EFFECT OF SHOT PEENING ON THE FATIGUE ENDURANCE AND FATIGUE CRACK GROWTH RATE OF 7050 & 7075 ALUMINUM ALLOYS

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ABSTRACT

The purpose of this investigation is to support the Federal Aviation Administration (FAA) in developing a better understanding of residual stress effects for high cycle fatigue in rotorcraft applications. Though the investigation of short fatigue crack behavior in metals have been the subject of considerable interest there are however very few studies that have been dedicated to the problem of crack growth in shot peened material. During this investigation the fatigue crack growth rates of short cracks embedded in the region of residual compressive stresses will be determined. This would help in quantifying the effectiveness of the shot peening process, and also the effect of different coverage levels and intensities on the fatigue crack growth rates of the 7050-T7451 and 7075- T7351 aluminum alloys. The depth of the compressive stresses in the shot peened aluminum alloys is less than 0.010 inches, the maximum value of the compressive stresses are in the depth range of 0.0020 ~0.0030 inches. Specimens with initial cracks smaller than 0.0010 inches will be tested to determine the crack growth rates of the peened material. Post failure analysis of the fracture surfaces will also be conducted using a scanning electron microscope, to determine the mode of crack propagation. This will help in further quantifying the effects of shot peening on the crack growth in the peened aluminum alloys.

1 INTRODUCTION

Shot peening is a cold working process in which the surface of a part is bombarded with small spherical media called shots. Every shot striking the material acts as a tiny peening hammer, imparting to the surface a small indentation or dimple. In order for the dimple to be created, the surface fibers of the material must be yielded in tension. Below the surface, the fibers try to restore the surface to its original shape, thereby producing below the dimple, a hemisphere of cold-worked material that is highly stressed in compression. Overlapping dimples develop an even layer of metal that is in a state of residual compressive stress. Shot peeing has proved to be an efficient surface treatment for enhancing the service life of a wide variety of structural and functional elements. Fuchs [1] and several other researchers have reported that the values of the compressive stresses are at least as high as 50% of the ultimate strength of the material.

In the open literature there seem to be very few articles that provide the da/dN versus ΔK results for shot peened materials. Kocańda [2] suggested that this is probably due to the fact that the observation of short crack initiation and propagation in a heavily deformed surface layer is very difficult to monitor. This investigation will focus on the fatigue crack growth rates of short cracks in the shot peened aluminum alloys.

The plastic deformations produced by the peening changes the internal structures of the deformed grains. Therefore a post-fracture analysis of the specimens is required to quantify the effects of shot peening on the growth of the short cracks.

2 BODY OF PAPER

To assess the effects of shot peening on crack growth and fatigue characteristics, constant amplitude tests are being conducted on test specimens fabricated from the 7050-T7451 and 7075-T7351 aluminum alloys. The material was obtained from Alcoa in the form of 0.25-inch thick sheets.

2.1 MATERIAL AND TEST SPECIMENS

Two specimen's types are being machined. Specimens with an hourglass shape, of $K_t \sim 1.0$, with the minimum width of 1.0 inch and length of 8 inches. These specimens are then surface ground to produce flat parallel surfaces with a tolerance lower than 0.0010 inches. To simulate a machining flaw a scratch will be machined through the width of the specimen. The depth of the scratch will be kept to less than 0.0010 inches, to ensure crack growth from within the residual stress field.

To produce specimens with short cracks several specimen geometries proposed by Suresh [3] were prospected, some of the geometries are not practical because of the requirement of shot peening. The method being employed for producing specimens with small cracks is by removing the wake material from long through cracks. This would result in specimens with a crack of predetermined length. The short through-crack fronts must necessarily sample many grain unlike the micro-structurally small crack whose plastic zone is less than the grain size. To account for this difference in the crack types the double edge notched specimen geometry used by Everett [4], is also going to be used with some differences to provide specimens with an initial crack size to be less than 0.0010 inches.

2.2 METHODOLGY

Constant Amplitude testing at an R-ratio of 0.5 is being conducted for both the hourglass and single edge eccentrically loaded ESE(t) specimens. The ESE(t) coupons are being tested at frequency of 20 hertz to produce specimen with cracks less than 0.080 inches (2.0 mm). The hourglass coupons are to be tested at frequency of 5 Hz till a crack is detected and then at a frequency of 2 Hz, so that the crack mouth opening displacement can be measured using a laser extensometer.

