



Comparison of the simulation and experimental fatigue crack behaviors in the nanoseconds laser shocked aluminum alloy

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ABSTRACT

This investigation was performed to compare the simulation and experimental results of the fatigue crack growth rates and behaviors of the 7050-T7451 aluminum alloy by nanoseconds laser shock processing (LSP). Forman–Newman–deKoning (FNK) model embedded in the *Franc2D/L* software was utilized to predict fatigue crack growth rate, which was conducted to weigh the stress intensity factor (SIF) changing on the surface cracks. LSP induced high compressive residual stresses that served to enhance fatigue properties by improving the resistance against fatigue crack initiation and propagation. The circulating times of crack growth obtained from the simulation and experimental values indicated a slower fatigue crack growth rates after LSP. The relationships between the elastic–plastic materials crack growth rates and the SIF changing after LSP are resolved.

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1. Introduction

Fracture mechanics typically offers a reliable foundation for the description of the fatigue growth of cracks. It is well known that residual stress plays a crucial role in fatigue crack growth behavior [1–4]. LSP is a competitive technology as a method of imparting compressive residual stresses into the metal surface to improve fatigue and corrosion properties [5,6].

The research on stress shock wave on cracks has made great progresses in aspects of theoretical and numerical simulations. A numerical model for predicting the depth of plastic deformation and resulting residual compressive stress at the surface has been completed by Abul Fazal [7]. The plastic behavior near the tip of stationary crack in engineering materials has been intensively studied by using classical plasticity theory based on the Von-Mises yield criterion [8] and the associative flow rule [9]. Ray and Patanker [10] derived the crack closure models on the crack opening stress by finite element computations. Then, the theoretical analysis work which confirmed the effect of the compressive residual stresses generated by LSP on the SIF has been put forward [11,12], showing the influence of compressive stress on the 3D non-through hole-edge crack's SIF after LSP.

However, the relationships between the fatigue crack growth rates and the surface SIF changing after LSP have never been reported in literature to the authors' best knowledge. With respect

to the continuity information between this study and the available literature, we aim to characterize the effects of residual stress on fatigue crack propagation under variable laser shock amplitude loading. Moreover, we will also discuss simulation results on the dynamic response of cracks under the actions of various shock loads, and we use the crack growth function of *Franc2D/L* to present the curve of the surface SIF changing under residual stress loads. Further studies on the issue of optimal fracture with the action of stress pulses will be summarized in our next study.

2. Simulation method

2.1. *Franc2D/L* code

Franc2D/L is the professional fracture analysis software based on finite element analysis and developed by Cornell Fracture Group. *Franc2D/L* initialized cracks and predetermined the initiation spots of cracks. Then the software judged the cracks growing direction so as to perform numerical simulation of crack growth and obtain results automatically. Fig. 1 shows the sample of the singularized element growing along with the crack tip. The crack tip has been modeled with a rosette of eight quarter-point collapsed elements. The propagation of the crack is divided into many steps and in every step the crack is let to extend of a certain amount. The first propagation step is set to 0.5 mm while the following crack propagation steps are 1 mm each. After each step *Franc2D/L* re-meshes the region in front of the crack tip, and calculates the SIF and the kink angle. The crack propagation direction is determined according to the Maximum Hoop Stress Criterion (MHSC) [13,14], and K_I and K_{II} are determined at every step.

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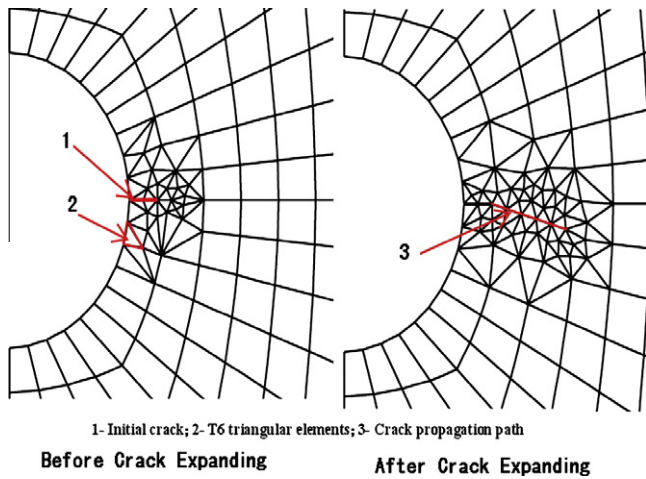


Fig. 1. Sample of the singularized element growing along with the crack tip of 7050-T7451 aluminum alloy by Franc2D/L.

