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Simulations of a top-hat section subjected to axial crushing taking into account material and geometry variations

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ABSTRACT

Simulations of top-hat thin-walled sections of dual-phase steel DP800 subjected to axial crushing have been performed taking into account process history and measured geometric imperfections, thickness variations and material variations. The simulations were based on experiments performed by Fyllingen et al. [Fyllingen, Ø., Hopperstad, O.S., Langseth, M., 2008. Robustness study on the behaviour of top-hat thin-walled high-strength steel sections subjected to axial crushing. International Journal of Impact Engineering, in press, doi:10.1016/j.ijimpeng.2008.03.005], who investigated the robustness of a top-hat section subjected to axial crushing. The geometry variation and spatial strain hardening variation were mapped onto the model. The fracture parameter and strain-rate sensitivity were based on values obtained from one of the batches. It was emphasised to use an element type, element size, a fracture criterion and a spot-weld model typically used by the industry. Compared to nominal models especially the thickness variations, geometric imperfections and material failure criterion influenced the behaviour. The material batch variation resulted in large differences in the batch means of the mean crushing forces and the variation in the geometric imperfections and thickness resulted in variation in the mean crushing force within each batch. Compared to the experiments the model generally under-predicted the mean crushing force.

1. Introduction

In car collisions, most of the energy is dissipated by body deformation. Depending on the type of collision, members are loaded axially and by bending or a combination thereof. Axially loaded members will normally dissipate a substantial part of the energy during a front collision. Large scatter in the dissipated energy may be observed for such members, which normally collapse by folding and bending of the plate elements composing the component. Small variations in geometry, material properties as well as boundary and loading conditions can produce this scatter in the results. A non-robust behaviour may lead to a reduced energy dissipation and thus cause increased accelerations and intrusions in the compartment.

The automotive industry emphasises robust behaviour of the energy-dissipating structures. Hence, the structures should behave well even if there are variations in the material, geometry, loading and boundary conditions. In order to reduce the lead time to develop a new product and the cost, the automotive industry uses finite element analysis. Accurate description of the material behaviour, geometry, process history and boundary conditions may be necessary in order to obtain reliable results from such simulations.

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In the present study the effect of taking into account process history, material variation and geometric imperfections in simulations of axial crushing of a top-hat section will be investigated and compared to experimental results. The model is based on measurements and experiments performed by Fyllingen et al. (2008), who examined variation in the behaviour of a spot-welded top-hat section of DP800 subjected to axial crushing. It was emphasised to use an element type, element size and spot-weld model typically used by the automotive industry.

A review of literature showed that quite a few articles have been published on axial crushing of top-hat steel sections (e.g. Omar et al. (1996), White et al. (1999), White and Jones (1999a,b,c), Schneider and Jones (2004), Peixinho et al. (2003), Yamashita et al. (2003), Schneider and Jones (2004), Tarigopula et al. (2006)). The novelty of this paper compared to the investigations found in the literature, is to investigate the influence of measured in-homogeneities mapped onto the finite element model.

2. Constitutive model and parameter identification

The material used in the components was the dual-phase steel Dogal DP800 produced by the Swedish steel works SSAB Tunnplåt AB. In order to characterise the properties of this material an extensive testing program has been carried out by Tarigopula et al. (2008), Eriksson et al. (2007) and Fyllingen et al. (2008). Tarigopula et al. (2008) investigated the strain-rate sensitivity of DP800, while Eriksson et al. (2007) calibrated a material model for use in large scale finite element analysis that includes plastic anisotropy and failure. In the study carried out by Fyllingen et al. (2008), the variation of material properties within and between the batches was characterised by use of tensile tests. The choice of constitutive model was based on the experiences gained in the abovementioned investigations.

2.1. Constitutive model

Eriksson et al. (2007) performed tensile tests with orientations 0°, 45° and 90° to the rolling direction. From these tests they found that the material exhibits a weak anisotropy in the plastic flow in terms of the Lankford coefficient (width-to-thickness incremental plastic strains). In the present study the weak anisotropy is neglected, and consequently the material is modelled by use of an isotropic yield criterion. A high exponent yield criterion is adopted (Hershey and Dahlegren, 1954), where under the plane stress assumption the effective stress $\bar{\sigma}$ is expressed as

$$\bar{\sigma} = \left[\frac{1}{2}\{|\sigma_1|^m + |\sigma_2|^m + |\sigma_1 - \sigma_2|^m\}\right]^{\frac{1}{m}} \tag{1}$$

where (σ_1,σ_2) are the principal stresses in the plane of the sheet. According to Logan and Hosford (1980) the exponent m is typically 6 for bcc materials. The material is a dual-phase steel, but however it was chosen to use an exponent m equal to 6. Further, associated flow and isotropic work hardening are assumed. The following non-linear strain hardening function is chosen:

$$\sigma_Y(\bar{\varepsilon}) = \alpha_1 + \alpha_2(\beta + \bar{\varepsilon})^{\alpha_3} \tag{2}$$

Here, σ_Y is the flow stress, $\bar{\varepsilon}$ is the effective plastic strain, and $(\alpha_1, \alpha_2, \alpha_3)$ and β are fitting parameters determined from standard tensile tests. This strain hardening function was chosen for several reasons which will be explained in Section 2.2. The strain-rate dependency of DP800 was investigated by Tarigopula et al. (2008) and it was proposed to take into account the strain-rate dependency by the constitutive relation:

$$\bar{\sigma} = \sigma_Y\left(1 + \frac{\dot{\bar{\varepsilon}}}{\dot{\varepsilon}_0}\right)^q \tag{3}$$

where $\dot{\bar{\varepsilon}}$ is the effective plastic strain-rate, and $\dot{\varepsilon}_0$ and q are material parameters.

Eriksson et al. (2007) argued that at least three different failure-related phenomena should be represented and characterised for DP800: thinning instability, ductile fracture and through-thickness shear instability. It was proposed that for large-scale simulations the criterion developed by Cockroft and Latham (1968) could represent ductile fracture. The Cockcroft–Latham (C–L) criterion for workability reads:

$$W = \int_0^{\bar{\varepsilon}} \langle\hat{\sigma}_1\rangle d\bar{\varepsilon} \geqslant W_c \Rightarrow \text{ fracture} \tag{4}$$

where W is the Cockcroft–Latham integral, W_c is a material parameter and $\langle\cdots\rangle$ is the Macauley bracket.

The model was implemented as a user-defined model in LS-DYNA and is similar to the model described by Reyes et al. (2006). The main differences between the models are the strain hardening given in Eq. (2) and the possibility of assigning each element different values of $(\alpha_1, \alpha_2, \alpha_3)$ and β. In addition, several of the features provided in the model described by Reyes et al. (2006) were excluded, such as plastic anisotropy and kinematic hardening.