A Path-Independent Forming Limit Criterion for Stamping Simulations

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\textbf{Abstract.} Forming Limit Diagram (FLD) has been proved to be a powerful tool for assessing necking failures in sheet metal forming analysis for majority of stamping operations over the last three decades. However, experimental evidence and theoretical analysis suggest that its applications are limited to linear or almost linear strain paths during its deformation history. Abrupt changes or even gradual deviations from linear strain-paths will shift forming limit curves from their original values, a situation that occurs in vast majority of sequential stamping operations such as where the drawing process is followed by flanging and re-strike processes. Various forming limit models have been put forward recently to provide remedies for the problem, noticeably stress-based and strain gradient-based forming limit criteria. This study presents an alternative path-independent forming limit criterion. Instead of traditional Forming Limit Diagrams (FLD) which are constructed in terms of major – minor principal strains throughout deformation history, the new criterion defines a critical effective strain $\varepsilon^*$ as the limit strain for necking, and it is shown that $\varepsilon^*$ can be expressed as a function of current strain rate state and material work hardening properties, without the need of explicitly considering strain-path effects. It is given by $\varepsilon^* = f(\beta, k, n)$ where $\beta = \frac{d\varepsilon_2}{d\varepsilon_1}$ at current deformation state, and $k$ and $n$ are material strain hardening parameters if a power law is assumed. The analysis is built upon previous work by Storen and Rice [1975] and Zhu \textit{et al} [2002] with the incorporation of anisotropic yield models such as Hill’48 for quadratic orthotropic yield and Hill’79 for non-quadratic orthotropic yield. Effects of anisotropic parameters such as R-values and exponent n-values on necking are investigated in detail for a variety of strain paths. Results predicted according to current analysis are compared against experimental data gathered from literature and good agreements are achieved. This provides a powerful validation for this approach.

The new criterion retains all the advantages of the traditional FLDs since it's still constructed in the strain space. Its relationship with stress-based forming limit criteria is discussed. It is believed that the approach is especially suitable for production stamping CAE analysis since the strain rate state at any material point during forming deformation is readily available from FEA simulations. It can be easily embedded in forming simulation software or alternatively deployed as a post-processing function for forming simulations.