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Development of Cleavage Fracture Initiation Model for Bainite Steels Based on Micromechanism

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The authors propose a cleavage fracture initiation model for bainite steels. The authors considered three stages of fracture initiation in the model: stage I, microcrack initiation in the brittle phase; stage II, propagation of the microcrack to a neighbor matrix; and stage III, propagation of the cleavage crack across the packet boundary. The cleavage fracture is assumed to initiate when all three stage conditions are satisfied in any one of the volume elements surrounding a notch tip. The authors applied this assumption to bainite steels and validated this model by comparing results of the analysis and toughness test results.

INTRODUCTION

Recently, the strength of steel plates used for offshore structures and container ships has been increased, satisfying the demand for the increase in structural size scale and for performance in more severe operating conditions. Bainite steels have been used for various structures for achieving higher strength. However, the mechanism of cleavage fracture initiation in bainite steels remains unclear.

Beremin (1983) proposed a stochastic model of brittle fracture, assuming that brittle fracture follows, essentially, a weakest-link mechanism. He assumed multiple volume elements in a material and that each volume element contains one microcrack. In Beremin's model, the critical stress of the microcrack in a volume element controls the fracture of the whole of the material. Beremin's model led to Weibull stress, and the Weibull stress parameters can be obtained from multiple fracture toughness tests. These parameters are considered as material properties that control the fracture toughness distribution of the material. However, this model requires many fracture toughness tests to derive these parameters and does not explain the details of the fracture initiation mechanism of complex microstructures like bainite.

On the other hand, Martin-Meizoso et al. (1994) proposed a model for predicting the fracture toughness of bainite steels. In that model, the process by which a carbide crack grows into a bainitic packet and propagates across a packet boundary was formulated. Lambert-Perlade et al. (2004) assumed the same process as in the model by Martin-Meizoso et al. (1994) and modeled fracture initiation of the simulated heat-affected zone (HAZ) containing an upper bainite microstructure. However, formulations for critical conditions of the fracture initiation process in the models are too simple to predict the toughness of the bainitic steels.

Shibanuma et al. (2015a, 2015b) proposed a numerical model to predict the fracture toughness of ferrite–cementite steels based on a micromechanism. They assumed three stages of fracture initiation and that cleavage fracture is initiated when the three stage conditions are simultaneously satisfied in any one of the volume elements. Fracture toughness predicted by their model showed good agreement with experimental results. However, ferrite–cementite steels are rarely used in structures because of low strength and low toughness. A model to predict the toughness of commercial steels like bainite steels based on a micromechanism is needed.

For the above reasons, the authors propose a numerical model to predict the fracture toughness of steels with a bainite microstructure. First, the authors examined a micromechanism of fracture initiation in a bainite microstructure by observing microcracks and fracture initiation points. Second, the authors proposed a fracture initiation process composed of the three stages and formulated each stage based on the micromechanism. Finally, the authors applied the model to fracture toughness tests of bainite steels to validate this model.

TEST STEELS

Preparation of Steels

To investigate the microstructural dependency of fracture toughness, two test steels, H-C and H-D, were prepared. They have the same chemical composition as shown in Table 1 but have different microstructures by different heat treatments as shown in Table 2. Steel H-C was produced by hot rolling, while steel H-D was produced by controlled rolling. Both rolling processes were followed by accelerated cooling. Their microstructures were quantitatively

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KEY WORDS: Bainite steel, cleavage fracture, fracture initiation, local approach, fracture toughness.