Relaxation of compressive residual stress. Part 1: Relaxation of stage I

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In this study, 2024-T351 aluminum alloy specimens were shot peened into three shot peening intensities condition to induce compressive residual stresses (RSs). Fatigue test was performed for the first and second cyclic load. Initial RSs at initial condition and after first and second cycle of fatigue loading were measured using X-ray diffraction method. Relaxation for first cycle was found to reach over 40% of initial RS and it depended on load amplitude.

Keywords: Residual stress, Residual stress relaxation, Shot peening, X-ray diffraction

Introduction

Heavier materials (steel or copper) are being replaced with aluminum alloys due to high strength and stiffness to weight ratio, excellent corrosion resistance, good formability, weld-ability and recycling potential for applications in aerospace and automotive. Residual stresses (RSs) exist in a structural component prior application of external forces. Beneficial compressive RSs can be added to structural component by shot peening, laser peening, low plasticity burnishing, ultrasonic impact treatment and deep rolling to increase fatigue life. Shot peening is very simple and comparably cheap method to enhance fatigue life of metal and alloy, such as aluminum. Compressive RS reduces surface crack growth due to fatigue. Mechanical or thermal processes cause RS relaxation during component service. There have been several investigations about relaxation behavior of RS under only thermal exposure, static loading, cyclic loading, and thermo-mechanical loading conditions. During fatigue cyclic load, RS relaxation can be divided into two stages: i) relaxation due to surface yielding under initial cycles; and ii) gradual relaxation under subsequent cycles. In these stages, RS of shot peened specimens decrease considerably when compared to those with no fatigue cycles. Kodama measured RS relaxation of shot-peened specimens, using X-ray diffraction techniques, and proposed linear logarithmic decrease relationship between RS and load cycles only after the first cycle.

In present study, specimens of Al-2024-T351 alloy were subjected to three different shot peening intensities to get different magnitudes of initial RS. Relaxation of RS due to cyclic loading was investigated under first and second cycles. RS was measured by X-ray diffraction (XRD) technique before and after application of each loading cycle to investigate RS stability.

Materials and Methods

An aluminum alloy AA2024- T351 as plate (thickness, 6 mm; mean tensile strength, 484 MPa; yield strength, 348 MPa; elongation, 15%) was used for study. Chemical composition of AA2024-T351 is as follows: Al, 93.50; Fe, 0.50; Si, 0.50; Cr, 0.10; Mg, 1.20-1.80; Ti, 0.15; Cu, 3.80-4.90; Mn, 0.30-0.90; Zn, 0.25; Ni, 0.05; Pb, 0.05; Zr, 0.20%. Fatigue specimens were scaled in accordance with airbus standard (Fig. 1). Specimens were treated with three intensities of shot peening (0.0054A, 0.0067A and 0.0090A). Two stress levels (15.5 & 30 KN) were chosen for fatigue test. Cyclic load (0, 1, and 2 cycles) were applied to specimens for both stresses levels with three shot peening intensities. Specimens were tested in material testing machine Instron 810 with load ratio (R, 0.1) at frequency (30 Hz) under normal room temperature.
Residual Stress Measurement

RSs were measured in longitudinal direction at the center of gage length on width side at surface of specimens using XRD. Measurements were performed using a two-angle sine-squared-psi technique in accordance with SAE HS-784. Diffraction peak angular positions at each of psi tilts were determined from the position of K-alpha 1 diffraction peak separated from superimposed K-alpha doublet assuming a Pearson VII function diffraction peak profile in high back-reflection region. Samples were rocked through an angular range of ±1.5° around mean psi angles during measurement to integrate diffracted intensity over more grains to minimize influence of grain size. Details of diffractometer fixturing are as follows: incident beam divergence, 1.0°; detector, scintillation set for 90% acceptance of chromium K-alpha energy; psi rotation, 10 & 50°; and irradiated area, 5.1 mm × 5.1 mm. Value of x-ray elastic constant, $E/(1+\nu)$, required to calculate macroscopic RS from measured strain was determined empirically on a simple rectangular beam manufactured from 2024-T351 aluminum alloy loaded in four-point bending on diffractometer under known stress levels.

Results and Discussion

Initial RS for three shot peening intensities was measured using XRD. Shot peening intensities introduced RS in specimens as follows: 0.009 A, -196±13.5 MPa; 0.0067 A, -179±12.5 MPa; and 0.0054 A, -168±12.8 MPa. Shot peening has been found to improve fatigue life of specimens (Fig. 2). Higher shot peening intensity introduced higher compressive RS. Shot peened specimens used for S-N curve was peened to the intensity of 0.0054 A, which introduced lowest RS. Other intensities had same effects on fatigue life since RS introduced was higher than RS introduce by intensity of 0.0054 A.
For 15.5 KN load, reading of RS after first cycle showed relaxation (37% ± 5) of initial residual stress (IRS) in shot peening intensity of 0.0054A (Fig. 3). Relaxation of RS of shot peening intensity of 0.0067A was 35% ± 6 of IRS and for shot peening intensity of 0.0094A, RS relaxation was 34% ± 6 of IRS. After second cyclic load, RS of three shot peening intensities were continued to relax with a range of 2-3% increasing of first cycle relaxation. Relaxation of RS for 30 KN load, after first cycle reached 46% ± 7 of IRS for shot peening intensity of 0.0054A, 43% ± 6 of IRS for shot peening intensity of 0.0067A and 44% ± 6 of IRS for shot peening intensity of 0.009A (Fig. 4). After the second cycle load, the relaxation of the three shot peening intensities was continued to relax with a range of 2-3% increasing of the first cycle relaxation. Relaxation due to load of 30 KN showed greater relaxation than relaxation of 15.5 KN. Relaxation of RSs occurred within first loading cycles were increased with increasing loading stress amplitude and due to quasi-static relaxation effects.

Conclusions

Maximum relaxation (46% of IRS) for IRS after first cycle was found in the load 30 KN and shot peening intensity of 0.0054A. Minimum residual stress relaxation (34% of IRS) after first cycle was found in load 15.5 KN and shot peening intensity of 0.009A. Effect of high load is severe in low shot peening intensity. Relaxation of RSs occurred within first loading cycles were increasing with increasing loading stress amplitude and due to quasi-static relaxation effects.

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