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Numerical Evaluation of Damage Models in Notched Round-Bar Tensile Tests of API X65 Sour Steel

Letícia d. S. Pereira[1]; Miguel Mattar Neto[1]; Gustavo H. B. Donato[2]
1.Instituto de Pesquisas Energéticas Nucleares; 2. Fundação Dom Cabral

Introduction

In the oil and gas industry, advanced high-toughness steels are applied in pipelines. However, understanding the failure mechanisms is essential to prevent accidents. One approach to investigating these mechanisms is to combine laboratory tests with nonlinear finite element analysis using damage models.

Stress triaxiality is a key factor in the ductile failure process and influences the calibration of damage models. The present work investigates the effect of the stress state on a high-toughness steel used in pipelines, using six round-bar tensile specimens and three damage models: Extended Finite Element Method (XFEM), Gurson–Tvergaard–Needleman (GTN), and Ductile Damage (DD) [1-3].

Methodology

The geometries evaluated consisted of standard and modified tensile specimens (Fig.1). The material used was API 5L X65 sour steel, with a Poisson's ratio equal to 0.3 and a density of 7.85 g/cm^3. The Young's modulus and the true stress vs. plastic strain curve were obtained from the S10 and S12 results, shown in [2-3]. The elements used were CAX4R with a minimum size of 0.1×0.2 mm. The three models were calibrated to reproduce the experimental curves, as shown in [3].

A Python routine was used to obtain the values of plastic stress and strain, stress triaxiality and node coordinates. Then a MATLAB routine was used to organize the results and export them to an Excel spreadsheet for graphical analysis.

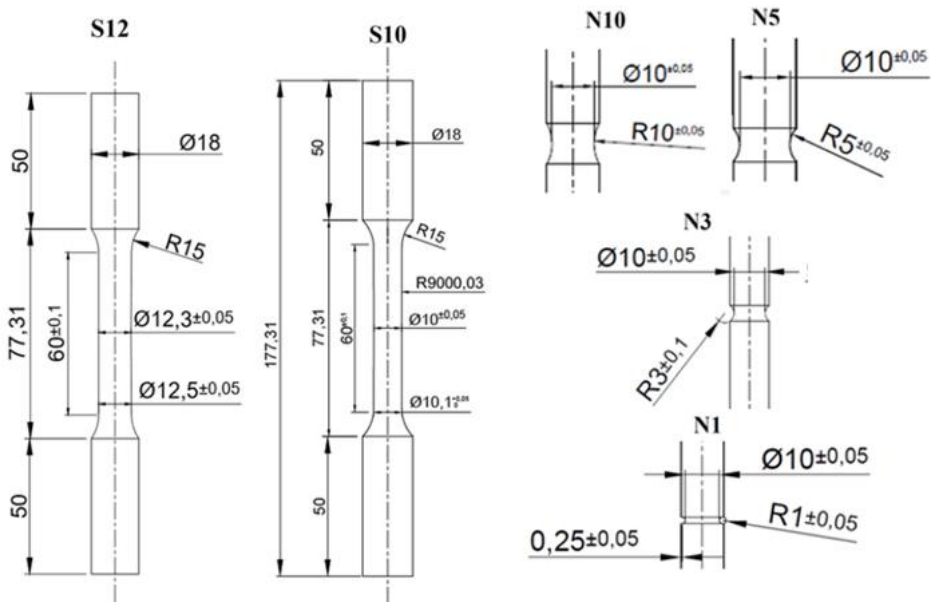


Figure 1. Specimen geometries

Results and Discussion

The results obtained using the DD and GTN models are shown in Fig. 2. For the standard specimens at low strains, the stress state is uniaxial. As expected, the smaller the notch radius the higher the stress triaxiality, which reaches its maximum value at the center. Furthermore, after necking initiates the stress triaxiality increases. The results obtained using XFEM and GTN were similar. However, damage tended to be localized at the center, whereas in the DD model, it spread over a larger region, resulting in greater deformation and higher stress triaxiality values.

