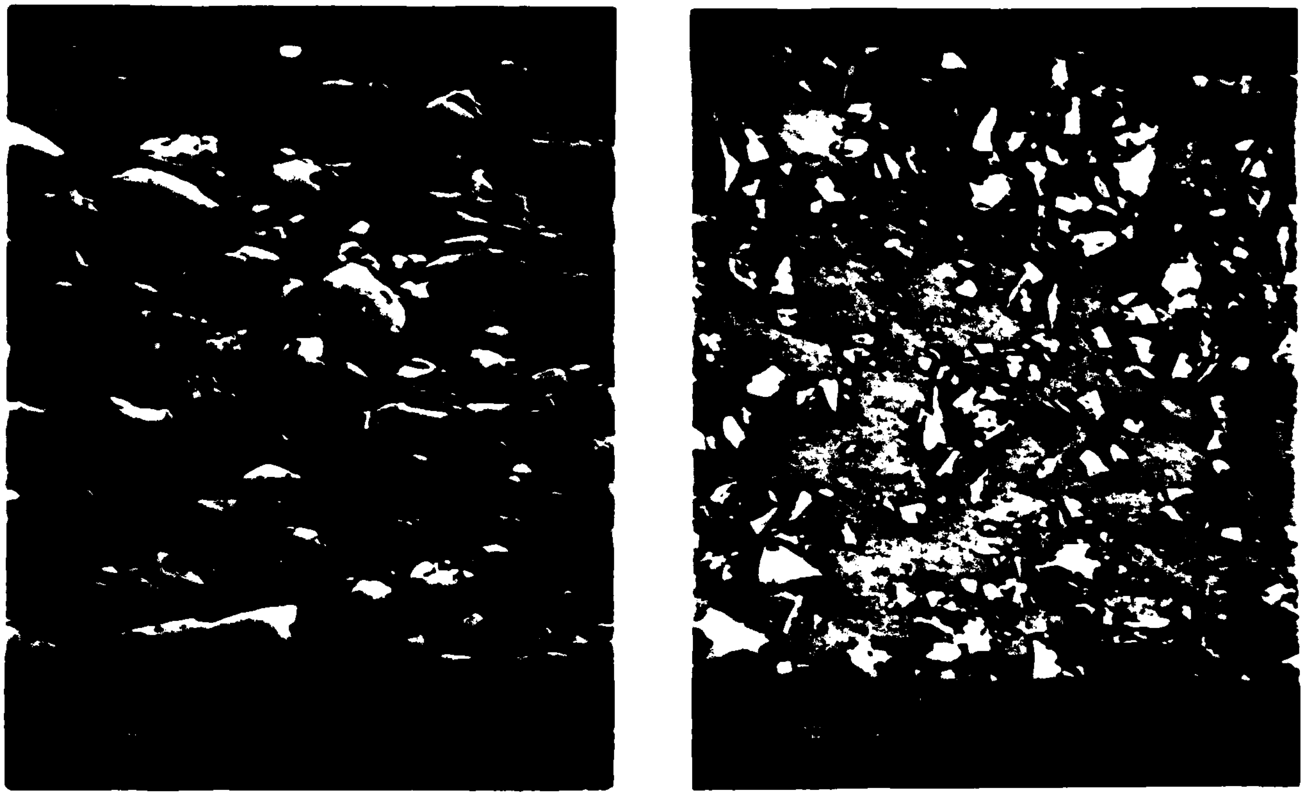
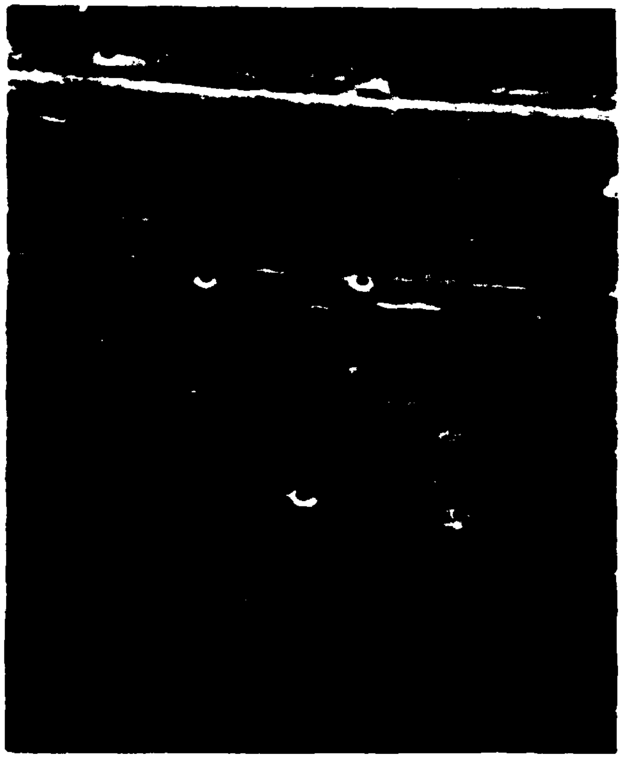
