

## Comparison of GTN Model and XFEM for Fracture Mechanics Analysis

Sung-Jun Lee <sup>a</sup>, Yoon-Suk Chang <sup>a\*</sup>

<sup>a</sup> Dept. of Nuclear Engineering, Kyung Hee University, 1732 Deokyoungdae-ro, Yongin, Kyunggi, 446-701, Korea

\*Corresponding author: yschang@khu.ac.kr

### 1. Introduction

The simulation of discontinuities such as stationary and growing cracks by conventional finite element(FE) method is limited for bulk materials due to the necessity of computationally expensive remeshing process and high mesh densities. Accordingly, several advanced finite element techniques have been introduced to model crack propagation without remeshing. However, there are still many modeling uncertainties relating to arbitrary discontinuities in respect of accuracy and efficiency. In order to overcome this problem, eXtended Finite Element Method(XFEM) which allows the presence of discontinuities in elements by enriching degrees of freedom(DOF) with special displacement function was developed by Belytschko and Black[1]. In this paper, the XFEM was applied to tensile tests for API X65 steel to implement crack simulation based on fracture mechanics analyses and verify through the comparison with the preceding study using Gurson-Tvergaard-Needleman (GTN) model[2].

### 2. Analysis methods

#### 2.1 XFEM

The principle of XFEM is based on the enrichment function with additional degrees of freedom. The approximation for a displacement vector function is given by the following equation

$$u = \sum_I N_I(x) \left[ u_I + H(x)a_I + \sum_{\alpha=1}^4 F_{\alpha}(x)b_I^{\alpha} \right], \quad (1)$$

where,  $N_I(x)$  is the nodal shape function,  $u_I$  is standard DOF,  $H(x)$  is the Heaviside function,  $F_{\alpha}(x)$  is the crack tip function,  $a_I$  and  $b_I^{\alpha}$  are the corresponding DOFs.

#### 2.2 Analysis models

Fig. 1 shows the 3D FE models of tensile specimen and notched round bars. Those models consist of 24,582 nodes and 22,624 elements for tensile specimen, 56,232 nodes and 53,536 elements for 1.5R notched specimen, 76,112 nodes and 72,780 elements for 3R notched specimen and 106,260 nodes and 102,920 elements for 6R notched specimen. Element types were selected as C3D8R for stress analysis in general-purpose commercial program element library[3] and the corresponding mechanical properties are summarized in Table I.

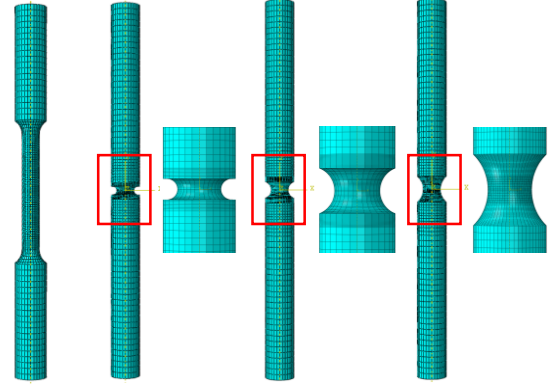


Fig. 1. 3D FE models of tensile specimen and round bars with 1.5R, 3R and 6R notches.

Table I: Mechanical Properties of API X65 Steel

Young's modulus (GPa)	Poisson's ratio	Yield strength (MPa)	Tensile strength (MPa)
210.7	0.3	464.5	563.8

#### 2.3 Analysis procedures

The theories that govern the behavior of XFEM-based cohesive segments for a fracture mechanics analysis are related to those used for cohesive elements with traction-separation constitutive behavior[4]. The traction separation law is determined by any two of three parameters(cohesive strength  $T_0$ , cohesive energy  $\Gamma_0$  and critical separation  $\delta_0$ ).

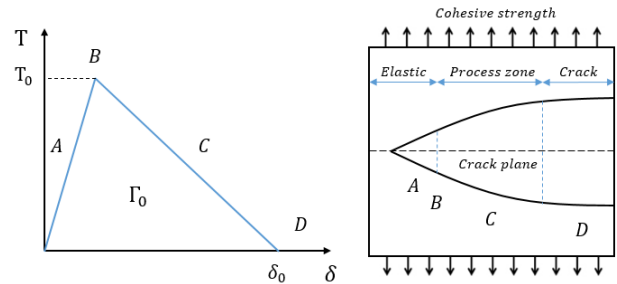


Fig. 2. Typical traction separation law.

To determine the cohesive parameters, numerical fitting procedures and direct procedures based on specific tests have to be performed. Table II shows the cohesive parameters that were used to conduct these analyses.

Table II: Cohesive Parameters of API X65 Steel

$T_0$ (MPa)	$\Gamma_0$ (N/mm)	$\delta_0$ (mm)
1393.5	22.6	0.05

In this study, maximum principle strain(MAXPE) was used as a damage initiation criterion in the XFEM enriched region for tensile and notched round bars. With regard to the boundary and loading conditions, the bottom surfaces were fixed and then applied 30mm displacement to top surfaces of each FE models.

