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Technical paper

Path independent limiting criteria in sheet metal forming

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ABSTRACT

The Forming Limit Diagram (FLD) is a conventional failure diagram to estimate necking limits of sheet metal for proportional loading conditions. Previous studies reveal that the FLD is not suitable for predicting the influence of nonlinear strain paths. This paper presents methodical comparison among all common available strain path independent strain/stress based limiting criteria. All the strain path independent strain based limiting criteria (Traditional Failure Diagram (TFD), Extended Forming Limit Diagram (XFLD), Extended Stress Ratio Based Forming Limit Diagram (ESRFLD), and Polar Effective Plastic StrainDiagram (PEPSD)) and stress based limiting criteria (Traditional Stress based Failure Diagram (TFSD), Stress Based Forming Limit Diagram (FLSD), Stress Ratio and Stress Based Forming Limit Diagram (SRFLSD), Extended Stress Based Forming Limit Diagram (XFLSD), and Polar Effective Stress Diagram (PESSD)) are approximately path-independent for smaller amount of pre-straining and path dependent for large pre-straining conditions. From advance image correlation technique precisely determination of local strains near necked area is possible today. However direct determination of local stresses near necked area is not possible. Therefore, local stresses and equivalent stress are determined by employing both yield criterion and strain-hardening law. Similarly equivalent strain is calculated by the use of yield criterion. Therefore, the choice of yield criterion has an impact on the results for TFD, XFLD, ESRFLD and PEPSD. However, selections of both yield criterion and strain-hardening law have substantial influence on the results for TFSD, FLSD, SRFLSD, XFLSD and PESSD. The inherent calculation error can be minimized by generation of experimental data for each material and then selection of representable yield criterion and strain-hardening law. Improvement of experimental techniques and generation of rigorous material data bank in various strain paths may help researchers to diagnose and resolve the issue. TFD, TFSD and XFLSD have inherent variables to take care the effect of through thickness stress, however rigorous experimental verification is needed before the field application.

1. Introduction

Remarkable efforts have been devoted to understand the physical nature of forming limits in sheet metal forming operations due to the wide use of Forming Limit Diagram (FLD) in sheet metal forming industry. The forming limit is generally defined as the ability of metal to deform without necking or fracture into desired shape. The sheet metal can be deformed successfully without failing only up to a certain limit, which is normally known as forming limit curve (FLC). FLC is generally governed by localized necking (an instability phenomenon), which eventually leads to the ductile fracture [1,2]. The FLC can be divided into two branches: "left branch" and "right branch". The "right branch" of FLC is valid for positive major and minor strains (i.e. stretching), while the "left branch" of FLC is applicable for positive major and negative minor strains (i.e. drawing). The FLD is a plot of limit strains in principal strain space under linear (i.e. proportional) strain paths. The FLD is experimentally determined through limiting dome height examinations where a hemispherical punch is used to deform a sheet until localized neck or fracture observed. The state of strain near the necked region is called the forming limit strain. The limiting strains along different strain paths (e.g. uniaxial, plane strain and equi-biaxial) can be achieved by altering the initial blank size. The forming limit strains are predicted by the onset of localized necking. Localized necking is observed during ductile fracture of the materials due to void nucleation, coalescence and growth with strain paths ranging from uniaxial tension to equi-biaxial tension. However in case of materials with low ductility, fracture often occurs without any obvious necking phenomenon. The sheet metal forming is different