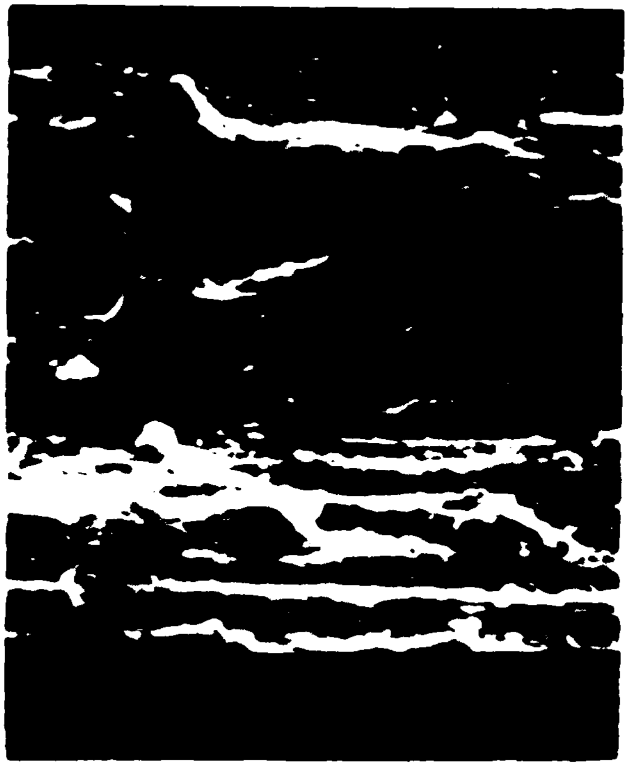


