PREDICTING DUCTILE FRACTURE FOR MIXED MODE OF LOADING USING THE MODIFIED MOHR-COULOMB CRITERION

Diego F.B Sarzosa*, Daniel Lopez

University of são Paulos, São Paulo, Brazil
** Presenting Author email: dsarzosa@usp.br*

Abstract
Reliable and robust fracture prediction tools are necessary for designing and analyzing critical engineering structures. This paper uses a phenomenological damage model to study the fracture response of a pressure vessel steel under complex loading conditions. Details of the experiments and numerical procedures are provided for calibrating and validating the proposed framework for predicting ductile fracture.

1. Introduction

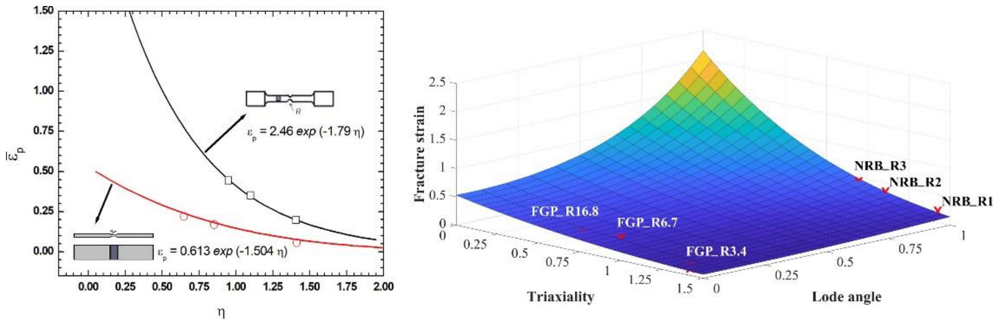
Prevention of fracture is a crucial step in designing and analyzing critical structures. Natural disasters, like earthquakes or floodings, are responsible for collapsing essential facilities such as bridges and buildings, risking lives and everyday activities. Pipelines, aircraft, and ships are other important structures that may accumulate damage and eventually fail due to extreme loading conditions during operation. Often, catastrophic failures happen due to the lack of knowledge of the potential damage mechanisms operating in the structure under analysis. Ductile fracture under pure Mode I of loading has been studied extensively over the last decades.

Moreover, due to its inherent complexity, ductile fracture under combined loading (Mixed Mode I and II) has received less attention. Thus, this paper presents a detailed numerical and experimental study to predict ductile fracture under a mixed loading mode using asymmetric four-point bend tests. First, pure Mode I and Mixed (tension and shear) Mode fracture toughness tests are carried out to cover a broader range of mechanical loading applied to the material used in this study. Then, the modified Mohr-Coulomb (MMC) criterion is calibrated and used to predict the material response under different loading conditions applied during testing. The MMC criterion is dependent on the stress triaxiality and Lode angle. Therefore, This feature makes the criterion robust enough to predict material failure initiation under a wide range of stress states. The MMC model is used to predict the onset of fracture. The propagation phase is modeled by using a softening law. This paper describes the procedure for calibrating the material damage parameters of the MMC criterion by using nonlinear finite element analysis. Then, symmetric three-point bend (SEB) tests and single edge notch tension (SENT) tests are used for calibrating and validating the softening law. Finally, nonsymmetric four-point tests are used to check the capability of the adopted framework to predict the material response under a mixed Mode of loading.

2. Results

The fracture toughness tests were conducted at the experimental facilities of the University of São Paulo, Brazil, using an MTS machine with a capacity of 250 kN. The Digital Image Correlation (DIC) technique was used to measure the displacement at the specimen surface. In addition, finite element (FE) analyses were performed to map the evolution of stress triaxiality and Lode angle for calibrating the fracture surface locus. The calibrated surface (2D and 3D views) is shown in Fig. 1.

Figure 2 compares the measured and predicted load-displacement curve for the SEB geometry and SET sample. Note that the 3-point bend sample was used to calibrate the softening law, and the clamped SET specimen serves as the first verification of the calibrated parameters. Also, note that both geometries have different levels of stress triaxiality (high and low conditions). Overall, the numerical predicted load vs. displacement curves agree with measured data for all tested samples.



(a) (b)

Fig.1 – Calibrated fracture locus for the ASTM A285 steel..

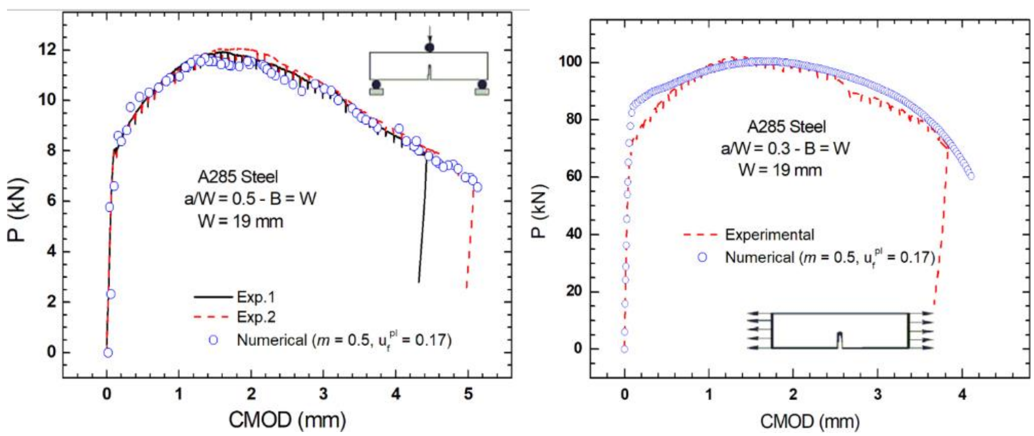


Fig.2 – Comparison of measured and predicted response using SEB and SET specimens

Figure 3 illustrates the measured response of the asymmetric four-point bend test. The FEM simulation well reproduced the fracture response observed during the experiment. The final comparison of global and local responses is under preparation. Concluding, the adopted framework for modeling ductile fracture shows to be robust and reliable and can be used to identify critical defects and loading conditions that may compromise the integrity of critical engineering structures

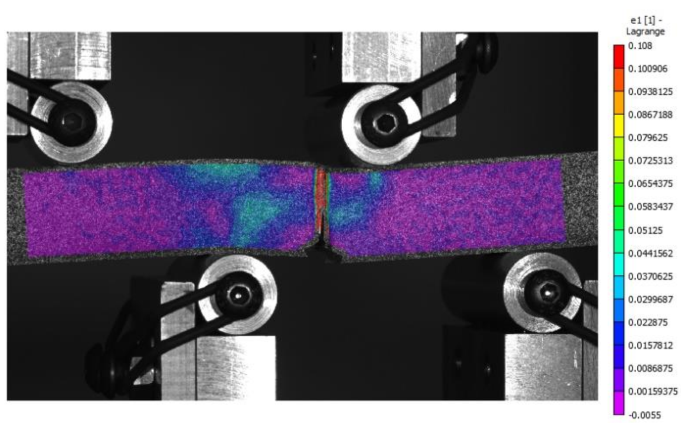


Fig.3 – Specimen being tested in asymmetric four-point bend condition.