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Fatigue strength evaluation of small defect at stress concentration

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Abstract

The effect of individual large notches on the fatigue strength of components is one of the oldest and most studied topics in the history of metal fatigue. When a small defect is present at the notch root, both the stress concentration of the main notch and the effect of the small defect interact and simultaneously influence the fatigue strength. The effect of the main notch can be evaluated from the viewpoint of stress concentration and stress gradient. Both have a strong influence on the fatigue notch factor. The $\sqrt{area}$ parameter model has been successfully applied to fatigue limit evaluation of materials containing small defects under uniform stress condition. If a small defect is present at the notch root, the effect of stress gradient must be also considered in the application of the model. In the present study, the fatigue tests and fatigue crack growth analyses are carried out for specimens containing a small defect with the size $\sqrt{area}$ =46.3μm at the root of notch with 1mm depth and root radius of 1.0mm or 0.3mm. Fatigue limit predictions are made based on the $\sqrt{area}$ parameter model and the stress intensity factor analyses for a small crack subject to a steep stress gradient. Existing fatigue notch effect methods are reviewed and used in fatigue limit predictions for comparison. Moreover, new fatigue notch effect method based on the $\sqrt{area}$ parameter model is proposed. The greatest advantage of the proposed method is that it can predict fatigue limit using easily obtainable parameters and without requiring fatigue tests or troublesome analyses. Suggestions for the extension of the proposed method to practical engineering problems are also made.

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Nomenclature

AS	Allowable stress
F	Dimensionless stress intensity factor
HV	Vickers hardness
K_t	Stress concentration factor
lin	Linearly changed stress condition (subscript)
uni	Uniform stress condition (subscript)
β	Ratio of dimensionless stress intensity factors F_{lin}/F_{uni}
ΔK_{th}	Threshold stress intensity factor range
σ_w	Fatigue limit
σ_{w0}	Fatigue limit of unnotched specimen
σ_{w1}	Fatigue crack initiation limit
σ_{w2}	Fatigue crack propagation limit
σ_0	Nominal stress
ρ	Notch root radius
$\sqrt{area}$	Square root of defect/crack area projected normal to the maximum principal stress

1. Introduction

Fatigue notch effect is one of the most studied topics in the history of metal fatigue. Typically, these studies consider an individual large notch in a component and the fatigue strength is determined in terms of stress concentration and stress gradient. It is known that the stress distribution in the close vicinity of the notch mainly influences the fatigue strength. Thus, the stress distribution can be approximated by the straight line and its gradient is used as the representing factor of the stress distribution. However, the absolute value of the stress gradient is not useful in fatigue notch effect evaluation, because it depends on the applied stress even for identical notches (Murakami (2002)). Detailed review of fatigue notch effect models has been provided by Murakami and Endo (1994). Isibasi's (1967) pioneering work on notched components pointed out the fact that two fatigue limits can be distinguished if a notch becomes sharp enough. One is the fatigue limit σ_{w1} as the critical stress for microscopic crack initiation and non-propagation at the notch root which is very alike the fatigue limit of unnotched specimens. The other is the fatigue limit σ_{w2} as the threshold stress for non-propagation of the crack around the circumference of the notch root (Fig.1).

According to Nisitani (1968), the fatigue limit tends to become constant, when notch root radius ρ is smaller than critical ρ (= ρ_0) for a material (typically 0.4-0.5mm for various materials with tensile strength less than 1000 MPa). Small ρ implies to large stress concentration and a crack initiates easily from notch root. At the fatigue limit, cracks initiate but stop propagation, thus, *fatigue limit must be determined by the threshold condition of non-propagating cracks*. If a small defect is present at the notch root the fatigue limit is determined by the threshold condition of a non-propagating crack emanating from the small defect. The $\sqrt{area}$ parameter model, proposed by Murakami & Endo (1983), has been successfully applied to fatigue limit evaluation of materials containing small defects under uniform stress condition. However, as the stress condition is not uniform at the notch root, the model must be modified to consider the effect of stress gradient. In the present study, the fatigue tests and stress intensity factor analyses are carried out for specimens containing a small defect with the size $\sqrt{area}$ =46.3μm at the root of notch with 1mm depth and root radius of 1.0mm or 0.3mm. Fatigue limit predictions are made based on the $\sqrt{area}$ parameter model and the stress intensity factor analyses for a small crack subject to a steep stress gradient. In addition, new fatigue notch effect model is proposed.