The cracks in the ESE(t) specimens are being initiated in the specimens using low values of K_{max}. The value of K_{max} being used to initiate the cracks is 6.0 Ksi-in$^{0.5}$ (ΔK of 3.0 Ksi-in$^{0.5}$), this is being done in order to minimize the crack closure stresses on the crack tip of the specimens. Since after machining the wake the closure load on the cracks could be substantial. The specimens with the short cracks will then be heat treated at a temperature for a specified time. This will be done such that they do not lose their temper but some of the residual stresses are relieved. The specimens are then to be shot peened to encompass the short crack in a zone of residual stresses.

The methodology to determine the Fatigue Crack Growth characteristics of the shot peened material are outlined in the following steps:

- Test ESE(t) specimens and create specimens with long cracks
- Machine (by surface grinding) the long crack specimens to produce small crack specimens 0.0010 inches (~ 0.25 mm) length
- Shot peen these specimens
- Conduct fatigue crack growth testing on these coupons

2.3 SHOT PEENING

The specimens are being shot peened at the Metals Improvement Company Inc. in Wellington Kansas. The peening process for the hourglass coupons and the short crack specimens is described in the following sections.

2.3.1 HOURGLASS COUPONS

Shot peening was conducted on some of the hourglass coupons according to the specifications of AMS-S-13165. The intensity of the peening was 0.077~0.078A on the Almen strip.. Cast steel shots with a diameter of – 230R were used for the process. These specimens had a surface scratch which is ~ 0.010 inch deep. The SEM micrographs in Figures 1 and 2 show the 7050-T7451 aluminum specimens with peening coverage of 100 and 200% coverage. The specimen were analyzed to determine the residual stress profile using the X-ray diffraction technique and the respective profiles of the two coverage levels are shown in Figure 3.

2.3.2 SHORT CRACK COUPON

The short crack specimens will be shot peened at two locations. The edge containing the short crack will be shot peened so that the crack is embedded in the residual stress field. The specimens will also be shot peened on the front and back surfaces such that there is a zone on the surface of the specimens which is unpeened. This will allow the crack to emerge from the residual stress field caused by the peening of the edge and grow for a length of 0.20 ~ 0.25 inches in a zone free of compressive residual stresses (tensile residual stresses will be present). The crack will then again encounter another region of residual stresses caused by peening of the two surfaces.

The crack length of the specimens will be monitored using the ACPD equipment, and a traveling microscope (maximum resolution of 300X).

