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Influence of exposure to aggressive environment on fatigue behavior of a shot peened high strength aluminum alloy

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ABSTRACT

Pre-corrosion tests were performed on the high strength aluminum alloy 7050 in the T7451 temper that was subject to shot peening surface treatment. This was done for different time intervals and compared one-on-one with samples of the alloy that were not subjected to shot peening. The shot peening surface treatment was conducted for shot peening intensities of 0.006A and 0.008A. The pre-corrosion test specimens were subsequently subjected to fatigue loading and the resultant life was determined with the prime objective of establishing the intrinsic influence of damage due to corrosion on response of the alloy when subjected to cyclic loading. Fatigue fracture surfaces of the non-shot peened samples that were exposed to the environment and concomitant corrosion revealed crack initiation to occur at the pits. The overall fatigue life of the pre-corroded test specimens that were subject to shot peening was noticeably higher than the non-shot peened counterpart. An increase in shot peening intensity on the sample surface revealed an observable improvement in the fatigue life of this high strength aluminum alloy.

1. Introduction

Corrosion can be safely categorized as being a common and regular damage experienced by components and structures made from a spectrum of both medium- and high-strength aluminum alloys. This is especially true for those components and structures that are made from the 2XXX-series and 7XXX-series aluminum alloys. The observed degradation in material properties that occurs due to mutually interactive influences of cyclic stress and corrosion does affect the overall integrity and safety of the component and/or structure of interest. In recent years, few articles in the published literature have attempted to discuss the influence of corrosion-induced damage under natural conditions on: (i) fatigue life, (ii) residual strength, and (iii) performance of components and structures that are used in the aerospace industry [1–4]. These studies have convincingly shown that the onset and occurrence of corrosion-induced damage does degrade the life and/or endurance of an aircraft structure by as much as 40–60% under conditions of either constant amplitude or variable amplitude loading [5]. An assessment of the intrinsic influence of damage induced due to pre-corrosion on fatigue life of an aluminum alloy is the focus of this research study. In more recent years, the sustained need for innovations in engineering commensurate with advances in technological applications has provided the stimulus for noticeable advances in the manufacturing industry and related technologies. This has provided the much needed interest, inclination and impetus in use of the technique of shot peening as an economically affordable and viable surface treatment process to enhance the mechanical strength, toughness, wear resistance, fatigue resistance and even stress corrosion cracking resistance of an aluminum alloy [6–8].

Shot peening, which can be safely categorized as both an effective and efficient surface enhancement technique, has gradually grown in stature and strength to be chosen for use in a spectrum of applications in the industries spanning automobile, aerospace, marine and even daily house-hold goods. In essence, it is a cold working process that can be put to effective use to harden the surface of a metallic component by bombarding it with a stream of small particles called ‘shots’. By this process, a state of compressive residual stress is induced on the surface of the material. Potential benefits arising from the prudent and efficient use of shot peening can be attributed to a synergism of cold working and resultant compressive stresses induced on the surface. Compressive stresses have been found to be beneficial in increasing the resistance to fatigue failure, corrosion fatigue, stress–corrosion cracking, hydrogen-assisted cracking, fretting, galling, and even erosion induced by cavitation [9,10]. The salient benefits arising from cold working include the following: (a) work hardening, (b) improved resistance to intergranular corrosion,

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(c) closing or sealing of the fine pores, and (d) increasing the bond strength of components [11–14].

This paper deals with understanding the conjoint influence of corrosion and fatigue on the behavior of high strength aluminum alloy, a viable candidate for use in aircraft structures that see use over prolonged periods of time by the Navy of the Chinese military. This critical need provided the incentive for performing accelerated corrosion tests in the environment of laboratory air. When the aircraft are stationed or positioned on the aircraft carrier the specific influence of environment in promoting degradation due to corrosion of the materials used in the aircraft was the primary objective of this research study. Subsequent use of the aircraft following exposure of the material to the aggressive aqueous environment subjects the material to fatigue. Thus, the impetus for this study was to evaluate the conjoint influence of exposure to the environment, i.e., corrosion, and fatigue on behavior of the chosen high strength aluminum alloy. In the prevailing time period there have been only few studies devoted to investigating, understanding and rationalizing the influence of pre-corrosion on mechanical behavior of a shot peened aluminum alloy. The cyclic fatigue behavior of a corroded high strength aluminum alloy that has been subject to shot peening is the focus of this research study. In this research investigation, experiments were designed with both care and caution with the primary purpose of analyzing the influence of corrosion damage on fatigue life of shot peened aluminum alloy when subject to cyclic loading. To bring out the specific influence of shot peening on life or endurance of the component or structure, the fatigue behavior of this aluminum alloy is compared with the non-shot peened counterpart. Careful analysis of the experimental results helps in drawing useful conclusions on the specific influence of corrosion and shot peening on performance and life of the chosen high strength aluminum alloy 7050 in the T7451 condition.

