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Comparison of damage models in numerical simulations of fillet welds under quasi-static and impact loading

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Abstract

Finite element (FE) simulations can be a powerful tool for predicting the response of fillet welds subjected to various types of loading. This requires that the fillet welds are modelled adequately, which can be a great challenge. Capturing the correct evolution of material damage and failure in the welds can be particularly difficult. This paper investigates two approaches to model damage in fillet welds of steel that are subjected to quasi-static and impact loading. One approach uses a shear-modified Gurson model, whereas the other employs an extended Cockcroft-Latham failure criterion, which is uncoupled from the constitutive equations. In both cases, a linear elastic-thermoviscoplastic constitutive relation is used. The two approaches produce practically the same global force-deformation response up to the instant the first elements are eroded. Thus, coupling damage with the constitutive relations has minor effect on this part of the response. Both damage models yield a decent agreement in terms of maximum force and weld deformation at failure when comparing the quasi-static tests with the respective simulations. On the other hand, noticeable discrepancies with the experimental results are observed for the simulations of the impact tests. However, the simulations using the extended Cockcroft-Latham criterion gave weld deformations at failure that were in better agreement with the experiments than the shear-modified Gurson model. In conclusion, an uncoupled damage model may be sufficient for predicting the global response of fillet welds.

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1. Introduction

Fillet welds are common in civil engineering and marine structures. Thus, fillet welds are subjected to various types of loading, which can be static or dynamic. Grimsmo et al. [1] noted that no publications in the open literature apparently investigate the behaviour of fillet welds subjected to severe impulsive loading. They therefore initiated an experimental program where fillet welds were subjected to both quasi-static and impact loading. The fillet welds were either oriented longitudinally or transversely with respect to the load direction. Performing numerical simulations of these tests can increase the insight of the behaviour of the welds. For instance, such simulations can give indications of the evolution of strain rates and temperatures in the welds, which influence the material behaviour. The authors therefore conducted various material tests of the weld metal in order to calibrate a suitable material model. Grimsmo et al. [2] report the calibration and application of a shear-modified Gurson model in finite element (FE) simulations of the fillet welds tests. This model is based on a modification of the widely used porous plasticity model proposed by Gurson [3]. The modification was suggested by Nahshon and Hutchinson [4] to account for void softening in shear typically occurring at low stress triaxialities, in addition to the void growth taking place at higher stress triaxialities. We chose this shear-modified Gurson model because a large range of stress triaxialities develops in the welds during deformation. Moreover, we observed a prominent localization of deformation in the welds, which suggests that a material model including softening is appropriate. The results reported by Grimsmo et al. [2] demonstrate that the simulations agree well with the quasi-static tests, both in terms of maximum force levels and weld deformation at failure. Some discrepancies were observed between the impact tests and corresponding simulations, which may partly be due to inaccuracies of the strain-rate and temperature parameters.

The purpose of this paper is to compare the results obtained by using the shear-modified Gurson model and a damage model that is uncoupled from the constitutive equations. Obviously, uncoupled damage models do not influence the stress-strain behaviour during deformation, and thus cannot induce material softening. However, they are in general computationally faster and simpler to implement in numerical simulations. Grimsmo et al. [2] compared the responses acquired by using the shear-modified Gurson model and the failure criterion proposed by Cockcroft and Latham [5], which was uncoupled. They observed that the Cockcroft-Latham criterion was unable to capture the experimentally observed response to the same extent as the shear-modified Gurson model. In particular, the Cockcroft-Latham criterion was inadequate when the fillet welds were predominantly loaded in shear. As a continuation of the work by Grimsmo et al. [2], we chose to perform simulations with the extended Cockcroft-Latham failure criterion proposed by Gruben et al. [6] in the current study. In contrast to the original failure criterion, the extended version enables explicitly accounting for the Lode dependence of failure.

In Section 2, we briefly describe the test specimens and setup. The reader is referred to Grimsmo et al. [1] for more details on the experimental program. Section 3 provides essential equations of the material models, and outline the procedure for identifying the material parameters. The FE model of the component tests is presented in Section 4. For more information on the material and FE modelling, the reader is referred to Grimsmo et al. [2]. In Section 5, the results obtained with the two damage models are compared and discussed. Finally, some concluding remarks are given in Section 6.

2. Laboratory experiments

2.1. Component tests

We designed the two types of test specimens displayed in Fig. 1. Both specimen types consist of two 15 mm plates and a brick with measures 60×60×30 mm^3. These parts were made from S355 steel. The principal difference between the two specimen types is that one has four fillet welds with the weld seams parallel to the applied load direction, whereas the other has two fillet welds with the w transverse to the applied load direction. These two specimen types are denoted longitudinal and transverse specimen, respectively. The welds were manufactured with stick electrodes