A More Accurate Approach to Evaluate Material Formability

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In sheet metal forming simulation, Forming Limit Diagram (FLD) has long been used to evaluate sheet metal formability. In conventional method, FLD is obtained by assuming linear strain path (Fig.1); while in real production environment, strain path can be very non-linear due to the complexity of geometry or different forming steps. Both experimental observations and theoretical analysis show that strain history will affect the final limit strain (Fig. 1). As a result, large safety margin has to be used for FLDs.

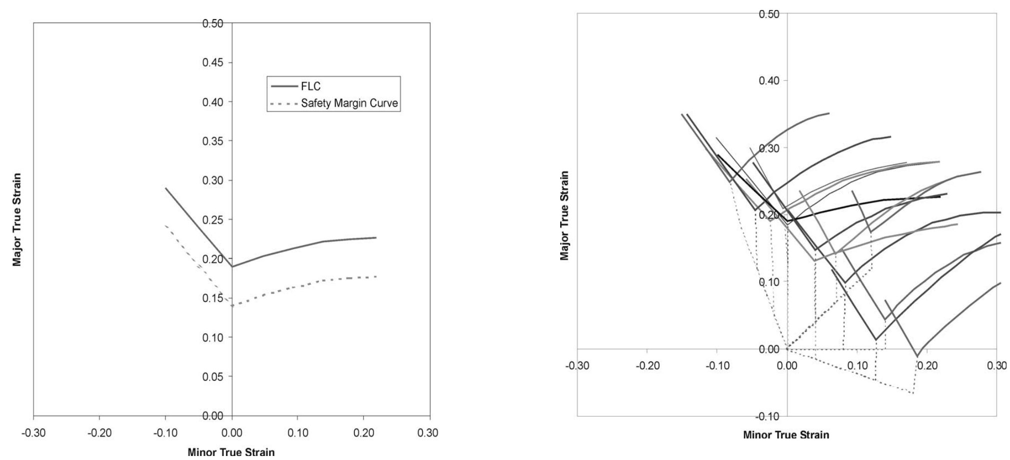

Figure 1. FLDs from linear and non-linear strain path [Stoughton and Zhu, 2003]

To find the effect of non-linear strain path on the forming limit, many studies have been conducted. Stress-based method, initially proposed by Stoughton, was found to be effective in considering strain path effect (Fig. 2). Later, Zeng et al, proposed a method based on critical effective strain (Fig. 3). It turns out both methods are nearly equivalent and can give the exact critical failure point.

Though both methods are theoretically sound, their applications to real production parts are not always easy. The critical value (stresses or critical strain) depends on the selected yield surface, and users have to convert the conventional FLD into the new space, which can be a challenge for most of the users. In addition, to effectively apply the methods in production environment, sophisticated user-interfaces have to be developed. Furthermore, wrong conclusions could have been drawn if the new theories are used inappropriately.

Formability Index (FI) was recently implemented into LS-DYNA version 971 (R5) based on the aforementioned theories, and it can successfully take into account the strain path effect and significantly simply the user interface. Figure 4 is a sketch showing how FI is calculated corresponding to a certain value of strain ratio. For virgin material, FI is assumed to be zero; and it fails when FI reaches 1.0. FI can be activated using keyword *MAT_TRANSVERSELY_ANISOTROPIC_ELASTIC_PLASTIC_ NLP_ FAILURE. It is stored in a history variable and can be plotted in LS-PrePost through FCOMP/MISC. In an example provided as shown in Figure 5, both locations "A" and "B" were shown as safe in conventional FLD. When examined in FI vs. time space, both locations were predicted as failure, with the failure of location "A" preceding location "B". In reality, location "A" failed relieving nearby location "B" of unsafe strains.

Reference

1) T.B. Stoughton, X. Zhu, "Review of Theoretical Models of the Strain-Based FLD and their Relevance to the Stress-Based FLD, International Journal of Plasticity", V. 20, Issues 8-9, P. 1463-1486, 2003.

