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Improvement of fatigue property in 7050–T7451 aluminum alloy by laser peening and shot peening

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ABSTRACT

The fatigue strength for 1×10^7 cycles of 7050–T7451 aluminum alloy was determined for machined, laser-peened, and shot-peened specimens. Moreover, fatigue lives were compared under the same load conditions. Results show that the laser peening induces a deeper compressive residual stress layer and better surface finish, therefore, it improves fatigue properties more effectively. Fractographic examination and analysis shows that the fatigue cracks initiate in the subsurface layer beneath the compressive residual stress field for laser- and shot-peened specimens, whereas the fatigue cracks form at surface for as-machined ones.

1. Introduction

Surface enhancement technologies, which are mainly made by modifying the surface integrity of parts, are widely employed to improve the properties of components including fatigue, stress corrosion cracking, wear, and fretting. Among these surface enhancement technologies, shot peening is a conventional and widely applied process to increase fatigue performance of parts, which has been applied for many years in aircraft components. Laser peening is a recently developed process and is being widely investigated. Due to its accurate positioning and precise operation, laser peening can be applied to many aircraft components such as blades and gears with good repeatability and reliability, although it costs more than shot peening due to its low production rate. Laser peening induces compressive residual stress in the surface layer by pulse laser impact energy and plastic deformation occurs in the surface layer.

Surface integrity [1–8] changes induced by shot peening mainly include: (1) Fine microstructure due to the formation of subgrains, whose size can be micros to nanometers, depending on the peening intensity; (2) phase transformation caused by deformation, such as the metstable austenite transfers to martensite by shot peening; (3) work-hardening due to the increase in the dislocation density, giving the surface layer higher yield strength and hardness, but lower ductility; (4) surface topography due to the dents by the shots, increasing the roughness and stress concentration; (5) residual stress induced by recovering its original geometric form by the elastically deformed layer underneath and surrounding the dent-layer on the top.

Shot peening has both the beneficial and detrimental effects, therefore, it is a difficult and time-consuming task to determine the optimized process parameters based on the fatigue life prolonging factor (FLPF) under the same stress/strain conditions and/or fatigue strength improvement percentage (FSIP) under the given fatigue life, usually for the 1×10^7 cycles.

In order to reduce the surface roughness and deepen/enlarge compressive residual stress field, many new surface enhancement technologies such as double peening [9–11], laser peening [11,12], ultrasonic peening [13,14], and/or pulsed electron beam treatments [15,16] were developed. Laser peening is a novel process and has recently been used in aeronautical engineering, but less attention has been put on the surface integrity changes caused by laser peening and its effects on fatigue performance of aluminum alloys.

The objective of this paper is to explore the effects of laser peening and shot peening on the fatigue performance of a 7050–T7451 aluminum alloy, which has been employed in the fatigue-critical aircraft components due to its high strength, good stress corrosion cracking property, and high fracture toughness. Through comparing the effects of laser peening with that of shot peening on fatigue strength and analyzing the difference of surface roughness, compressive residual stress field induced by these two processes, this paper will be of value for the application of these two sur-

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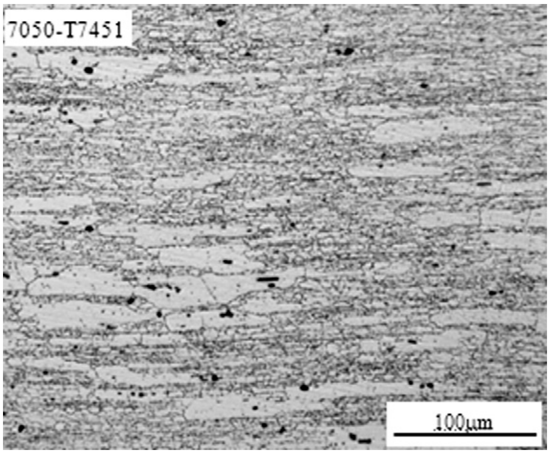

Fig. 1. Microstructure of the heat treated 7050–T7451 aluminum alloy.

Table 1
Chemical composition of 7050–T7451 aluminum alloy in wt%.

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Zr	Others	Al
0.021	0.051	2.11	0.008	2.29	0.009	5.9	0.026	0.13	0.01	*Balanced*

face strengthening technologies in aircraft components made of 7050–T7451 aluminum alloy.

2. Material and experimental procedure

2.1. Material

The 7050–T7451 aluminum alloy plate with the thickness of 40 mm was cold rolled to 20 mm and all samples were made along rolling direction. The samples were heat treated at 474 °C for solution, aged at 120 °C for 4 h and 160 °C for 24 h. Initial microstructure of the heat treated specimens is shown in Fig. 1. Chemical composition of the plate employed in this investigation is listed in Table 1 and the mechanical properties are provided in Table 2.

