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The surface treatment influence on the fatigue crack propagation of Al 7050-T7451 alloy

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ABSTRACT

The objective of this research is to evaluate 100 μm thickness hard chromium electroplated coating on the fatigue crack propagation of Al 7050-T7451 alloy. The shot peening process was carried out to create residual stresses using ceramic and glass shots. Reverse bending fatigue tests were performed with base material, base material chromium electroplated and base material shot peened and chromium electroplated. In order to study the influence of residual stresses on fatigue life, the compressive residual stress field was measured by an X-ray diffraction method. Scanning electron microscopy technique was used to analyze fracture surface and identify crack origin sites. Glass shot peening results are better with respect to fatigue crack nucleation and propagation in comparison to ceramic shot peening. An overpeening may have occurred which produced damages on the ceramic shot peened surface.

1. Introduction

Materials surface damages, which result from environmental interactions, are responsible for failures of structural components during service. The surface treatment of hard chromium electroplating on steel has been extensively used in the aerospace, automotive and petrochemical fields, to control wear and corrosion of mechanical parts. The negative influence of chromium coatings on the fatigue strength is attributed to high residual tensile stresses and microcracks density from electroplating [1]. These stresses generation mechanism in the hard chromium coating is attributed to inclusion by solid solution of oxygen and hydrogen co-deposited with chromium in the crystallographic lattice. Tensile stresses are released by microcracking that occurs during deposition process, when the cohesive strength of the last deposited layer is exceeded [2,3].

An important characteristic of chromium electroplating is that these high tensile residual internal stresses increase as coating thickness increases [4,5]. It was also observed that the chrome layer contraction during the electroplating process generates high equibiaxial tensile stresses in the coating and compressive stresses in the base material [6].

Normally fatigue cracks nucleation occurs on the specimen surface, influenced by aspects as residual stresses. The effect of the compressive residual stress zone on the crack initiation points is to push it beneath this region. Shot peening is an effective technique of surface treatment in engineering components widely used for the introduction of residual stresses and improving the fatigue strength. This is particularly the case of the aeronautical industry where structural components from high strength alloys are shot peened in accordance with their specific requirements [7,8].

Increase in fatigue life due to the shot peening process is associated to compressive residual stresses induced in the surface and subsurface layers. The surrounding elastic material, on attempting to return the yield surface to its initial shape, creates residual compressive stress field within the cold work-hardened surface layer [9]. Surface roughening, strain hardening and residual stresses are surface modifications produced by shot peening [10]. On the other hand, surface damage produced by the shot peening process during overpeening may result in fatigue failures [11,12]. The shot peening intensity that produces best results in fatigue life is influenced by the relaxation of induced compressive stresses during the fatigue process, by surface conditions created by shot peening and the possibility of the compressive residual stress field to push the crack source beneath the surface [13]. The objective of this paper is to evaluate the shot peening influence on the fatigue crack propagation of aluminum 7050-T7451 alloy chromium electroplated. The shot peening process was carried out to create residual stresses using ceramic and glass shots. To understand the superposition effect from shot peening and chromium electroplating processes,

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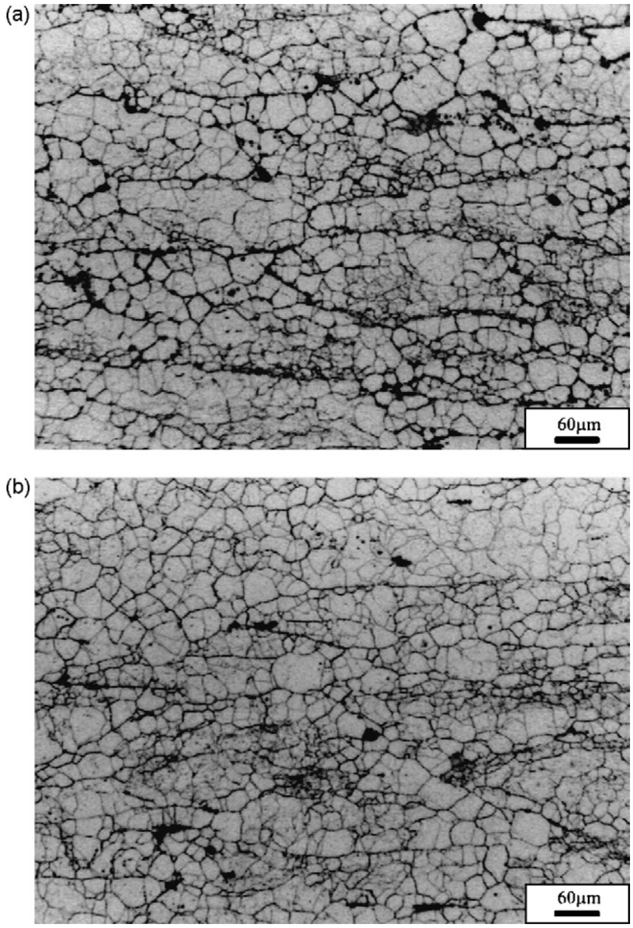

Fig. 1. Typical microstructure of the partially recrystallized regions that are course grains surrounded by finer grains that consist in the equiaxed grain population, (a) longitudinal and (b) transversal directions. Both samples have been etched with phosphoric reagent.

the behavior of compressive residual stress field and the crack initiation points of tested specimens were studied.