2) Danielle Zeng, Xinhai Zhu, Laurent B. Chappuis, Z. Cedric Xia, "A Path Independent Forming Limited Criterion for Sheet Metal Forming Simulations", 2008 SAE Proceedings, Detroit MI, April 2008

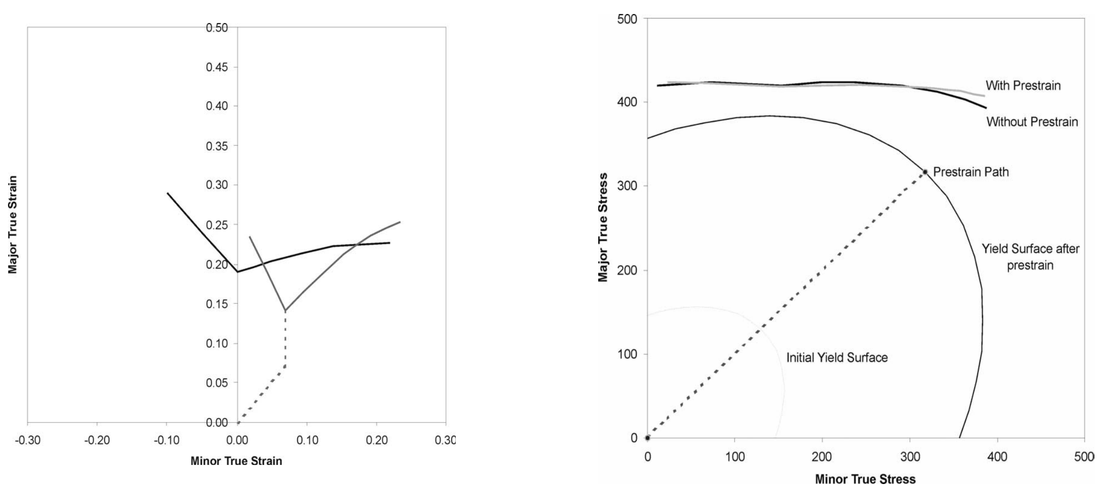

Figure 2. Stress based method [Stoughton and Zhu 2003]

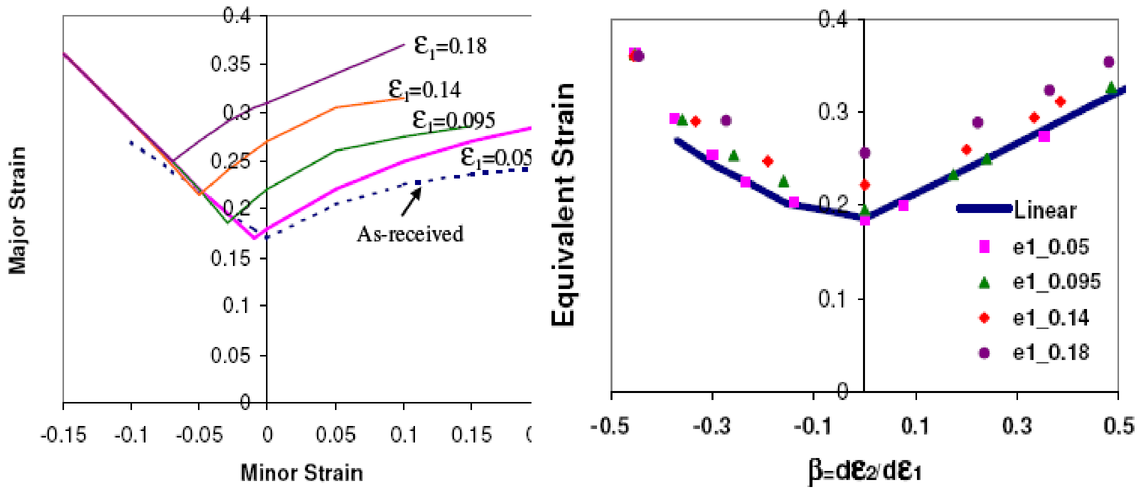

Figure 3. Critical effective strain based method [Zeng et. al, 2008]