2. Experimental procedures

2.1. Test specimen preparation

The material chosen for this experimental investigation was the high strength aluminum alloy 7050 in the T7451 temper. The alloy was provided by the Aluminum Company of America (ALCOA, USA). Nominal chemical composition of the as-provided material is given in Table 1. The uniaxial tensile properties of the alloy at ambient temperature (298 K) are: (i) tensile strength (σ_{UTS}) =510 MPa, (ii) Yield strength (σ_{ys}) =441 MPa, (iii) Elongation =8.0 pct, and (iv) Elastic Modulus =71.7 GPa. The shape and dimensions of the test specimen conform to the standards specified in ASTM E-466 [15]. The specimens were dog-bone in shape and with a thickness of 3-mm. A schematic of the test specimen is shown in Fig. 1. The shaded area, rectangular in section, at the gage section of the test specimen is the region where selected test specimens were subject to shot peening surface treatment. The test specimens are divided into two groups:

(a) Test specimens subject to shot peening surface treatment, and
(b) The non-shot peened test specimens.

Table 1
Nominal chemical composition of aluminum alloy 7050-T7451.

Element	Mg	Mn	Fe	Cr	Si	Cu	Zn	Zr	Aluminum
Percentage	2.6	0.10	0.15	0.04	0.12	2.6	6.7	0.15	Balance

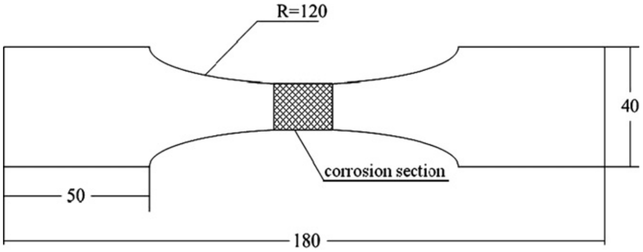

Fig. 1. A schematic showing shape and dimensions of the specimen used for testing (thickness =3 mm).

For those aluminum alloy test specimens that were subject to shot peening we consider them in two groups:

(i) Series #1: test samples shot peened using an intensity of 0.006A, and
(ii) Series # 2: test specimens that were shot peened using an intensity of 0.008A.

2.2. Initial microstructure characterization

Samples of the as provided aluminum alloy, i.e., 7050-T7451, were mechanically ground and coarse polished using progressively finer grades of silicon carbide impregnated emery paper along with copious amounts of water both as a coolant and lubricant. The mechanically ground and coarse polished samples were then finish polished using alumina powder suspended in distilled water as the lubricant. The fine polished samples were dried in laboratory air and subsequently etched using Keller's etch [a solution mixture of hydrofluoric acid (5 pct), nitric acid (15.5 pct) and water (84 pct)]. The etched surfaces were examined in a light optical microscope [*Model*: Nikon EPIPHOT 300] and photographed using the standard bright field illumination technique.

2.3. The shot peening process

The area chosen on each test specimen for purpose of shot peening was at the center of the gage section of the dog-bone shaped specimen. The chosen area is rectangular in shape and measures 20 mm by 15 mm. The shot peening parameters are summarized in Table 2. Prior to exposure of the test specimen to the corrosive environment a thin layer of wax was applied to the test specimen at all regions except the rectangle at the gage section, which was subject to shot peening.

2.4. The corrosion treatment

The aqueous environment chosen for purpose of inducing corrosion in the chosen aluminum alloy 7050 was the EXCO (Exfoliation Corrosion) solution. This solution was prepared with care and caution in conformance with the procedures and specifications detailed in ASTM Standard G34-01 (2007) [16]. Precise chemical composition of the solution is summarized in Table 3. The composition was diluted with deionized water to obtain one-full liter prior to exposing the samples to the environment by immersion. This was made possible in a large-sized glass beaker. The pH of the starting solution was 0.4.

The area on the test specimen that was subjected to shot peening was cleaned with acetone with the purpose of removing any and all metal related residue adhering on to the surface. Subsequently, record was taken of the surface conditions of the corroded area and includes the following: