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A bifailure specimen for accessing failure criteria performance

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ABSTRACT

Many engineering ductile materials, such as metals, show inelastic behavior with corresponding large deformations. For these materials, the prediction of failure, defined as local material separation, is still nowadays a scientific challenge. Failure initiation, its locus and evolution, has been discussed extensively in recent literature. This work presents a bifailure specimen, especially developed to evaluate failure criteria at high and low triaxiality. In order to explore further the failure phenomenon, uncoupled models are numerically implemented in an explicit finite element code. Simulations were performed and do indicate that, for the studied examples, uncoupled models are not capable of correctly predicting failure.

1. Introduction

Nowadays, the engineering international scenario is characterized by rapid technological development. It is evident the need for accurate and realistic virtual models, in order to minimize the number of experimental tests. Moreover, as pointed out by Matsumoto et al. (2012), post-processing tools allow a more detailed and deep analysis of the behaviour and sensibility of a component or structure.

The quality of virtual analyses is basically dependent on the knowledge of the material behavior, geometry, loading and boundary conditions. The large number of constitutive models presented in the literature can describe different material behaviors fairly well under different conditions of loading, strain rate and temperature. However, for a plasticity model to be more general, the number of material constants should increase. Here it is opted for a simple isotropic plasticity model based on a quadratic yield criterion (Hill, 1950), where temperature and strain rate effects are neglected. Such a model is readily available in many codes, such that the user material subroutine here implemented could be validated with a small number of physically-based parameters. More sophisticated yield surface definitions (Barlat, July 1987; Cazacu and Barlat, 2004; Barlat et al., 2007; Brünig, 1999; Brünig and Driemeier, 2007) could enhance the numerical results, particularly for metal sheets, but are not considered here.

On the other hand, damage and failure phenomena offer so many challenges that so far it remains a key issue in design and they are explored in many experimental investigations in literature. Historically, Bridgman (1952) tested the effect of hydrostatic pressure on the fracture of different types of steel. The author performed uniaxial tensile tests under high pressure conditions and concluded that deformation to fracture increases with increasing hydrostatic pressure. Rice and Tracey (1969) concluded that, for moderate to high levels of stress triaxiality, defined as a ratio between hydrostatic and equivalent stress, the voids growth rate increases exponentially with the hydrostatic stress.

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Currently, notched specimens are used to develop different levels of localized hydrostatic stress, leading, consequently, to different stress triaxialities - see, for example, Hancock and Mackenzie (1976), Alves and Jones (1999), Wilson (2002), Bao and Wierzbicki (2004), Driemeier et al. (2010). Hancock and Mackenzie (1976) investigated the relationship between ductility and stress triaxiality for three types of steel, testing axisymmetric specimens with different notches. Accordingly, the authors concluded that the ductility decreased with increasing level of stress triaxiality for all materials studied. As a consequence, the onset of failure is at highest stress triaxiality locus, as shown in Fig. 1 in a typical tensile test in steel.

Bao and Wierzbicki (2004) conducted a pioneering extensive experimental program in 2024-T351 aluminum with eleven distinct specimen geometry. They covered a wide range of stress triaxialities, from negative levels (−0.3) to values close to unity (0.95). The results suggested that the equivalent fracture strain versus stress triaxiality is not a monotonic curve. According to the authors, there are different fracture mechanisms at different stress triaxiality ranges, as illustrated in Fig. 2. For *negative and low positive stress triaxialities*, shear mechanisms govern damage evolution and failure, while for *large positive triaxialities*, growth and coalescence of voids is dominant. At stress triaxialities between these two regimes, damage and failure occur due to a combination of shear and void growth mechanisms. Later, Bao and Wierzbicki (2005) proposed a cut-off value of −1/3 in the stress triaxiality for fracture. In contrast, Khan and Li (2012) found fracture surfaces along maximum shear direction in a biaxial non proportional compression test at a stress triaxiality level of −0.495. Wierzbicki et al. (2005b) present a complete review of seven fracture models, including the experimental tests necessary for the material parameter calibration. Several authors developed experimental techniques and specimen geometries to investigate the onset of fracture at large ranges of stress triaxialities. Mohr and Henn (2007), Mohr and Oswald (2008) and Driemeier et al. (2010) analyzed positive low to intermediate stress triaxiality, while Haltom et al. (2013) studied specimens subjected to shear-dominant load.

The failure fractures at negative stress triaxiality matches the idea that hydrostatic pressure contributes to the closing of voids, while high positive stress triaxiality cooperates with nucleation and growth of voids and material weakness. However, in the range of low positive stress triaxiality, the literature agrees that there is another parameter that plays an important role in controlling ductile fracture.

It can be shown that a given stress field can be uniquely expressed by the stress triaxiality, hydrostatic stress and the Lode parameter, defined via the third invariant of the deviatoric stress state. Wilkins et al. (1980) were the first to introduce the effect of the Lode parameter in a ductile failure model. According to Argon and Im (1975) and Wilkins et al. (1980) two factors are responsible for the damage evolution: hydrostatic tensile stresses and asymmetric deformation. The first is responsible for void growth and the second factor takes into account the experimental observations that final elongation before failure decreases with increasing shear forces (Wilkins et al., 1980). In fact, Kim et al. (2007) and Gao and Kim (2006) remarked that different stress states with the same stress triaxiality ratio level lead to different void growth and coalescence behavior. Barsoum et al. (August 2007b) proposed a new specimen, a double notched tube, loaded in combined tensile and torsional loading at fixed ratio, controlling stress triaxiality. The authors concluded that stress triaxiality is not a sufficient parameter to characterize ductility, especially at low levels.

Nowadays, the Lode angle and the stress triaxiality are investigated by many authors, as it is considered that they control the behavior of ductile failure (Cazacu and Barlat, 2004; Bai and Wierzbicki, 2008; Brünig et al., 2008; Gao et al., 2009; Mirone and Corallo, 2010; Barsoum and Faleskog, 2011; Malcher et al., 2012). Gao et al. (2009) studied, numerically and experimentally, the influence of stress triaxiality and Lode angle on the hardening evolution and failure process of flat and axisymmetric specimens of the aluminum alloy 5083. The authors suggested that the Lode angle plays a minor role on the damage process, but significantly affects the plastic flow. The stress triaxiality has the opposite effect, it has negligible influence on the hardening evolution, but it is a significant parameter on the failure strain of the studied material. Mirone and Corallo (2010) tested different ductile materials and arrived to similar conclusions. It is well established in the recent

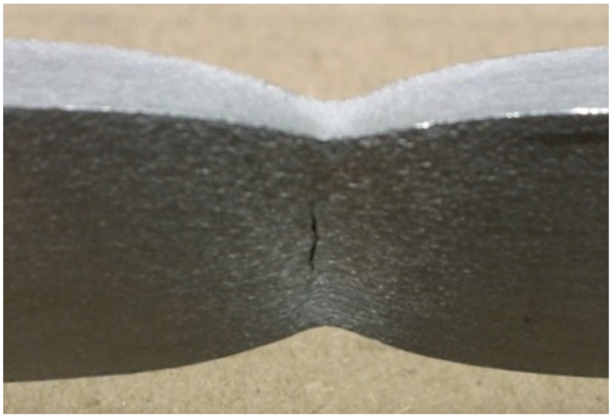

Fig. 1. Failure initiation, in the center of the necking.