2.2. Experimental procedure

Fatigue specimens were machined from 20-mm-thick rolled plates with the length directions of specimens parallel to the longitudinal rolling direction. The final machining is the fine grinding and the surface roughness of machined specimens is R_a 0.8–1.2. The configurations and dimensions of fatigue specimens are shown in Fig. 2. Fatigue tests were carried out on a four-point-rotating–bending fatigue test machine HY-10 with a frequency of 50 Hz at room temperature. The fatigue strength σ_{-1} for 1×10^7 cycles was determined according to a stair-case method [1,2]. The fracture surfaces of broken specimens were investigated using SEM and the positions of fatigue crack sources were determined.

Three groups of specimens are used for fatigue tests. The first group is untreated as machined, tested as the referenced ones. The second group is the shot peened ones under different shot peening regimes (a regime of shot peening includes parameters of shot type, shot size, shot hardness, peening intensity, and coverage etc.) in a pneumatic machine. Shot peening parameters are described below in detail. The third group is the laser-peened ones under different times (N = 2, 4, 6, 8 times, and the duration each time is 60 s) under the laser pulse energy density of 2×10^9 W/cm^2, the pulse duration is 50 ns, and the pulse energy is 50 J at a frequency of 0.54 Hz, with the Almen intensity of 0.08 C. The ablative layer was the black paint coating and the flowing water was run over the surface as translucent layer. Laser peening used a neodymium-doped glass (Nd: glass) slad laser system having a square-shaped laser spot with the wavelength λ = 1064 nm. The energy level and duration were determined with a pulsed energy sensor and a PIN photoelectric tester, respectively with the controlling by computer.

Table 2
Mechanical properties of 7050–T7451 aluminum alloy.

Material	$R_{p0.2}$ (MPa)	R_m (MPa)	Elongation (%)	Reduction of area (%)
7050–T7451	470	539	13.6	38.0

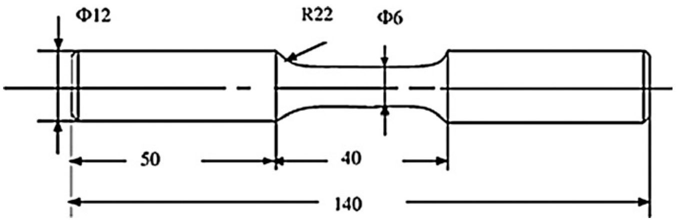

Fig. 2. Configurations and dimensions of fatigue specimens.

The surface topography of all groups of specimens was studied using the profilometer microscope and the values of surface roughness, R_a, were determined. The residual stress distribution curves as the function of distance from surface were determined by using an X-ray stress analyzer type AST Xstress3000 (manufactured in Finland) with CrKα target and a step-by-step electrolytic-polishing procedure [17] for all specimens. The subsurface stresses were obtained with measuring layer by layer and the effect of polishing on stress relaxation was corrected [17].

3. Results and discussion

3.1. Residual stresses caused by shot peening

The compressive residual stress distribution along the surface layer for shot-peened samples under different regimes is shown in Fig. 3. For the specimens peened at the intensity of 0.10 A by the glass bead (GB150) with the diameter of 0.15 mm, the maximum residual stress is at the surface, the absolute value is the lowest among all peened samples, and moreover the depth of compressive layer is the thinnest compared with the others. For the

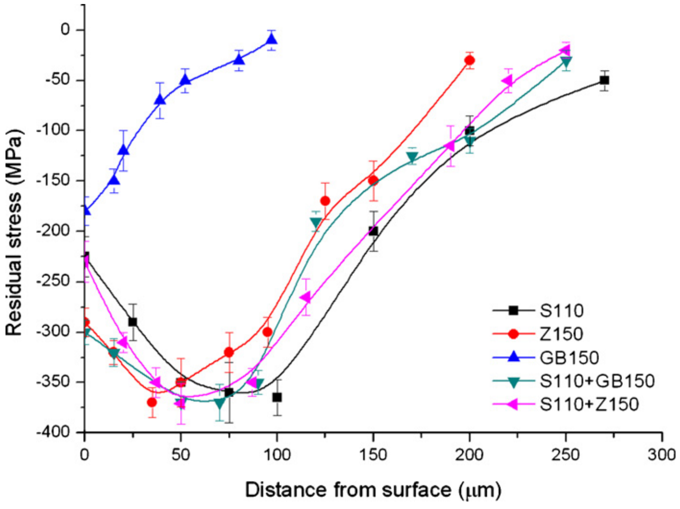

Fig. 3. Compressive residual stress field caused by shot peening.