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Friction control for accurate cold forged parts

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ABSTRACT

An oscillating ram movement can be used to reduce friction and thereby forming forces in cold forging. This effect is attributed to the rebuilding of the lubricating film during back stroke. A corresponding motion control also affects the final part's geometry and enables a reaction to uncertainties like the actual semi-finished product properties. Based on numerical and experimental investigations the paper discusses the potentials and prerequisites of this kind of closed-loop control of the final part's geometry.

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1. Introduction

High quality products generally stand out due to narrow tolerances in the final part's geometry. Keeping close dimensional tolerances allows for numerous favorable product properties like attractive appearance, low level of noise pollution, smooth movement of mechanisms or high safety of operation.

Different uncertainties come along with manufacturing processes and impair achievable tolerances. This paper focuses on cold forging processes. For cold forged products a high sensitivity of the product geometry to fluctuations in semi-finished product properties is crucial [1].

Uncertainties in manufacturing processes can be controlled by different approaches. A conventional way is to reduce the occurring fluctuations of the manufacturing process and system properties. When applied to cold forging, semi-finished product properties have to be restricted, which usually yields higher cost [2].

Other approaches use adaptions of process parameters to compensate varying manufacturing system properties. Several studies of metal forming processes made use of adaptive controls. In incremental sheet metal forming [3], deep drawing [4] and ring rolling [5] the material flow and the final product geometry are controlled. Furthermore, it is documented in [5] that finite-element simulations are useful tools for the layout of the control. The approaches mentioned before employed either multiple driven axes to modify the positions of tools [6] or an adjustment of the primary drive operation [7]. Both possibilities are facilitated considerably by modern servo drives.

Although cold forging is a widespread technology for the production of quality products, investigations on closed loop control for these processes are rare. So far, uncertainties resulting from varying properties of the semi-finished products can hardly be controlled by an adaption of the forming process. Consequently, variations of semi-finished product properties in geometry or material quality lead to fluctuations of the tool load. This induces different expansions of the tool during the forging processes and thus a change in the final part's geometries. Conventional approaches to restrict this effect concentrate on the die design. One effective measure is the use of strip-wound containers instead of reinforcing rings to improve the prestress condition inside the tool [8].

This paper discusses prerequisites of cold forging processes with a closed-loop control of the final product's geometry. It is restricted to adjustments of the primary drive operation and makes use of oscillating movements of the tool or workpiece. The manufacturing of a toothing serves as an example. A state of the art strip-wound container (STRECON Dyna-Fit) is employed in the experimental investigations.

2. Oscillating cold forging

Oscillating forming of longitudinal toothings is an incremental bulk metal forming process [9]. In this kind of forming process the linear feed motion of the tool or workpiece is superimposed by a reciprocating motion. It is nowadays industrially used to produce high quality toothings, e.g. drive shafts (Fig. 1, right), on hydraulic servo presses. The use of oscillating ram movements during

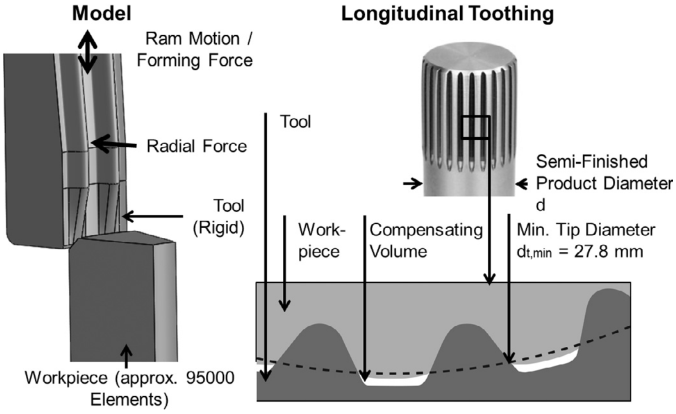

Fig. 1. Numerical model (left) and formed gear (right).

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forming of toothings reduces the forming force up to 40% compared to a purely unidirectional movement [7]. Similar effects have been found in the compression of plates [10]. The force reduction is attributed to the rebuilding of the lubricating film during the back stroke. Due to that rebuild the friction and thereby the forming force is reduced. Furthermore, the change of friction conditions affects the material flow. Higher friction leads to a restraint in the axial material flow and thereby a larger tip diameter. Since friction depends on the ram movement, forming force and material flow can be controlled by the control of the main press drive.

The following studies are carried out on an external toothing with module 1 and 26 teeth. The semi-finished products consist of cylinders with a diameter d made of 16MnCr5 (AISI 5115) whereas the tool is made of carbide metal. Oil with a viscosity of 41 $m/s^2/40\,^{\circ}C$ is applied as lubricant. In order to allow material volume compensation a corresponding compensating volume is provided (see Fig. 1, right). To ensure the functionality of the gear the tip diameter d_t must exceed $d_{t,min}$ but does not have to completely fill the mold. The oscillating ram movement is realized in the experiments by a mechanical servo press "synchro press SWPT 2500".

The numerical simulation is set up with Simufact Forming 10.0 (Fig. 1, left) which uses an implicit solver. Symmetry conditions are applied. Elements of type Hex8 (full integration) are used and remeshing is activated. Friction is modeled by Coulomb friction law with a friction coefficient depending on the sliding distance.

Experimentally in sliding compression tests according to [11] determined friction coefficients show an increase over the sliding distance. Fig. 2 left shows results of sliding compression tests carried out with contact normal stresses of 2200 N/mm^2 and 2500 N/mm^2. In both experiments friction is initially represented by a friction coefficient of approximately $\mu = 0.1$ and rises with increasing sliding distance.