### 3. Analysis results

#### 3.1 Crack initiation and propagation

Fig. 3 depicts FE models to represent a process of crack simulation for tensile specimen. The STATUSXFEM variable are available for discrete crack initiation and propagation along an arbitrary path through the fracture mechanics analyses with the XFEM.

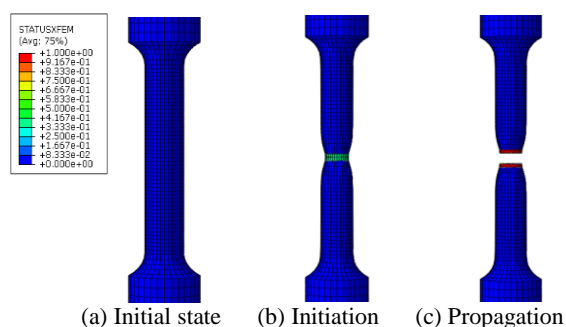


Fig. 3. Schematics of 3D XFEM analysis result for tensile specimen.

#### 3.2 Verification of XFEM

In the preceding study[2], fracture mechanics analyses for the same objects were performed using GTN model. Fig. 4 shows the results of experiments and numerical analyses. The analyses results showed the accuracy comparing with the GTN model as well as experimental results within 5% differences.

### 4. Conclusion

In this paper, a comprehensive numerical analyses were carried out to verify an adequacy of the XFEM by comparing its results with those obtained from experiments and GTN model. The XFEM has an efficiency due to the accessibility to the corresponding parameters such as cohesive strength, cohesive energy and critical separation. Also, visualization of crack simulation has an advantage compared to the GTN model. In these respects, the XFEM can be widely used in industrial fields and further analyses for bulk materials are needed.

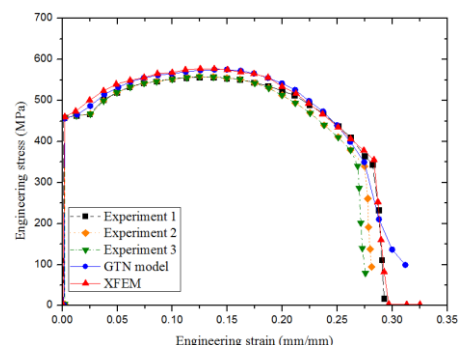
### REFERENCES

[1] N. Moës, J. Dolbow and T. Belytschko, A finite element method for crack growth without remeshing, International Journal for Numerical Methods in Engineering, Vol. 46, pp. 131-150, 1999.

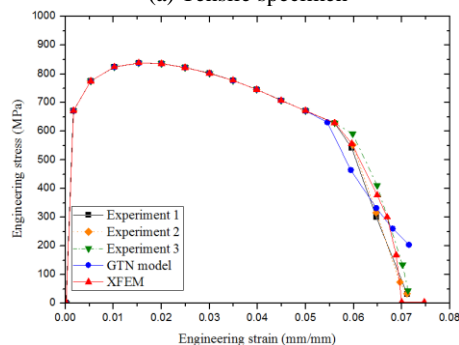
[2] C. K. Oh, Y. J. Kim, J. H. Baek, Y. P. Kim and W. S. Kim, A phenomenological model of ductile fracture for API X65 steel, International Journal of Mechanical Science, Vol. 49, pp. 1399-1412, 2007.

[3] ABAQUS User's Manual, Ver.6-10.1, 2010, Dassault Systems.

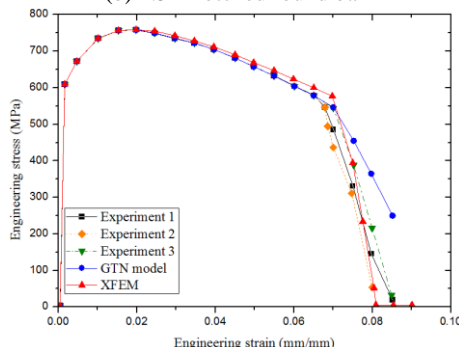
[4] K. H. Schwalbe, Ingo Scheider and A. Cornec, Guidelines for applying cohesive models to the damage behaviour of engineering materials and structures, Springer, New York, 2013.



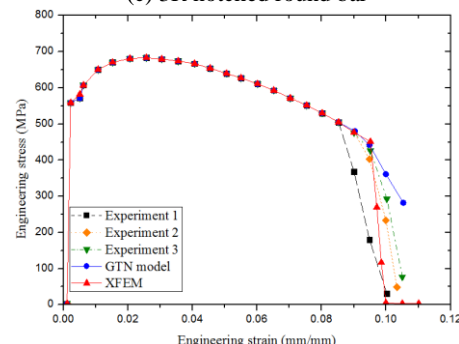
(a) Tensile specimen



(b) 1.5R notched round bar



(c) 3R notched round bar



(d) 6R notched round bar

Fig. 4 Results of experiments and numerical analyses.