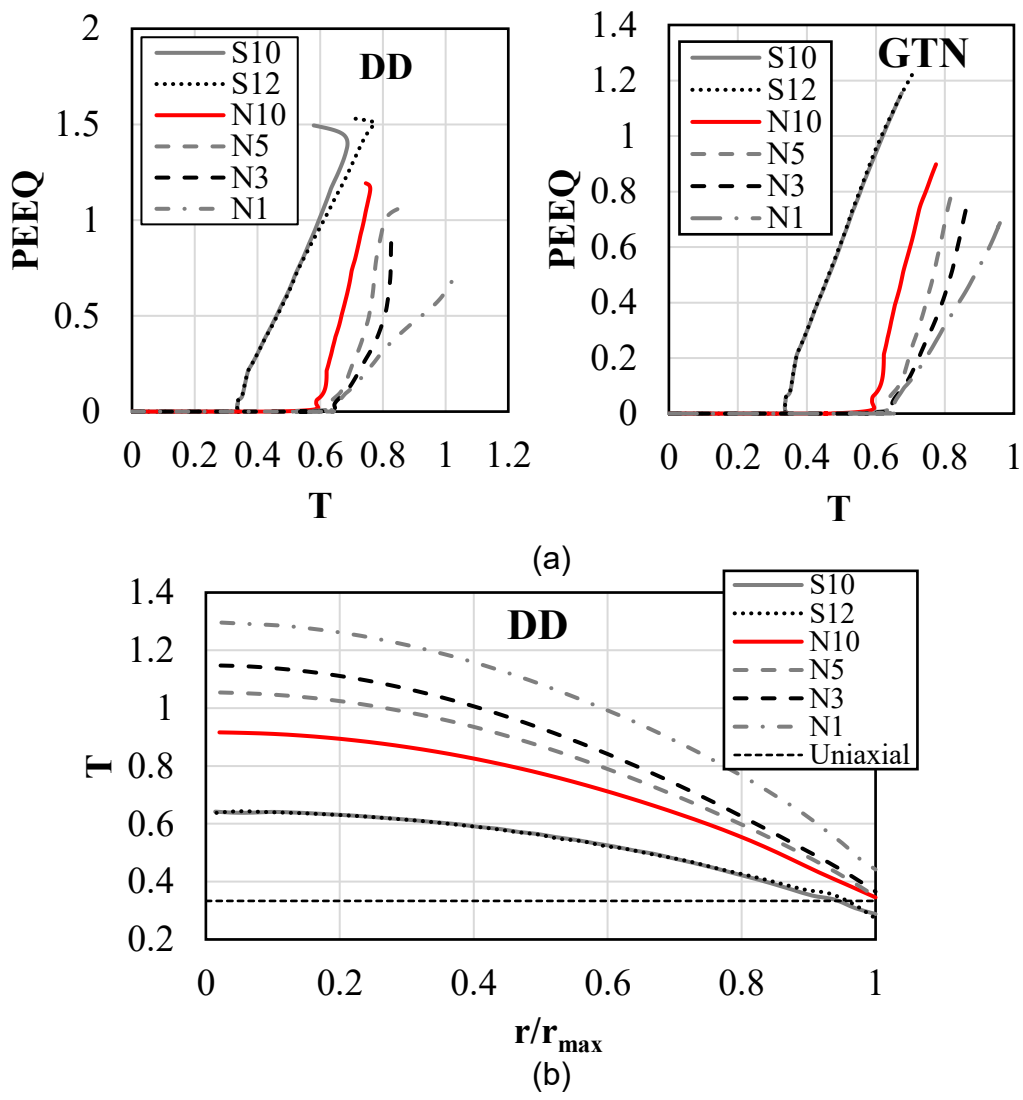


Figure 2. Curves: (a) Equivalent plastic strain vs. stress triaxiality; (b) Stress triaxiality vs. relative radius after the maximum strength.

Conclusions

The results indicate that stress triaxiality is an important parameter for describing the fracture behavior of high-toughness steels, and increases considerably with the necking process. Among the evaluated models, the DD model presented the most consistent response, indicating its potential for this material.

References and Acknowledgments

[1] Dassault Systèmes, Abaqus Analysis User's Guide, Dassault Systèmes Simulia Corp., Providence, USA (2023).
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[3] L. d. S. Pereira, M. Mattar Neto, G. H. B. Donato, "Numerical Investigation of the Notch Effect in Round Bar Tensile Tests of High-Toughness X65 Steel Using XFEM, GTN, and Ductile Damage Models", paper presented at the International Nuclear Atlantic Conference (INAC 2026), 2026, paper ID R05_27586.