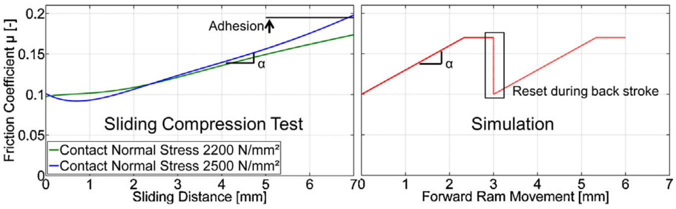

Fig. 2. Friction coefficient determined in sliding compression tests (lubricant: Zeller + Gmelin Multidraw CF4) and numerical simulations.

The friction coefficient in the numerical simulation is modeled according to Fig. 2, right. It starts with an initial value of $\mu = 0.1$ and increases linearly during the forward stroke. Quantitative differences between results of best-fit numerical analysis and results of sliding compression tests are attributed to higher levels of contact normal stresses (locally up to 2900 N/mm^2) in the cold forging experiments which could not be reached in the tribological tests so far. A back stroke is accounted for by a reset of the friction coefficient to the initial value. Assuming a maximum contact normal stress of 2900 N/mm^2 the friction coefficient is limited to $\mu = 0.17$. This prevents exceeding the shear yield stress of the material.

In order to control the relevant tooth root geometry of the longitudinal toothing the forming force is controlled. Fluctuations of the forming force can result from varying properties of the semi-finished products. As described above, these fluctuations lead to different expansions of the tool. Negative impacts on the workpiece geometry could be avoided by a closed loop control of the forming force according to Fig. 3. The actual forming force $F(t)$ is limited to the maximum permissible forming force, the control force F_{max}, i.e. $F_{max} - F(t) = \Delta F(t) > 0$. As long as this condition is fulfilled the forward ram motion is sustained. If the actual forming force reaches the control force, a back stroke is initiated. During a back stroke the lubricant film can rebuild which will reduce friction (see Fig. 2, right) and thus the forming force during the beginning of the next forward movement of the ram. Due to that control a ram movement is generated that ensures a constant maximum force independent of the semi-finished product properties.

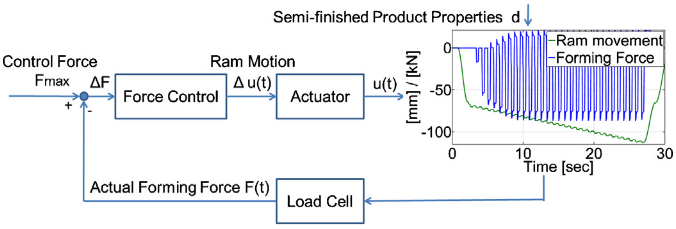

Fig. 3. Control strategy for accuracy-optimized cold forged parts.

The investigations described in the following should prove whether the application of this control strategy leads to a reduction of the influence of a varying semi-finished product' diameter on the final product' geometry. Additionally, the limitations of the control strategy are to be determined.

3. Results

The effect of a change in the semi-finished product diameter without using a closed-loop control is pictured in Fig. 4. This figure shows the experimentally determined forming forces generated by the nominal diameter $d_n = 27.3$ mm and diameters $d_n \pm 0.2$ mm. In these experiments constant forward strokes of 3 mm and backward strokes of 1.5 mm are used.

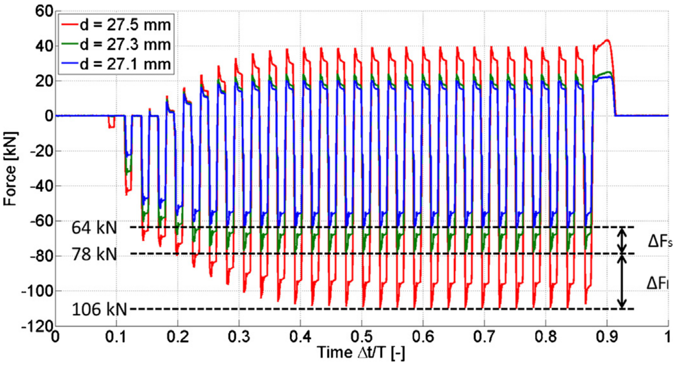

Fig. 4. Resultant forming force using semi-finished products with different diameters.

During the steady-state phase of the process the maximum forming force is about 78 kN using the nominal diameter whereas a larger (smaller) diameter leads to an increase (a decrease) of the forming forces. The retracting forces show similar effects. They rise with an increasing diameter and decrease using smaller diameters. Evaluating the geometry, the tip of the tooth is completely filled using a diameter of 27.5 mm which explains the larger difference of the forming force to the reference ΔF_l compared to the difference of the smaller diameter ΔF_s. The same applies to the retracting force. The root diameter rises by 15 μm using the larger diameter. This indicates a larger expansion of the tool due to the higher tool load. Using the small workpiece, the tip diameter falls below the minimum tip diameter and thereby functionality is not fully provided.

In the numerical model the above mentioned control strategy is implemented. The control variable is the actual forming force. In the numerical simulations the semi-finished product diameter is changed within 26.7 mm–27.7 mm as well as the control force F_{max} within 65 kN–130 kN. To investigate the impact of the control strategy on the toothing, the resultant ram motion, the tip diameter and the radial forces acting on the tooth forming die are investigated (Fig. 1).

Fig. 5 shows exemplarily the ram movements which result from the control with a control force of 84.5 kN. All simulations were stopped at the same process time T. The smaller the semi-finished

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