CRACK INITIATION AND EARLY CRACK GROWTH IN LOW CYCLE FATIGUE OF ANODIZED 2024 ALUMINIUM ALLOY

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INTRODUCTION

In general docementation of fatigue-crack nucleation has been accomplished through a number of direction experimental observations. Most of the data generated from such experimental observations have emphasized that there are three types of nucleation sites (1):

1. Fatigue slip band
2. Grain boundaries
3. Second phase particles.

It is worth noting that most of these observations were obtained from experiments conducted on pure metals or commercial alloys in tension-tension, tension-compression and reverse bending fatigue conditions (2-5). The objective of the present work is to document the preferential sites for fatigue crack nucleation in 2024 aluminium alloy at a high stress level, i.e. under condition described as low-cycle fatigue by applying the rotating bending-fatigue condition.

EXPERIMENTAL DETAILS

Fatigue specimens were fabricated from 2024-T4 aluminium bar stock according to the standard specifications of rotating bending fatigue samples. The chemical composition of 2024 aluminium alloy is 93.4% Al, 4.5% Cu, 0,6% Mn and 1.5% Mg.

Two sets of specimens were solution annealed at 515.5 C° for 60 minutes then water quenched. Thereafter, one set of the specimens was aged at 204.4 C° and the other set aged at 260 C° for 10 hours (these conditions will be referred to as T71 and T72, respectively) to produce overaged, stable microstructures. A third set of machined specimens was used without heat treatment, i.e. in the as-received T4 (naturally aged) condition.

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The surface of the fatigue specimens were polished and electropolished.

The tensile properties of the three heat treated conditions of the alloy are given in Table I. In addition the S-N curves are plotted in Figure 1. The loading condition was completely reversed cyclic loading, i.e., the fatigue stress ratio R = -1.

Fatigue crack nucleation was investigated by cyclic loading at a stress amplitude corresponting to 90 percent of yield strength and periodically interrupting the test to examine the specimen surface. The stress levels used were 370 MPa (T4), 304 MPa (T71) and 207 MPa (T72). The cyclic frequency was 5 Hz. Note that at 90 percent of yeld strength the fatigue lifes of the three conditions (T4, T71 and T72) are equivalent to 29,900 cycles, 16,200 cycles and 9,400 cycles, respectively (see Figure 1).

The specimen surface was examined in an ETEC scanning electron microscope.The aim of the SEM examinations was to record any microstructural irregularities that might form at the sample surface. The SEM examinations were performed at an intervals of cyclic loading. The intervals of cyclic loading were began with 820,410 and 170 cycles for T4, T71, T72 specimens respectively.

The SEM examinations were performed at intervals for all the heat treated conditions until the first microcracks were detected at 22 (T4), 20.8 (T71) and 14 (T72) percent of accumulated fatigue life. Prior to the detection of the microcracks, some microstructural irregularities were observed at earlier stages of fatigue life on the anodized surface of all conditions of the alloy. Significant features of the microstructural irregularities were photographed.

After documenting the first microcracks, the SEM examinations were carried out periodically for larger increments of cyclic loading until final rupture occurred. The interval of cyclic loading were increased to 6,570; 3,340; 1,390 cycles for the T4, T71 and T72 specimens, respectively. The purpose of SEM examinations at these larger intervals was primarely to document the development of microcracks to macrocracks and eventually the processes leading to the final rupture.

RESULTS AND DISCUSSION

Qualitative and quantitative results of the fatigue crack nucleation of all conditions of 2024 aluminium alloy based on SEM examinations and number of cycles are presented in Table I.

TABLE I

TENSILE PROPERTIES AND COMPARISON BETWEEN RESULTS IN 2024 ALLOY

	HEAT TREATMENT CONDITIONS		
	T4	T71	T72
Yield strength (MPa)	410	338	292
Tensile strength (MPa)	520	392	357
Reduction of area (percent)	14,3	21	24
Fatigue life at 90 % of yield strength (N cycles)	29,920	16,210	9,440
First cycle increment (N cycles) % of fatigue life	820 cycles 2.75 %	410 cycles 2.6 %	170 cycles 1.84 %
First observation of surface damage (N cycles) % of fatigue life	1,640 5.5 %	830 5.2 %	340 3.7 %
First crack initiation (N cycles) % of fatigue life	6,570 22 %	3,340 20.8 %	1,390 14.7 %
Second cycle increment until failure (N cycles)	6,570 22 %	3,340 20.8 %	1,390 14.7 %
Sites of first surface damage	a crazed oxide film at the surface of inclusions	a crazed oxide film at the surface of precipitate clusters	a crazed oxide film at the surface of precipitate clusters
Sites of fatigue microcrack nucleation	inclusions	precipitate clusters	precipitate clusters and grain boundaries

Illustrations 2, 3, 4, 5 are some examples of the documentation of the early surface damage and fatigue crack initiation in all conditions of heat treatment. Refer to these illustrations for more details.

