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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.

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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