Numerical Study of Enhancement of Fatigue Crack Propagation Life by Grain Refinement

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ABSTRACT.

The possibility of grain size refinement treatment using high energy concentrated heating methods for the enhancement of fatigue life are investigated by applying numerical simulation of fatigue crack propagation. The strip yield model in order to represent fatigue crack opening / closing behaviour and improved effective stress intensity factor range ($\Delta K_{RPG}$) are implemented into the numerical simulation model.

The effect of grain refinement for the enhancement of fatigue crack propagation is confirmed in this study.

OUTLINE OF NUMERICAL SIMULATION

Toyosada et al. (2004) proposed an improved effective stress intensity factor range by replacing the crack opening load according to Elber (1971) with the RPG (Re-tensile Plastic zone Generating) load at which stress at the crack tip reaches the value of the material yield stress. The novel crack driving force parameter based on the RPG load level is termed $\Delta K_{RPG}$. Unlike the traditional effective stress intensity factor range based on the crack opening level, the $\Delta K_{RPG}$ parameter can account for the threshold behaviour. Consequently, the crack growth rate versus $\Delta K_{RPG}$ data can be described using the Paris equation within the full range of crack growth, including the threshold region.

Besides, the numerical simulation of fatigue crack propagation based on the strip yield model, which enables to describe the fatigue crack opening / closing behaviour and the effect of fatigue crack wake generated over crack surfaces for the crack propagation. The $\Delta K_{RPG}$ parameter is applied in order to describe the fatigue crack propagation law in this simulation. This simulation procedure is implemented into the numerical simulation code FLARP. FLARP has been shown to give accurate crack growth predictions under various constant and variable amplitude loading conditions and in the residual stress field. However, current FLARP can only consider the crack growth problem in uniform yield strength field. Then, the simulation code is developed in order to apply the crack growth problem in yield stress distributed zone. In this study, improved simulation code based on FLARP is applied.

INTRODUCTION

Many fatigue life prolongation techniques has already been proposed in order to keep the structural integrity of large welded built-up structures. One of authors (Nagata et al., 2004) proposed the prolongation method by applying the grain size refinement treatment using high energy concentrated heating methods, e.g. laser or high-frequency induction heating. By performing high energy concentrated heating around stress concentration regions, which correspond to the fatigue crack initiation sites in welded built-up structures, the grain size decrease by this treatment and yield strength in these regions are increasing. As a result of this effect, the appearance of plastic hysteresis by the cyclic loading around stress concentration regions decreases and these effects enable to achieve the significant life prolongation. However, above mentioned method was only confirmed by referring S-N curves of T-shaped non-load carrying fillet welded specimens. Quantitative retardation effect for fatigue crack propagation by applying proposed method has not been investigated yet.

In this study, numerical case studies of fatigue crack prolongation by grain refinement are performed in order to investigate the retardation effect for fatigue crack propagation. Numerical simulation code based on the strip yield model to represent fatigue crack opening / closing behaviour and improved effective stress intensity factor range are applied to perform the simulations.