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Accurate deep drawing simulation by combining analytical approaches

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ABSTRACT

The basic contribution of this work is the description of the development of an analytical simulation method for deep drawing processes. By considering multiple deformation steps, this method takes time dependent process parameters and non-linear deformation paths into account. Contrary to existing analytical approaches, this method allows an accurate strain prediction and, thus, a prediction of formability. Compared to numerical onestep solvers, the developed method is much faster, and due to a better consideration of deformation paths, also a higher accuracy is reached in simulating axisymmetric and prismatic parts. Due to its efficient combination of computation speed and accuracy, this method allows an application in fast process optimizations or online process control systems, where existing approaches are either too slow in case of numerical simulation or too inaccurate in case of analytical simulation.

1. Introduction

Process design in deep drawing by finite element methods (FEM) is very time-consuming. The development of fast simulation algorithms allows decreasing the costs of process optimization and even offers the possibility to improve process robustness by application as a basis in closed-loop process control strategies.

Many analytical as well as numerical approaches were developed by different researchers to allow a fast calculation of deep drawing processes. Oehler and Kaiser [1] developed an analytical method to calculate blank shapes of deep drawing parts by unwinding radial section lines. Rambke and Doege improved this method by introducing a shape function to predict radial straining of section lines [2,3]. Rambke [4] realized a further improvement of radial straining prediction by calculating the sheet thicknesses in six deformation zones of axisymmetric cup geometries with a finite difference method, which neglects the thinning caused by tension bending effects. Another approach often used to calculate blank shapes is the slip line field theory [5–7]. Glöckl [8] implemented a simulation software for blank shape predictions using this method. The slip line field theory also allows the calculation of stress and strain distributions in the part, but with poor accuracy due to the assumption of plain strain deformation. A geometric mapping method was proposed by Gerdeen [9,10] and Gerdeen and Chen [11] to calculate strain distributions in sheet metal parts including a consideration of given sheet thickness distributions. Kim and Kobayashi [12] developed a method to calculate blank shapes with a field of linear material flow lines described by different parameters, which were determined by experimental results. An upper bound approach to predict optimal blank shapes of axisymmetric deep drawing processes with anisotropic hardening was presented by Agrawal et al. [13]. Other approaches were developed with the aim of predicting the required punch force. An important contribution was made by Siebel [14], who developed, with some simplifications, a compact formula to calculate the punch force of axisymmetric parts considering ideal, friction and bending forces. Ramaeckers et al. [15] used a similar approach with fewer simplifications to study the limit drawing ratio. An improved method was proposed by Doege et al. [16] using the principal of virtual work to predict punch forces The most important fast simulation approach is the inverse finite element approach (IFEA), which is available in commercial software products like e.g. Autoform-Onestep or HyperForm, and established in industrial practice in preliminary process design. This method allows the prediction of strain distributions in deep drawing parts by calculating the blank geometry from a given part geometry in one single deformation step [17–20]. With a computation time ranging from a few seconds up to a few minutes, this method is much faster than the incremental finite element simulation.

The analytical simulation methods described above are more or less restricted in their application in process design. Most methods aim to predict blank shapes or punch forces, which are only single aspects of process design. A calculation of strain distributions in 3D parts is not possible or not accurate enough to allow a formability prediction. The IFEA provides this formability prediction, but the process optimization is restricted by the neglect of deformation paths. For example, kinematic hardening or changing blank holder forces cannot be considered. Also

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