FIGURE 1. POLISHED SURFACE OF Al/SiC PARTICULATE, SPECIMEN # 91 FROM PLATE 3 (800X)



(a) Al 6061-T6



(b) Al/SiC - SPECIMEN # 91, PLATE 3

(c) Al/SiC - SPECIMEN # 91, PLATE 3
OPPOSITE SIDE

FIGURE 2. SURFACES OF Al 6061-T6 AND Al/SiC PARTICULATE SHEETS

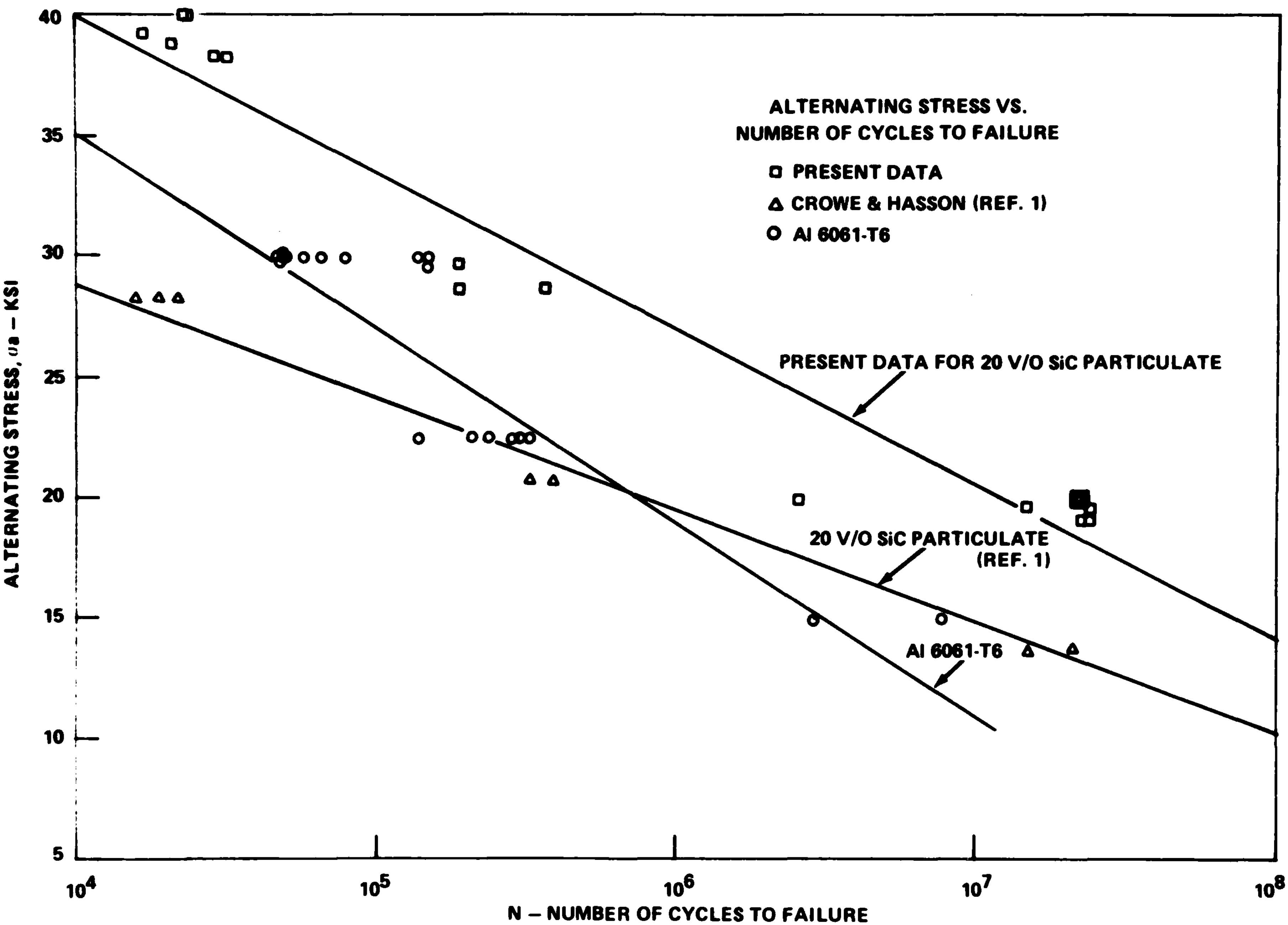


FIGURE 3. ALTERNATING STRESS VERSUS NUMBER OF CYCLES TO FAILURE FOR Al 6061-T6/SiC PARTICULATE COMPOSITES AND Al 6061-T6 SHEETS

