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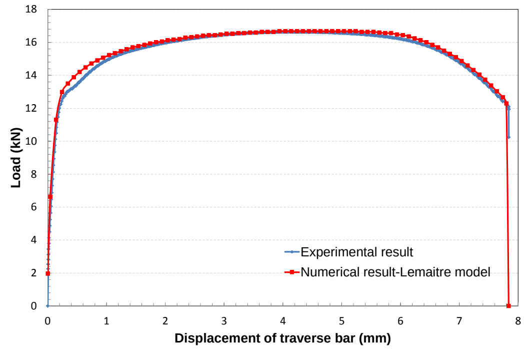
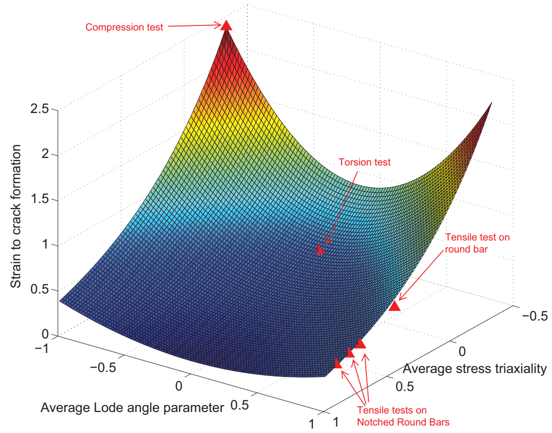
Understanding and modeling of ductile damage mechanisms remains a major issue for many industrial cold forming processes. The ability of numerical modeling to predict the ductile fracture is indeed crucial. However, this modeling is limited because of the complexity to take into account the influence of the complex loading paths (multi-axial and non-monotonic, non-proportional, shear effects, etc.) on damage mechanisms. The stress triaxiality ratio has proved to be a controlling factor of material's ductility ([1]). The continuum thermodynamics-based Lemaitre damage model ([2]), which accounts for the stress triaxiality, is nowadays widely used to deal with coupled damage analyses for various mechanical applications. However, several recent studies have demonstrated the importance of the third stress invariant in damage prediction; the Lode angle parameter is generally used to include it. The idea is to completely describe the stress state in damage model's formulations, which is defined by the equivalent stress, the stress triaxiality ratio and the Lode angle parameter. The latter has proved to have an important influence on ductile damage under low stress triaxiality ([3]). Bai's uncoupled formulations accounts for the third invariant of the deviatoric stress tensor, allowing a better balance between respective effects of shear and elongation on damage ([4]).

In an effort to numerically investigate the damage occurring in several forming processes, different damage models have been implemented in the Forge Finite Element (FE) software by the present authors. They will now be compared to choose the most relevant model for damage prediction.

The objective of this present paper is to detail the methodology of the identification process of Bai's uncoupled formulation as well as the Lemaitre coupled damage model. These identifications involve two steps: identification of hardening law parameters and identification of damage parameters. The second step differs between the two above-mentioned models: the identification of Bai's model is carried out through the experimental fracture strain of different proportional loading paths, while the identification of Lemaitre's model is based on the softening effect of damage. These identifications are based on different quasi-static mechanical tests such as cylinder compression test; torsion test, tensile test on round bar (RB) and tensile tests on notched round bar (NRB) with different notch radii ($R = 4mm, 6mm, 9mm$). The inverse numerical analysis identification of isotropic hardening law is carried out on the Force - Displacement curves of the compression test (the friction coefficient being separately identified using the bulged lateral surface shape), and of the tensile test before necking (to avoid the post-necking instability). The damage models are then identified for both Lemaitre's model



(a) Comparsion between experimental force-displacement curve of tensile test on round bar and the numerical result obtained with identified Lemaitre model and Swift hardening law.



(b) Representation of fracture locus obtained with the identified Bai model in the space of average stress triaxiality and average Lode parameter. This fracture locus predicts quite accurately the experimental results.

Fig. 1: Identification of Lemaitre coupled damage model based on the softening effect of damage on material strength (a); and identification of Bai's model based on fracture strain of different proportional loadings (b).

(based on softening effect of damage Fig.1a), and Bai's model (based on fracture strains of the different tests). The latter identification allows defining a fracture locus of this material, which predicts quite accurately the fracture of all tests through a damage indicator (Fig.1b). The "proportionality" of the studied loading paths is then discussed. Since the stress triaxiality and the Lode parameter vary during loading, their average values are often used in order to carry out the identification. The validity of this method depends strongly on the proportionality of studied loading paths. Therefore, this property plays an important role in uncoupled damage model calibration process. The next step of the present study consists in investigating damage mechanisms in different forming processes with the identified damage models, a topic for a future publication.

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