Numerical Study on the Fatigue Crack Propagation Behavior in Flattened Martensite Dual Phase Steel

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ABSTRACT

The relation between the fatigue crack propagation behavior and the microscopic characteristics (the morphology, distribution, hardness of the 2nd phase) of Ferrite / Martensite Dual Phase (FMDP) steel is investigated numerically using Crystalline-Elastic-Plastic F.E. (CPFE) analysis.

The calculation results lead us to a prediction that the crack growth rate of FMDP steels with polygonal and banded M-phase becomes much higher than that with flattened and banded M-phase because cracks can slip through M-phase when there exist narrow F-phase slits. The experimental results agree approximately with this prediction. This demonstrates the validity of the CPFE theory employed in this research.

KEY WORDS: Dual phase steel, Fatigue crack propagation, Crystalline plasticity, Finite element method.

INTRODUCTION

It was regarded that fatigue crack growth rate of steel depends neither on microstructures nor on static strength of steels. However, recently, new ship structural steels with significantly improved crack growth properties have been developed one after another by Japanese steel companies. The improvements of crack growth rate had come about by control of microstructures.

As an example of this kind of steel, Ferrite / Martensite Dual-Phase (FMDP) steel was developed by Nippon Steel Corporation (Nakashima et al., 2003). Martensitic phase (M-phase) was introduced as the barrier of fatigue crack propagation in this steel. Nakashima et al. (2003) and Nakashima et al. (2004) evaluated the crack growth properties of FMDP steels with various martensitic morphology and distribution. They found that the crack growth rate is affected by martensitic morphology and distribution, and FMDP steel with flattened and banded martensitic structure, hereafter called "flattened FMDP steel", shows the best fatigue crack growth property. Fatigue cracks wandered through M-phases in FMDP steels, and detour and branching of crack were observed along crack path in flattened FMDP steel. The crack growth rate in FMDP steel with polygonal and banded M-phase was higher than that with flattened M-phase. They also found that the crack growth rate of flattened FMDP steel is much lower than that of conventional one when a crack grows in the direction of the thickness (L-S dir.), whereas there is no significant difference in the growth rate when a crack propagate along the cross direction (L-T dir.).

These experimental results can be explained well by assuming the following:

a) A fatigue crack propagating in ferrite phase (F-phase) has as good a chance of changing its direction as going straight ahead when the crack tip approaches to M-phase boundary.

b) The driving force of crack propagation of a fatigue crack which propagates in a narrow F-phase slit nested between M-phases is equal to or greater than that of a crack which propagates in a wide F-phase.

The above hypotheses can be verified by numerical crack propagation analysis. The effect of the microscopic characteristics (the morphology, distribution, hardness of the 2nd phase) on the crack propagation behavior should be taken into account, and Crystalline-Elastic-Plastic F.E. (CPFE) analysis is appropriate for such studies. Fatigue crack propagation behavior was investigated using CPFE by Gall et al. (1996) and Potirniche and Daniewicz (2003). These studies focused on the deformation behavior of micro cracks, and the relation between the microscopic characteristics and the crack propagation behavior has not been fully understood yet.

In this study, the relation between the driving force of fatigue crack propagation and the microscopic characteristics of FMDP steel is investigated numerically using CPFE analysis in order to determine the mechanism of the improvement in the crack propagation property of flattened FMDP steel.

THEORY

The constitutive equation used in our analysis is based on the rate-dependent crystalline plasticity theory developed by Peirce et al. (1983). Hereafter, the superscripts \( a \) and \( b \) denote the identifiers of a slip system. We use the power law form expression of the shear rate \( \dot{\gamma}^{(a)} \).