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Comparison of fracture strain based ductile failure simulation with experimental results

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ABSTRACT

This paper provides experimental validation of the approach for simulating ductile failure using finite element methods, recently proposed by the authors. The proposed method is based on a phenomenological stress-modified fracture strain model. Incremental damage is defined by the ratio of the plastic strain increment to the fracture strain, and total damage is calculated using linear summation. When the accumulated damage becomes unity, all stress components at the finite element gauss point are reduced to a small value to simulate progressive failure. The proposed method is validated against four experimental data sets of cracked specimens made of three different materials. Despite the simplicity of the proposed method, the simulated results agree well with experimental data for all cases considered, providing sufficient confidence in the use of the proposed method to simulate ductile failure.

1. Introduction

The assessment of structures containing crack-like defects often requires performing full-scale tests, which are in general expensive and time-consuming. Furthermore, it is often very difficult to perform full-scale tests that reflect the complex geometries and loading conditions in practice in plant assessments. An efficient tool is needed not only to design such complex tests but also possibly to minimize the need to perform the tests. One possible tool is virtual testing using finite element (FE) damage analysis based on the local approach.

A number of studies have been reported in the literature up to present on finite element ductile failure simulations. Depending on a model employed for simulating damage, these existing works can be broadly classified into two categories. The first category uses a micro-mechanical model for ductile fracture, incorporating void nucleation, growth and coalescence, for instance, the Gurson-Tvergaard-Needleman model [1–6] and the Rousellier model [7–10]. The second category uses a phenomenological model for ductile fracture. One popular phenomenological model is, for instance, the cohesive zone model [11–17]. As many researchers have used these methods, their applicability and validity have been well discussed in the literature (see for instance Refs. [18–25]). One important issue for their use is concerned with the parameters contained in the models. For instance, the Gurson-Tvergaard-Needleman model has eight parameters related to micro-mechanisms of ductile fracture. The simplest form of the cohesive zone model has two parameters related to ductile fracture phenomenon. The determination of these parameters is not an easy task, and often not robust. Furthermore, simulated results can be sensitive to the choice of the parameter set. The determination of optimum parameters in a robust way may be a common problem in practical FE ductile failure simulations.

Recently, the authors proposed a simple method to simulate ductile failure using an FE method based on a phenomenological stress-modified fracture strain model [26]. The method is not new in the sense that the stress-modified fracture strain model is based on the well-known concept that the fracture strain for ductile fracture strongly depends on the stress state [27–35]. In fact, many researchers have used this model to explain ductile failure phenomena. An advantage of this model is that, for a given material, the stress-modified fracture strain model can be determined in a robust way from notched bar tensile test results. Once the stress-modified fracture strain model is determined, incremental damage is defined by the ratio of the plastic strain increment to the fracture strain. When the accumulated damage becomes unity at a FE gauss point, all stress components (at the gauss point) are reduced to a small value to simulate progressive failure. To validate the proposed method, simulated results have been compared with experimental fracture mechanics test data and full-scale burst test data for API X65 pipes containing gouge [26]. The comparison

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