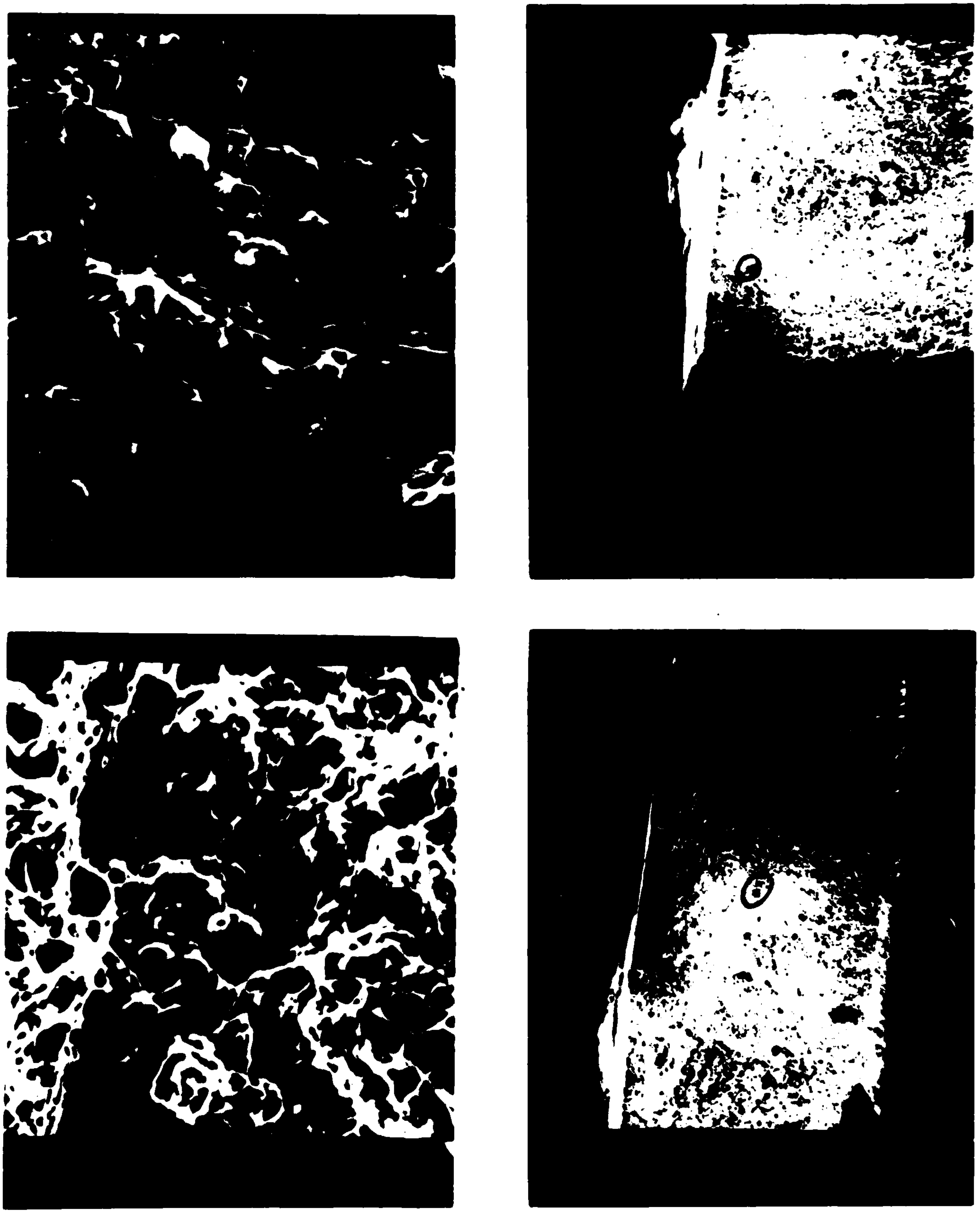


FIGURE 4. MICROGRAPHS ON LEFT SHOW FRACTURE SURFACE OF SPECIMEN # 84, 17 K CYCLES TO FAILURE, AT 800X. PICTURES ON RIGHT SHOWS ORIENTATION AND POSITION AT 10X.