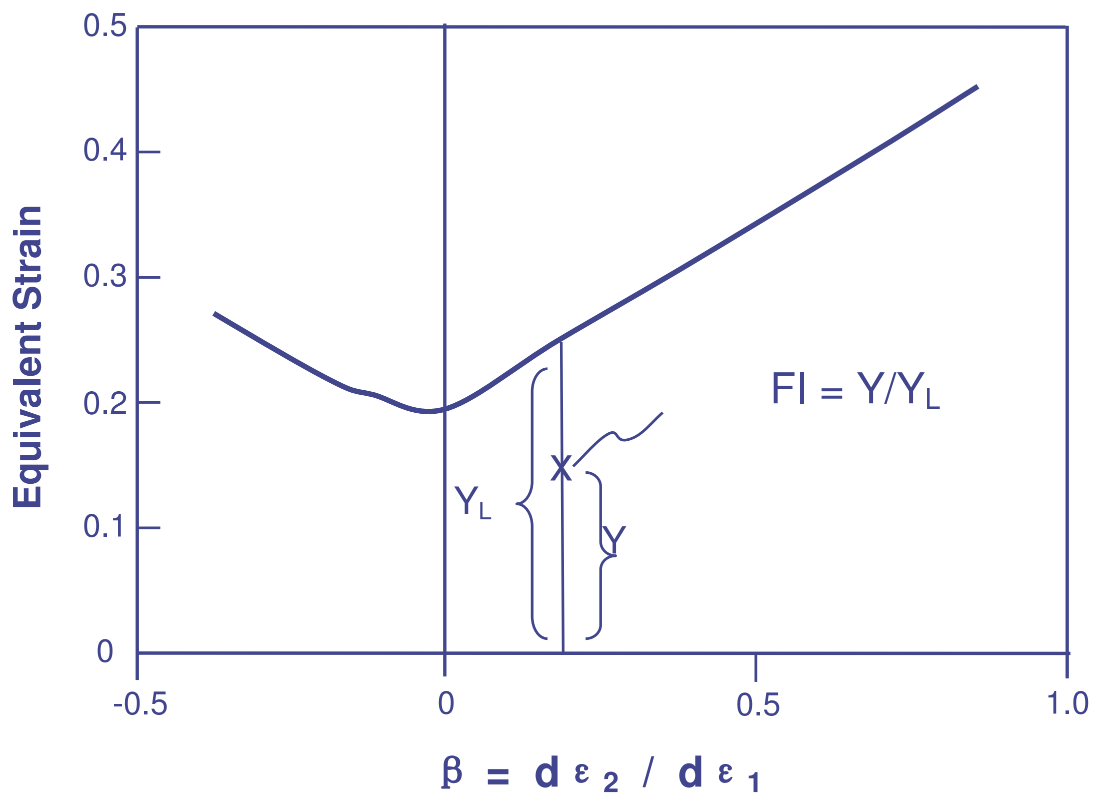

Figure 4. Calculation of FI based on critical effective strain method

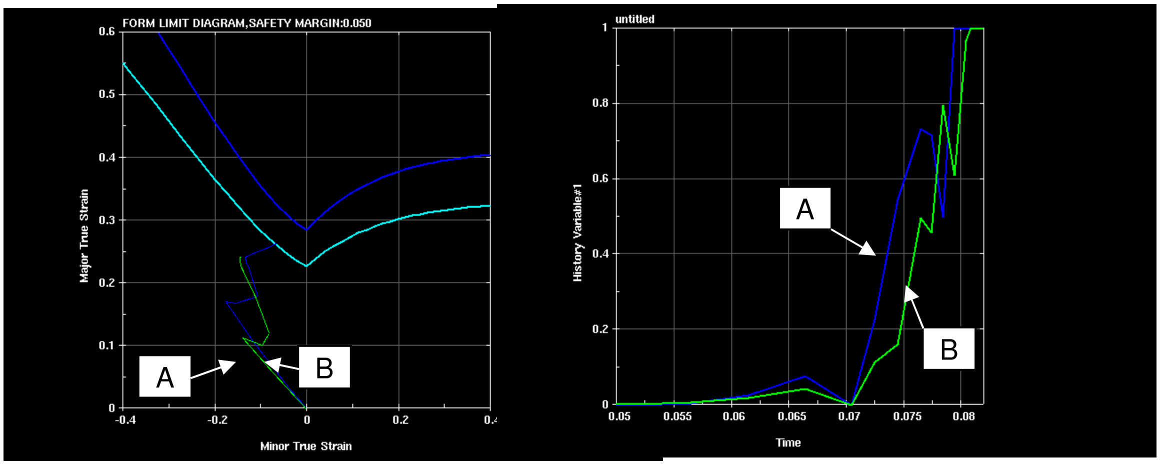

Figure 5. Effect of non-linear strain path