2.2. Crack growth model

The FNK model was used to determine the crack growth rate, which could account for retardation near threshold, acceleration near fast fracture, and the crack closure. This method is given as [15]:

$$\frac{da}{dN} = \frac{C(1-f)^n \Delta K^n \left[1 - \frac{\Delta K_{th}}{\Delta K}\right]^p}{(1-R)^n \left[1 - \frac{\Delta K}{(1-R)K_C}\right]} \tag{1}$$

where C, n, p are empirically derived by curve fitting test data [16,17], R is the stress ratio, f is the function of maximum applied stress and strain constraint factor, ΔK_{th} is the threshold value that is a function of R, K_C is a function of fracture toughness and specimen thickness, ΔK is the range of the stress intensity factor.

The analysis results of the cracked configuration are used to compute the mode I-type stress intensity factors which are used in a closed-form expression, and this expression determines the direction from the maximum circumferential stress around the crack tip. Propagation angle is also displayed to give the option of propagating the crack by an incremental distance along crack line during crack propagation.

3. Experimental methods

7050-T7451 aluminum alloy was made into Single-Edged Notched Tensile (SENT) samples, as shown in Fig. 2. The alloy's chemical composition and mechanical properties are shown in Tables 1 and 2 separately. LSP was performed by high power Nd:Glass laser implement to investigate the effect of the processing parameters on the residual stress distribution. Laser beam wavelength was 1.054 μm , pulse duration and power density were 20 ns and 2.91 GW/cm^2 respectively, and laser beam spot size was

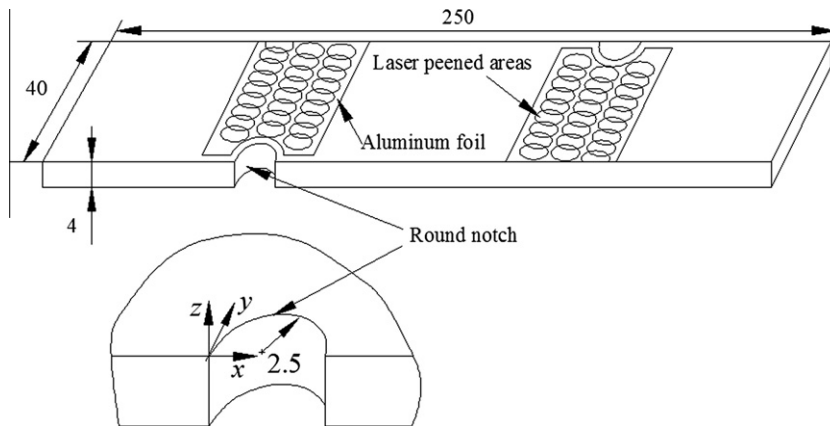


Fig. 2. Dimensions of the 7050-T7451 SENT specimen and laser shock processing route.

Table 1
7050-T7451 chemical composition.

Trademark	Si	Fe	Cu	Mn	Mg	Cr	Zr	Zn	Ti	Al
7050	≤0.12	≤0.15	2.0–2.6	≤0.10	1.9–2.6	≤0.04	0.08–0.15	5.7–6.7	≤0.06	Rest

Table 2
7050-T7451 mechanical properties.

Trade mark	Supply condition	Thickness (Mm)	Sampling direction	No less than		
				Tensile strength (MPa)	Non-proportional extension strength $\sigma_{0.2}$ (Mpa)	Elongation after break (%)
7050	T7451	60–76	L	503	434	9
			LT	503	434	8
			ST	469	407	3
		>76–102	L	496	427	9
			LT	496	427	6
			ST	469	400	3

Notes: L is portrait line section; LT is landscape orientation line section; ST is thickness.

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