CONCLUSIONS:

A number of conclusions can be drawn from this study:

1. Fatigue crack nucleation is strongly influenced by the strength of the alloy as determined by the heat treatment. The higher the strength the greater is the number of cycles for nucleation of fatigue cracks. However, in terms of percentage of fatigue life, i.e., cycles to failure, nucleation occurs at a constant percentage.
2. Crazed oxide layers at the surface of the second phase particles such as inclusions and precipitates are the first surface damages in all conditions of the alloy.
3. Second phase particles, such as inclusions and precipitates, are the preferential sites for crack nucleation in all the three conditions of the alloy.
4. Microcrack nucleation associated with grain boundaries was found in areas depleted from precipitates in 2024-T72 specimen.
5. The larger the size of the second phase particles the more susceptible they are to fracture.
6. In all the three heat treatment conditions, fatigue nucleated at a number of sites simultanuously, thereafter, microcracks extended in a direction approximately 45° with respect to the stress axis. A transition of the microcrack propagation from 45° to 90° orientation with respect to the stress axis was observed at above 50 percent of fatigue life.
7. The fracture surface for all the three heat treatment conditions indicated that multiple origins of microcrack nucleation were produced during cyclic loading.

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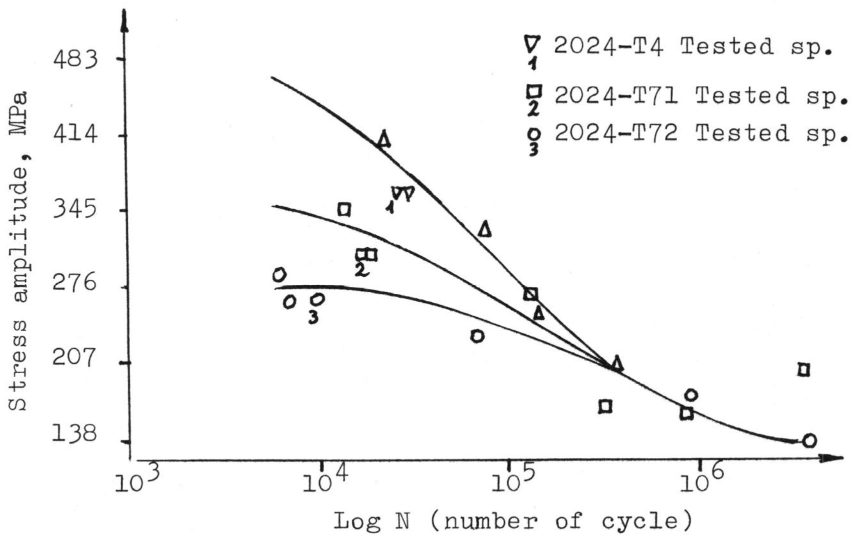

Figure 1 S-N fatigue curves for 2024 aluminium alloy in the three heat treatment conditions: T4, T71 and T72.

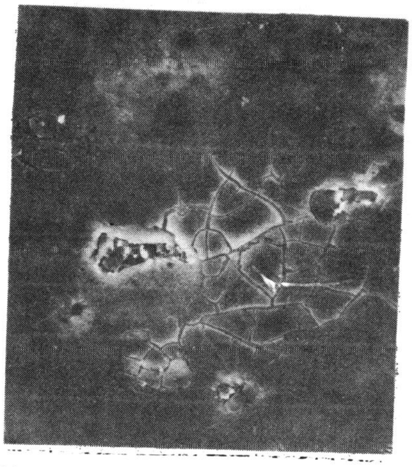

Figure 2 Some fracture inclusions interconnected by speading of the crazed oxide film in 2024-T4 specimen. 4930 cycles at stress amplitude= ± 370 MPa

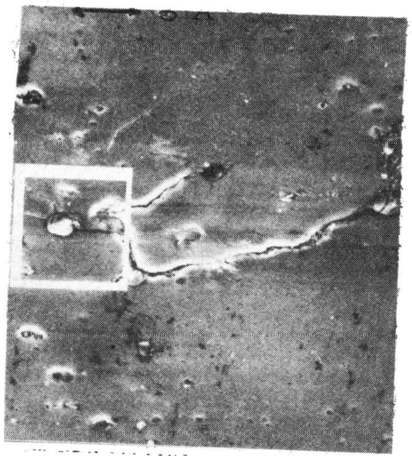

Figure 3 SEM photograph of microcracks emanated from inclusions in 2024-T4 specimen. 6580 cycles at stress amplitude = ± 370 MPa.

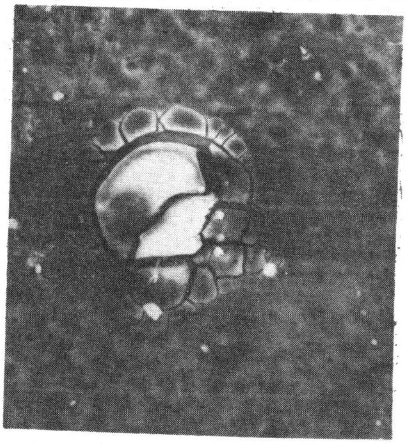

Figure 4 Crazed oxide film at the surface of the precipitate cluster in 2024-T71 specimen. 830 cycles at stress amplitude = ± 304 MPa

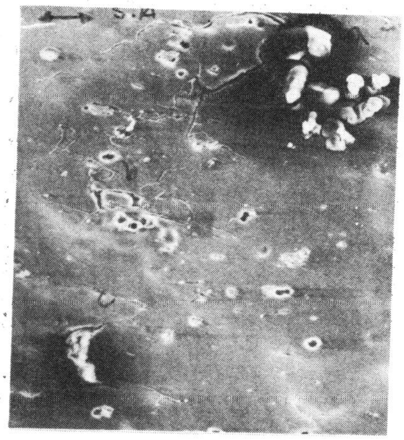

Figure 5 A general view of different sites of crack nucleation in 2024-T71 specimen. 3340 cycles at stress amplitude = ± 304 MPa. M = 200x