

Article

Analysis of Forming Limits in Sheet Metal Forming with Pattern Recognition Methods. Part 2: Unsupervised Methodology and Application

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Abstract: The forming limit curve (FLC) is used in finite element analysis (FEA) for the modeling of onset of sheet metal instability during forming. The FLC is usually evaluated by achieving forming measurements with optical measurement system during Nakajima tests. Current evaluation methods such as the standard method according to DIN EN ISO 12004-2 and time-dependent methods limit the evaluation range to a fraction of the available information and show weaknesses in the context of brittle materials that do not have a pronounced constriction phase. In order to meet these challenges, a supervised pattern recognition method was proposed, whose results depend on the quality of the expert annotations. In order to alleviate this dependence on experts, this study proposes an unsupervised classification approach that does not require expert annotations and allows a probabilistic evaluation of the onset of localized necking. For this purpose, the results of the Nakajima tests are examined with an optical measuring system and evaluated using an unsupervised classification method. In order to assess the quality of the results, a comparison is made with the time-dependent method proposed by Volk and Hora, as well as expert annotations, while validated with metallographic investigations. Two evaluation methods are presented, the deterministic FLC, which provides a lower and upper limit for the onset of necking, and a probabilistic FLC, which allows definition of failure quantiles. Both methods provide a necking range that shows good correlation with the expert opinion as well as the results of the time-dependent method and metallographic examinations.

Keywords: forming limit curve; pattern recognition; sheet metal forming; machine learning

1. Introduction

The forming range of sheet metal is assessed in terms of the forming limit curve (FLC), where the limits are typically defined by the major and minor strain pairs, with the onset of necking. In Europe, the FLC is evaluated according to DIN EN ISO 12004-2 [1], where stretch tests are carried out according to the Nakajima [2] and Marciniak [3] setups. In these setups, the sheet metal is clamped in a clamping unit and subsequently, a hemispherical or flat-shaped punch deforms the specimen until fracture. The evaluation method proposed in the ISO standard is based on the Bragard study of 1972 [4] and is referred to as the “cross-section method”. In this approach, the strain distribution of the material is evaluated just before failure. Here, sections are defined perpendicular to the crack initiation and the strain development is approximated with a second-order polynomial. Traditional strain measurement

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