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A notch strain calculation of a notched specimen under axial-torsion loadings

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ABSTRACT

In this paper, a notch analysis model is presented for the numerical prediction of multiaxial strains of a notched 1070 steel specimen under combined axial and torsion loadings. The proposed model is based on the notion of a structural yield surface and uses a small-strain cyclic plasticity model to describe stress–strain relations. A notch load–strain curve is calculated with Neuber's rule and incremental nonlinear finite element analysis. The presented model is applied to simulate the notch root deformations of a circumferentially notched specimen under cyclic tension–compression–torsion loading histories. The model predictions are evaluated with strain measurements at the notch root of the specimen in a comprehensive set of cyclic tests. The computed strain loops were in accord with experimental data and matched qualitatively with measured shear–axial strain histories irrespective of loading path of the test. In proportional balanced torsion-axial loading, the nonlinear shear strain–axial strain loops were calculated properly. The modeling errors were determined to be a function of the loading path shape, and compared to shear strains, axial strain predictions were more accurate.

1. Introduction

The constantly reducing lead-times and development expenses in automotive and related industries put more rigorous restrictions on the design development and verification practices of automotive components. Developing a fatigue-safe component design is probably the one of the most critical ingredients of manufacture of durable products. Therefore, engineers have devised both experimental and analytical methods to estimate the useful design life of structural parts and to assess associated fatigue damage under multiaxial fatigue loads at service conditions [1]. Since the design features such as fillets, welds, shoulders, generally known as the notch, are commonly the potential sides of component failures [2]; a proper investigation of local material deformations at such geometrical discontinuities is essential in both fatigue testing and analytical fatigue analyses in this context.

Due to the multiaxial stress state caused by the notch constraint, closed-formed analytical solutions do not exit to calculate inelastic stress–strain response at notches. The numerical modeling, in particular finite element (FE) analyses, provide a reliable solution that can be applied in the variety of component geometry [3,4], but the applicability of this approach depends on computer modeling of the testing process. The FE analysis costs should also be considered especially for cases where elasto-plastic notch deformations necessitate incremental FE solutions for relatively long loading histories [3]. Alternative to FE analysis, notch analysis methods have been introduced to calculate the stress and strain components at a single material point, usually the notch root [5]. These analytical models seek approximate stress–strain solutions under plane stress conditions and use the elastic stresses calculated with elasticity theory as the fundamental input. The notch stress–strain solutions by notch analysis methods are exact for elastic material deformations, but in the case of elasto-plastic notch deformations, additional equations besides plasticity relations are required and the calculated notch stresses and strains are approximate under general loading conditions. Compared to FE analyses, however, the notch analysis methods are practical in terms of computational efficiency and operational expenses, and consequently, engineers have devised different methods to estimate the fatigue life of structural parts under dynamic loading conditions [6–10].

In this study, a notch analysis model is presented for estimation of elasto-plastic notch stress and strains under proportional and nonproportional cyclic loading conditions. The proposed model uses elastically calculated notch stress history as the basic model input and effective stress/strain measures to extend the Neuber's rule to multiaxial stress states [11]. The small-strain cyclic plasticity model developed by Chaboche [12] is employed to describe the notch plasticity relations. The model is applied to simulate the notch root deformations of a circumferentially notched specimen loaded by cyclic tension–compression–torsion loading histories. The model predictions are compared with the measured notch strains determined with a comprehensive set of axial force-torsion testing programs.

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