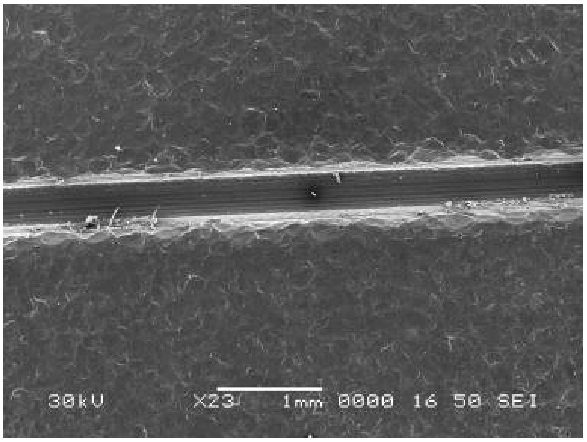

Figure 1: Al 7050-T7451 Specimen 100% Coverage

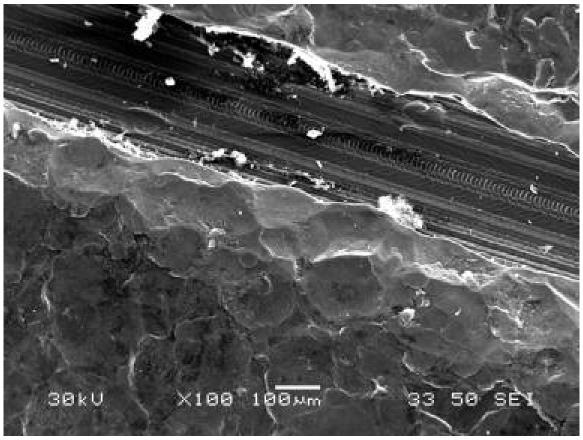

Figure 2: Al 7050-T7451 Specimen 200% Coverage

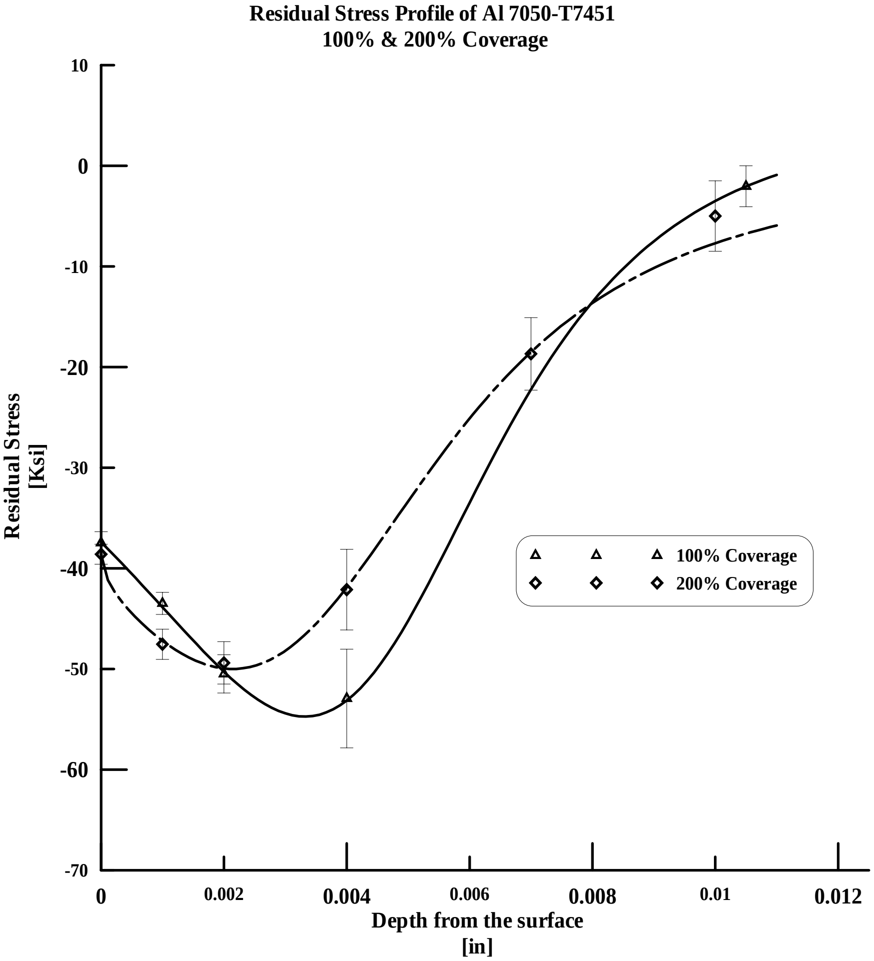

Figure 3: Residual Stress Profile of the Shot Peened 7050–T7451 Aluminum

2.4 FRACTOGRAPHIC ANALYSIS

Fractography is the descriptive analysis of the topographic features of fracture surfaces for the purpose of identifying the paths followed by the cracks as they propagate through the material during the fracture process. An important element of fractographic analysis is the identification of how the fracture path or mode is influenced by the microconstituents of the material such as inclusions and the microstructure of the material itself. Understanding the influence of shot peening on the fracture mode is central to any investigation of how this process may best serve to improve fatigue resistance of the material.

The shot peening process can modify the topography of the fracture surface at the crack initiation site. Turnbull [5] suggested that this was most likely caused by the distortion that the grain structure experienced due to the surface deformation as a result of shot peening. Features and evidence such as one described above need to be identified for the two aluminum alloys as this would help in better quantifying the effectiveness of shot peening.

2.5 CONCLUDING REMARKS

The investigation of short cracks and its interaction with the residual stress field is currently in the preliminary stage. Hourglass coupons are being fabricated. ESE(t) specimens are being tested to produce specimens with cracks of ~ 0.08 inches. Several problems have been encountered and some of them have been resolved and further work is underway.

3 REFERENCES

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