2. Experimental procedures

The material used in this investigation was a plate of 7050-T7451 aluminum alloy. The chemical composition is (in wt%): 6.06% Zn; 2.19% Cu, 1.90% Mg; 0.15% Zr; 0.10% Mn; 0.04% Cr; 0.12% Si; 0.14% Fe: 0.06% Ti. Mechanical properties obtained from tensile tests were: elastic modulus 63 and 69 GPa, yield stress 429 and 439 MPa, ultimate tensile strength 502 and 504 MPa and elongation 10% and 12% in the longitudinal (L) and transversal (T) to the rolling plane directions, respectively. Analysis by light microscopy revealed microstructure (Fig. 1) of the partially recrystallized regions that are course grains surrounded by finer grains that consist in the equiaxed grain population and uniformly distributed fine precipitates of η and η', that lead to precipitation hardening [14]. Aluminum alloy specimens were grinder machining to obtain a final thickness $t = 4.0$ mm which have represented surface roughness equal to 0.89 ± 0.32 μm.

2.1. Shot peening

The fatigue tests were obtained for the aluminum alloy treated with two intensities of shot peening: 0.022N (35 psi) and 0.013N (30 psi), using ceramic and glass shots, respectively. The shot used was (Ø 0.4 mm) with coverage of 120% for both conditions and carried out on an air-blast machine according to standard MIL–S–13165. The shot peening treatment was performed with high quality control, in which the shots were automatically selected and kept in perfect conditions.

2.2. Hard chromium electroplating

The hard chromium electroplating process was carried out from a chromic acid solution with CrO_3 and H_2SO_4, and H_2O, at 55–60 °C, with a current density from 34 to 46.5 A/dm^2, and a speed of deposition of 30–50 μm/h. To increase adherence on the surface specimens, a bath double of zincates was applied before the electroplating process. The hard chromium coating was deposited with a 100 μm thickness on the surface of the base material. Average surface roughness for chromium electroplated, ceramic shot and glass shot peening were Ra = 4.25 ± 1.25 μm, Ra = 4.65 ± 0.51 μm and Ra = 2.35 ± 0.76 μm, respectively.

2.3. Residual stress measurement

The compressive residual stress field induced by shot peening and chromium electroplating was determined by X-ray diffraction method using the Raystress equipment, whose characteristics are described in [15]: Ψ goniometer geometer, Cr Kα radiation and registration of diffraction plane was {2 2 2} and {2 2 1} for aluminum and hard chromium, respectively. The accuracy of stress measurement was $\Delta\sigma = \pm 20$ MPa. In order to obtain the stress distribution by depth, layers of specimens were removed by electrolytic polishing with a non-acid solution. Scanning electron microscopy LEO 1450 V P was used to perform fracture surface analysis.

2.4. Fatigue crack propagation tests

The fatigue crack propagation tests were performed in reverse bending, using a sinusoidal load of frequency 25 Hz, at room temperature, in a Shenck PWS fatigue testing machine, using specimens as shown in Fig. 2. For all conditions studied were obtained by results from two to three bending fatigue specimens. The crack growth was detected using a video system transformed into digital images and measured using an image analysis system. The initial detectable crack length, a, was 0.39 mm. The ratio between initial crack length and the reverse bending fatigue specimen width was 1.95%, according to Fig. 2. Considering that the fatigue crack propagation on specimen surface were measured as a function of the number of cycles, until fracture, this means that 98.5% of this dimension will be studied with respect to the influence of the shot peening process and chromium electroplating on the fatigue crack propagation. In all experimental tests, a stress ratio (R) of approximately −0.85, was used to ensure that cracking occurred on the upper surface of the specimen to guarantee detection by the video system. Namely, stress ratio has been obtained with specimen displacement up, using tampers on the clamp base which specimens were clamped. Experimental data was presented through curves crack growth versus number of cycles (axN_f) and crack growth versus the ratio N_{ip}/N_f, in which N_{ip} and N_f correspond to the number of cycles to achieve $a = 0.39$ mm (N_{ip}) and number of cycles until fracture (N_f), respectively. The following conditions were tested:

- Base material in the longitudinal and transversal directions, BML and BMT;
- Base material in the longitudinal direction, chromium electroplated BML + Cr;