Characterisation of anisotropic plastic behaviour using an inverse method

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Abstract. The objective of the present study is to determine constitutive parameters of an advanced yield criterion from uniaxial loading. An appropriate geometry which can provide very heterogeneous stress information from a uniaxial load is chosen. Full-field heterogeneous strain fields are measured from a digital image correlation technique. Then, an inverse method is used to retrieve the constitutive parameters.

Introduction

In general, several mechanical tests are needed to identify the anisotropic plastic properties. For instance, Hill1948 [1] and Yld2000-2d [2] criteria require four tests including three uniaxial tensile tests (0°, 45° and 90° from rolling direction) and one biaxial tensile test which are costly to derive the coefficients. A new methodology is applied in this study to identify the anisotropic yield function coefficients. If a specimen geometry is properly designed, abundant information of various stress states can be obtained from uniaxial tension. In this study, full-field logarithmic strain fields are measured from non-standard specimen which provides very heterogeneous stress states. Then, the virtual fields method (VFM) is used as an inverse method for plastic constitutive parameters identification.

Methodology

Materials. An advanced high strength steel (AHSS) sheet, Dual Phase (DP) 780, is adopted. The DP steels are widely applied to automotive parts due to their high strength, high strain hardening and good ductility.

Full-field Measurement. The strain fields on a non-standard specimen are calculated from the digital image correlation (DIC) technique. Synchronized load data is acquired from the load cell of a tensile testing machine for the identification of parameters.
Specimen geometry. In order to retrieve very heterogeneous stress states from uniaxial tension, the geometry of the specimen was optimized by changing size and location of the holes using FE simulation as shown in Fig. 1. To avoid the premature localized necking around the hole area, the effect of hole size on the necking was examined through experiments.

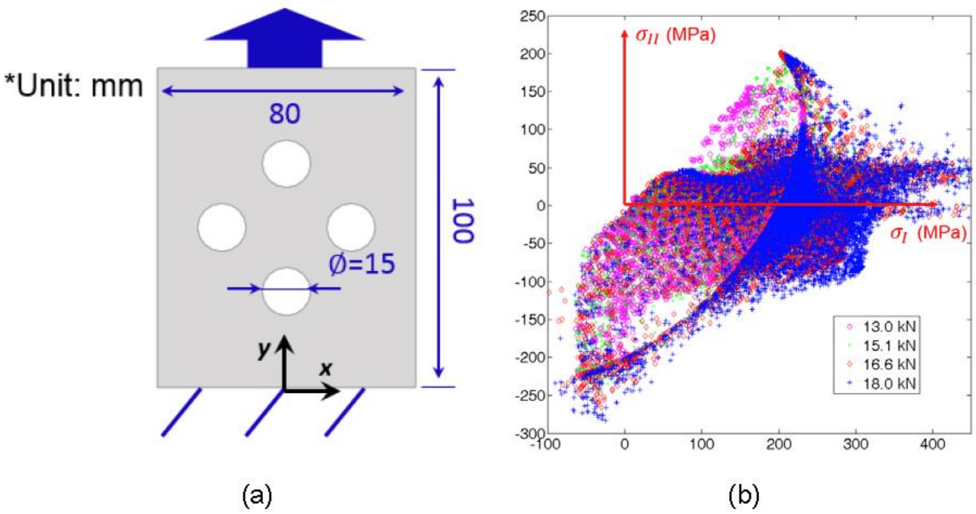

Fig. 1 (a) specimen geometry (b) Heterogeneous stress state information

Constitutive Model. In the present study, Yld2000-2d non-quadratic yield criterion [2] for plane stress condition is selected to describe the anisotropic plastic behaviour of the sheet material. The expression of Yld2000-2d yield criterion is given by:

$$\phi = \left[\frac{1}{2} \left(\left| \tilde{s}_1' - \tilde{s}_2' \right|^a + \left| 2\tilde{s}_2'' + \tilde{s}_1'' \right|^a + \left| 2\tilde{s}_1'' + \tilde{s}_2'' \right|^a \right) \right]^{1/a} \tag{1}$$

where $\tilde{s}_i'$ and $\tilde{s}_i''$ are the principal values of the tensor $\tilde{\mathbf{s}}'$ and $\tilde{\mathbf{s}}''$ which are defined by a linear transformation on the stress deviator $\mathbf{s}$, namely $\tilde{\mathbf{s}}' = \mathbf{L}'\sigma$ and $\tilde{\mathbf{s}}'' = \mathbf{L}''\sigma$. $\mathbf{L}'$ and $\mathbf{L}''$ consist of eight anisotropy coefficients $\alpha_{1\sim8}$ .In [3], the anisotropic coefficients of Hill 1948 yield criterion and hardening parameters were identified simultaneously, but in this study, hardening parameters are determined separately from standard uniaxial tensile tests and only the anisotropic properties are considered for the identification due to the increased number of parameters to be identified.

Inverse method. In this study, the virtual fields method (VFM) [4] is adopted for the inverse method. The VFM is based on the principle of virtual work which is equivalent to the equilibrium equation. In the case of elasto-plasticity, the equilibrium equation can be written as (in static loading without body force):

$$-\int_V \left[\int_0^t \dot{\sigma} dt \right] : \varepsilon^* dV + \int_{S_f} T.u^* dS = 0 \tag{2}$$

where $\dot{\sigma}$ is the stress rate which is a function of $\dot{\varepsilon}$ (actual strain rate), σ (actual stress) and unknown constitutive parameters, V the measurement volume, T the surface tractions acting on S_f, ε* the virtual strain field derived from u* (the virtual displacement field). The VFM identifies the unknown parameters through an iterative procedure by minimizing the quadratic gap between the internal virtual work and the external virtual work.

Conclusion

By utilizing the combination of the full-field measurement technique and the inverse method, the present study determines the anisotropic plastic properties of Yld2000-2d yield criterion of advanced high strength steel sheets from uniaxial tensile tests. Geometry of a specimen was successfully optimized in order to derive very heterogeneous stress states from uniaxial tensile loading, which is essential for the identification without the expensive biaxial tensile tests. In the presentation, the detailed procedure and the experimental results will be given.

References

[1] R. Hill, *A Theory of the yielding and plastic flow of anisotropic metals*, Proc. Roy. Soc. London. A, Vol. 193, (1948) p. 281-297

[2] F. Barlat, J. C. Brem, J. W. Yoon, K. Chung, R. E. Dick, D. J. Lege, F. Pourboghrat, S.-H. Choi and E. Chu: *Plane stress yield function for aluminum alloy sheets-part 1: theory*, International Journal of Plasticity, Vol. 19, no. 9, (2003) p. 1297-1319

[3] J. H. Kim, F. Barlat, F., Pierron, and M. G. Lee: *Determination of Anisotropic Plastic Constitutive Parameters Using the Virtual Fields Method*. Experimental Mechanics, Vol. 54, no. 7, (2014) p 1189-1204

[4] F. Pierron and M. Grédiac: *The Virtual Fields Method*, Springer (2012)