First comparative case study on a recent nonlinear sheet metal forming limit criterion

Marlon Hahn (marlon.hahn@iul.tu-dortmund.de, https://orcid.org/0000-0001-8921-4774), Institute of Forming Technology and Lightweight Components (IUL), TU Dortmund University, Baroper Str. 303, 44227, Germany

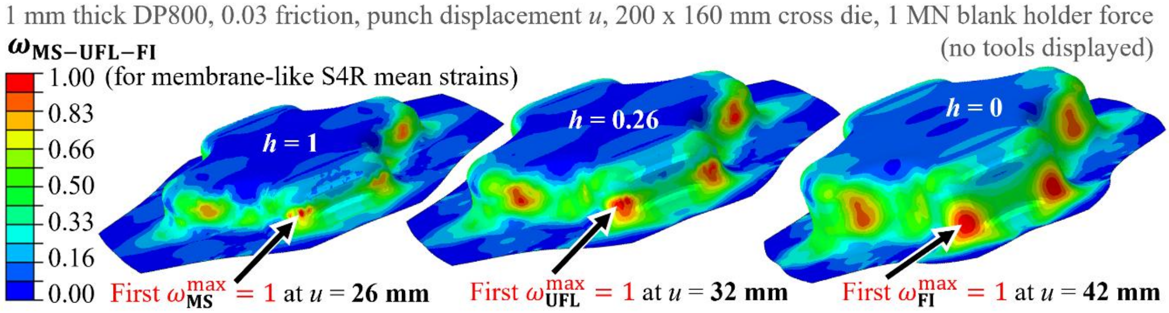
Background and approach

Exploiting sheet metal formability needs trustworthy necking criteria. Forming Limit Curves (FLC) describe limits for linear strain paths but real components typically follow nonlinear histories, so that several extensions exist. Many approaches imply a rather high analysis effort, such as the Modified Maximum Force Criterion, e.g. [1], Forming Limit Stress Curves, e.g. [2], or the Marciniak–Kuczynski method introducing imperfections, e.g. [3]. Phenomenological, purely strain-based criteria are applied more easily but often rely on a lot of experiments, e.g., the Generalized Forming Limit Curve [4]. Certain strain criteria only require the conventional FLC, though, notably the Müschenborn–Sonne (MS) concept, e.g. [5], and the Formability Index (FI) from commercial solvers, e.g. [6]. Instabilities are then evaluated in the equivalent plastic strain ($\bar{\varepsilon}$) space whereby the FLC is $\bar{\varepsilon}^{\mathrm{FLC}}(\alpha)$, $\alpha = \mathrm{d}\varepsilon_{\mathrm{minor}}/\mathrm{d}\varepsilon_{\mathrm{major}}$ is the principal strain (rate) path ratio (important: $\mathrm{d}\varepsilon_{\mathrm{major}} \geq \mathrm{d}\varepsilon_{\mathrm{minor}}$). The equation gives a necking level ω_k (met at 1) for three criteria: k = MS with h = 1 (strain path-independent, effectively $\omega_{\mathrm{MS}} = \bar{\varepsilon}/\bar{\varepsilon}^{\mathrm{FLC}}(\alpha)$), k = FI with h = 0 (like ductile fracture criteria), and k = UFL with $h \cong \bar{\varepsilon}^{\mathrm{FLC}}_{\mathrm{min}}/\bar{\varepsilon}^{\mathrm{FLC}}_{\mathrm{max}}$ ($0 \leq h \leq 1$ could also be calibrated). The latter is the Updated Forming Limit proposed by the author [7].

$$\omega_k = \int \frac{\mathrm{d}\bar{\varepsilon}}{\bar{\varepsilon}^{\mathrm{FLC}}(\alpha)} + h \int \frac{-\bar{\varepsilon}}{\bar{\varepsilon}^{\mathrm{FLC}}(\alpha)^2} \frac{\partial \bar{\varepsilon}^{\mathrm{FLC}}}{\partial \alpha} \frac{\mathrm{d}\alpha}{\mathrm{d}\bar{\varepsilon}} \mathrm{d}\bar{\varepsilon}$$

Numerical case study

Representing complex strain paths, a cross die forming experiment is chosen, specifically of advanced high-strength steel DP800 sheet [8]. An Abaqus Explicit model (von Mises plasticity for now) and a robust post-processing script for the three mentioned failure criteria are built. There is no precise validation yet (to be done) but the figure shows at which point necking is expected for each criterion, always in a similar region (α: early outside-FLC shear states [7, 9], afterwards toward plane strain). Here, the more path-independent the material is, the sooner and narrower it would neck. When taking equivalent shear limit strains > 0.52 [9], the UFL and FI would not predict any neck before a punch displacement of u > 50 mm where fracture occurred [8] while the MS result stays identical. For another cross die, a DP800 necks at u = 27 mm [10].



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