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Process-integrated Compensation of Geometrical Deviations for Bulk Forming

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Abstract

In many cases the design and development of bulk forming processes bases on inefficient trial-and-error procedures consisting of various iterations of numerical and real tests. To address this issue, a new numerical strategy to compensate systematic deviations of bulk-formed parts is deduced. Due to a parameter-based approach, control points allow for a direct mapping between the die and the workpiece. Thus, based on the required part shape, it is possible to directly adjust the die, where any kind of geometrical input data can be provided to derive a systematic compensation. The purely geometrical approach takes into account the entirety of systematical effects regarding deviations in bulk forming. The proposed concept is shown theoretically and moreover validated as well as verified utilizing deviation data of three manufactured industrial bulk-forming parts.

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Keywords: bulk forming; forging; compensation; parameter-based approach; control points

1. Introduction

The complex interactions of the thermo-elastic-plastic material behavior as well as the tool-workpiece system in many cases do not allow a sufficiently precise numerical modeling of the bulk forming process in a classical way [1]. This results in an increased need for prototypic tools and an elevated control expenditure during manufacturing. Furthermore, the digital or numerical support of the design and construction processes (Computer Aided Engineering, CAE) is currently not taking place in a holistic environment, but is divided into a constructive (Computer Aided

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Design, CAD) and a simulative part (e.g. Finite Element Method, FEM) [2]. Due to this separation, a hardly automatable reconstruction process of forming tools and components in CAD based on the discrete results is required. This holds considerable potential to significantly reduce time for development processes in bulk forming. Not only in the context of shorter product life cycles and increased product diversity, the process design and development is a major factor for profitability and success [2, 3].

2. State of the Art

Bulk-formed parts vary in their accuracy level due to different factors like material properties, complexity and size of the part as well as the used manufacturing process. In general, component accuracies achieved by conventional bulk forming are IT 14-16 (ISO tolerance range) according to DIN EN ISO 286-1. Regarding the precision hot forging process, component accuracies of IT 7-9 can be attained [4, 5]. The accuracy limits depend on the entire system consisting of the workpiece as well as the die and the used forging press. The main influencing factors arising during the forging process are the friction conditions and the elastic tool deformation, but also the material properties, the stress state and the prevailing temperature distribution in the tool and the workpiece. Further decisive factors for the dimensional deviations of bulk-formed components are secondary flow [6], dissipation of plastic forming energy into thermal energy, thermal expansion, shrinkage [7-9], the elastic proportion of the component deformation [10], volume changes due to structural transformations and subsequent process steps such as heat treatments or machining [11-14].

Approaches determining correction values to compensate the tool geometry are often exclusively based on results of numerical analysis taking the elastic deformation of the die or thermal influences into account. [4, 10, 15-17]. Frequently, a coupling of the numerical results with the surface reconstruction is utilized in order to optimize the tool shape [18-23]. The current course of action hardly meets the requirements of flexibility and integrability. Hence, a holistic methodology for the process-integrated deviation compensation for bulk formed components is presented, taking into account the entirety of deterministic effects for deviations by utilizing a pure geometric approach.

3. Problem Formulation

The problem of process-integrated compensation emerges as an inverse problem since the die geometry is part of the input data of the process next to e.g. material parameters. Hence, the compensation of the die shape could be formulated as an optimization problem [24]. For the modeling, an appropriate description of the geometry by certain design variables is inevitable. Typically two strategies are differentiated: The parameter-based and the parameter-free approaches [25, 26]. In parameter-free methods discrete nodal positions as of finite element meshes are typically associated with design variables, e.g. as presented in [27]. Because of the difficulty to maintain a smooth boundary, further developments led to a separation of the analysis model and the design model and thus, parameter-based representations came up. First, polynomials were used to describe the boundary shape, but due to problems with shape oscillations and thus a lack of local control for the design process, spline curves were used for the geometric representation [3]. Braibant and Fleury [28] as well as Fourment and Chenot [29] employ a parameter-based approach using the position of control points of Bezier and B-Spline curves as design variables. In [19] the approach is applied for a shape optimization of a forging preform.

Although the parameter-based representation of the geometry offers a suitable mathematical framework previous approaches do not address the continuity within the CAE environment in a holistic way. Within applied approaches no direct connection between the tool and the component geometry is established, but a detour using two geometric representations in the form of a discrete component and a discrete tool mesh. Since the uniqueness in the allocation of material points between tool geometry and component is not given, a systematic die modification based on discrete component data is hardly possible. Systematic in this context means that detected deterministic deviations of the component either from real measurements or simulation data can be used to compensate the die shape by a predefined rule. In order to incorporate real measurement data for the numerical adaption process, to deduce a general and systematic shape correction rule as well as to link all pieces of the CAE environment, a holistic parameter-based method for the process-integrated numerical compensation of bulk forming is developed.