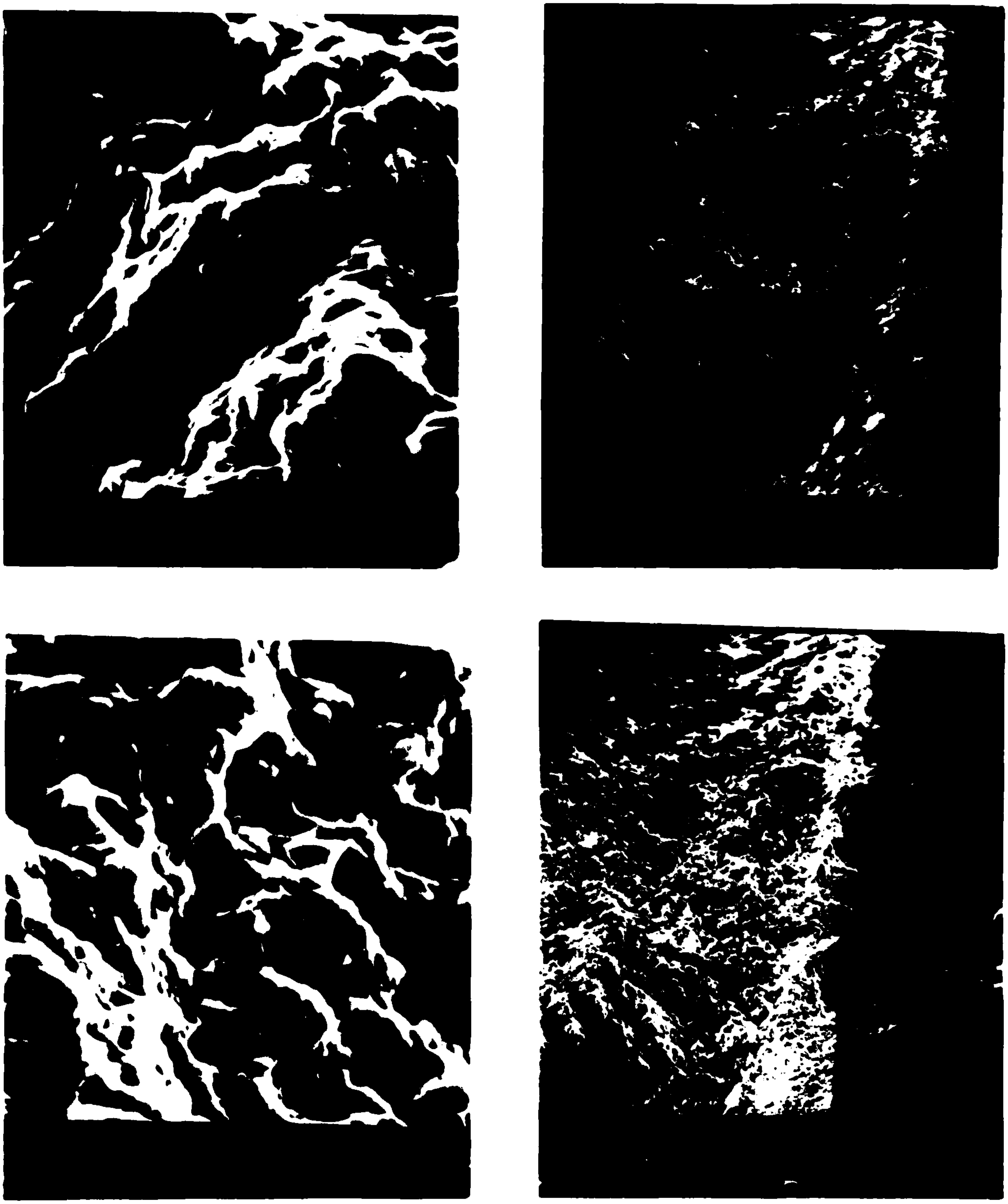


FIGURE 5. SEM MICROGRAPHS AT 800X (LEFT) SHOW FRACTURE SURFACE OF = 78 (23322 K CYCLES), PICTURES AT 10X (RIGHT) SHOWS ORIENTATION AND LOCATION OF SEM MICROGRAPH ON LEFT.

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