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Study on Crack Propagation for High Strength Steels using Isogeometric Analysis

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In recent years, high-strength steel plates have been increasingly used in automobile development to achieve both crashworthiness and weight reduction. However, fracture may occur during crack deformation because high-strength steel plates have lower ductility. Therefore, the establishment of fracture prediction technique for high-strength steel plates is currently an important research issue.

Many methods have been proposed for predicting fracture in CAE. Ductile fracture condition using principal strain, Cockcroft and Latham's integral ductile fracture condition, and the ductile fracture condition that specifies the fracture strain depending on the stress triaxiality $\eta(\eta=\sigma_m/\sigma_{eq}$, σ_m is average stress, σ_{eq} is equivalent stress) are used. However, when using shell element that assume plane stress, the fracture strains can only be defined between the compressive state($\eta=-\infty$) and biaxial tensile state ($\eta=0.66$), so the fracture strain under the triaxial tensile state ($\eta>0.66$, negative hydrostatic pressure state) cannot be considered. On the other hand, since fracture occurs at the point where the steel plate has been locally and significantly deformed, CAE must predict the local deformation with high accuracy. Furthermore, solid elements must be used if the effects of necking are to be considered.

In this study, BEXT solid element composed of third-order basis function described by the Bézier function employed in Isogeometric analysis was investigated. The stress triaxiality at the crack tip was confirmed by BEXT solid calculations to be in triaxial tensile state($\eta>0.66$), so the fracture strain in the triaxial tensile state was measured using small round bar tensile experiment(Fig.1). Finally, fracture model was constructed that defined the fracture strain corresponding to the stress triaxiality from the compression state($\eta=-\infty$) to the triaxial tensile state($\eta=1.0$), which was named as extended ductile fracture model(Fig.2).

Using this extended ductile fracture model and BEXT solid element, the direction of crack propagation in specimen with V-notches was investigated. In the experimental results with 30-degree angle between two notches, the direction of crack propagation was parallel. The result of the BEXT solid element with extended ductile fracture model showed the high correlation with experiment(Fig.3), and in the Force-Stroke curve, the BEXT solid model reproduced the experimental curve(Fig.4).

Next, the crack growth behavior after fracture initiation was examined using specimen with a notch on only one side, which was made of 980 MPa steel plate. It was found that the stress triaxiality at the crack tip changed during deformation of the specimen. After the fracture initiation, the crack growth was unstable, then in the next state it became stable, and finally it was unstable again. The stress triaxiality in the unstable crack growth state was found to be greater than $\eta = 0.66$, while that in the stable crack state was less than $\eta = 0.66$(Fig.5).

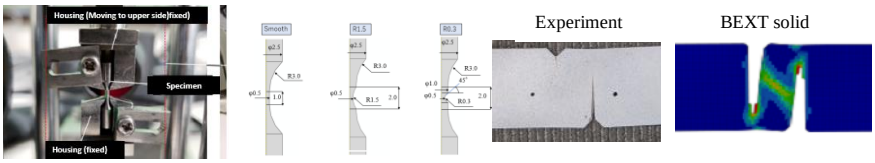

Fig.1 Small round bar tensile experiment

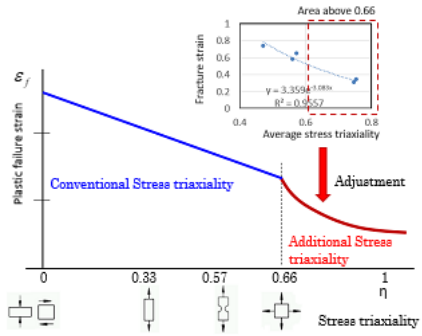

Fig.2 Extended ductile fracture model.

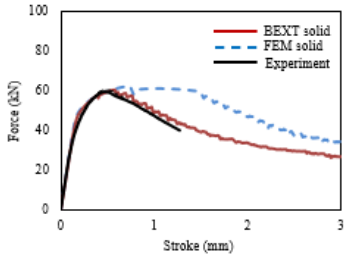

Fig.3 Crack propagation direction 30-degree specimen

Fig.4 Force-Stroke curve of V-notch specimen with extended ductile fracture model and BEXT solid

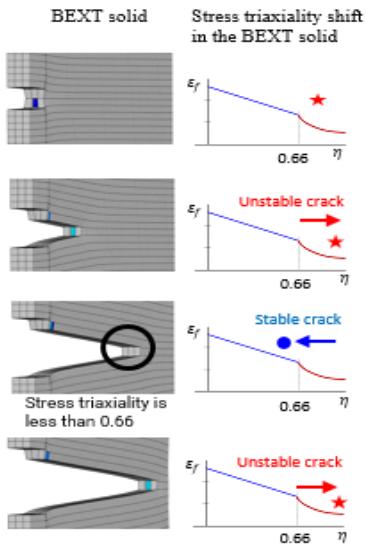

Fig.5 Behaviar of stress triaxiality at crack tip after fracture initiation