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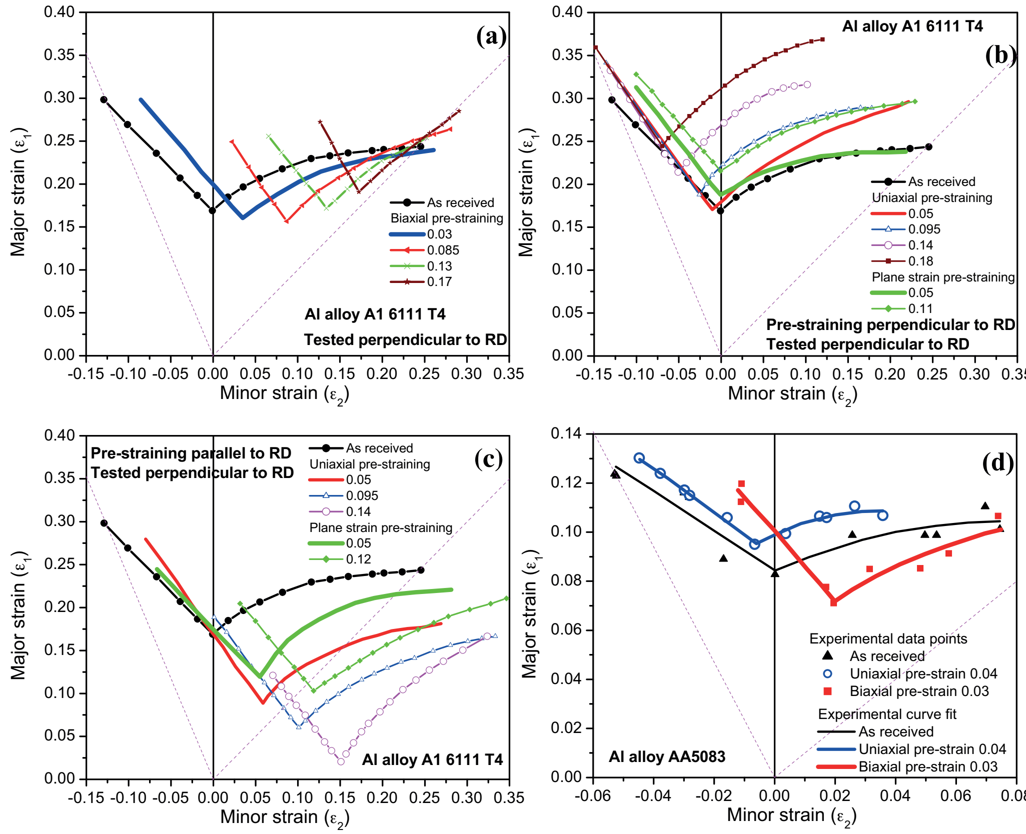

Fig. 1. Forming Limit Diagram (FLD): major strain (ε_1) vs. minor strain (ε_2) plot: (a) biaxial pre-strain paths of Al alloy A1611T4 [4] (b) uniaxial and plane strain pre-strain paths; pre-strain given in parallel to rolling direction (RD) of Al alloy A1611T4 [4] (c) uniaxial and plane strain pre-strain paths; pre-strain given in parallel to transverse direction (TD) of Al alloy A1611T4 [4] (d) uniaxial and biaxial pre-strain paths of Al alloy AA5083 [7].

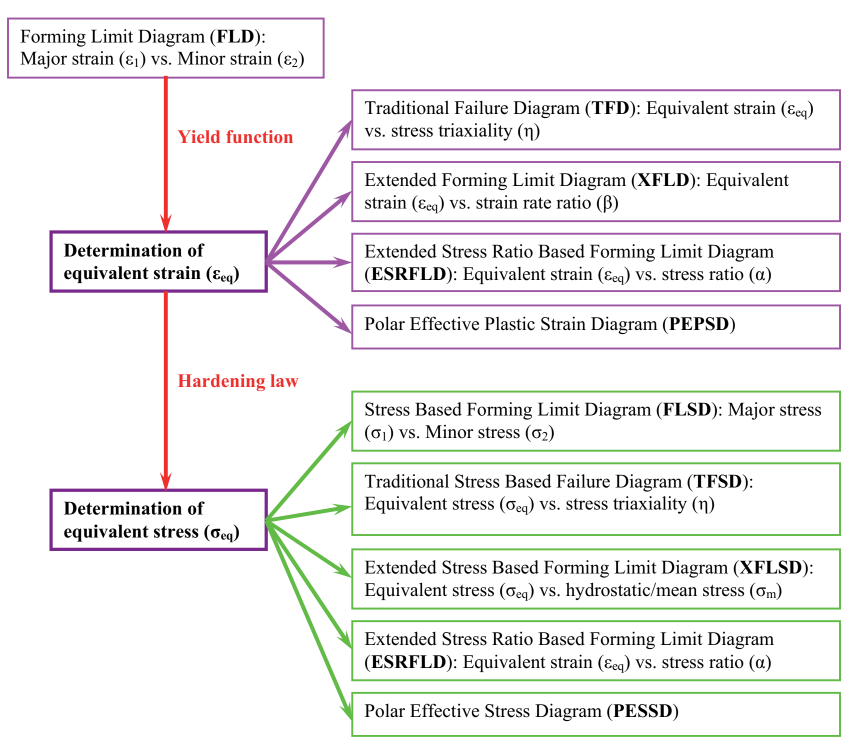

Fig. 2. Schematic diagram of procedure to determine path independent criteria.