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Friction Conditions in Sheet-Bulk Metal Forming

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Abstract

The ongoing trend towards the increasing component functionality and closely-tolerated complex functional components shows the limits of classical sheet and bulk metal forming operations. The combination of sheet and bulk metal forming operations to the new process class of sheet-bulk metal (SBMF) operations gives the possibility to produce the requested parts. Combining sheet and bulk metal operations is leading to different surface pressures and hence to different tribological conditions within the forming process. Thus, the basic investigations of the tribological conditions in SBMF are described within this paper. Also the idea of tailored surfaces for providing process adapted tribological conditions to improve the forming process and a method for realization are presented.

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Keywords: Tribology, Surface, Microstructure

1. Introduction

Metal forming processes are suited for the economical production of high quality mass products because of its cost and material effectiveness. But today, the traditional sheet metal and bulk metal forming processes are often reaching limits when closely-tolerated complex functional components with variants are to be produced. A promising approach is the direct forming of high-precision shapes starting from blanks, defined as SBMF [1, 2, 3]. In SBMF sheet metal forming operations, such as deep drawing, are combined with bulk metal forming operations, like the extrusion of variants. While surface pressures and surface enlargement in sheet metal forming principally are low, high surface pressures accompanied by high surface enlargement are characteristic for bulk metal forming operations [4]. The combination of sheet and bulk metal forming operations within one forming process is leading to a side by side situation of low and high surfaces pressures and thus to high temporal and local changes in tribological conditions.

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Because of the varying conditions, it is clear that tribological conditions in SBMF are of major importance for the process realization, its stability and for the quality of the produced part. Thus, a method consisting of three friction tests has been developed [5] to model the different conditions. For the investigations on the tribological behavior in sheet metal forming the double sided strip drawing test was chosen. The Double-Cup-Extrusion test (DCE) enables the determination of frictional behavior in bulk metal forming applications [6]. The pin extrusion test is used to model the conditions that are predominant when forming variants.

Investigations on SBMF processes using FE-simulation software simufact.forming 9.0, especially in forming teeth out of the sheet plane, have shown that locally adapted friction values result in an improvement in mold filling [7]. In Fig. 1 the effect of locally adapted friction factors is shown, by using the distance between tool and workpiece for illustration. A global friction factor (Fig. 1 a) of m = 0.12 leads to an insufficient mold filling of 81.2 %. The locally adapted friction factors (Fig. 1 b), m = 0.3 and m = 0.05 in front and behind the teeth, respectively, lead to an increase in mold filling up to 87.1 %. Additionally the velocity vectors in Fig. 1 illustrate the improved material flow.

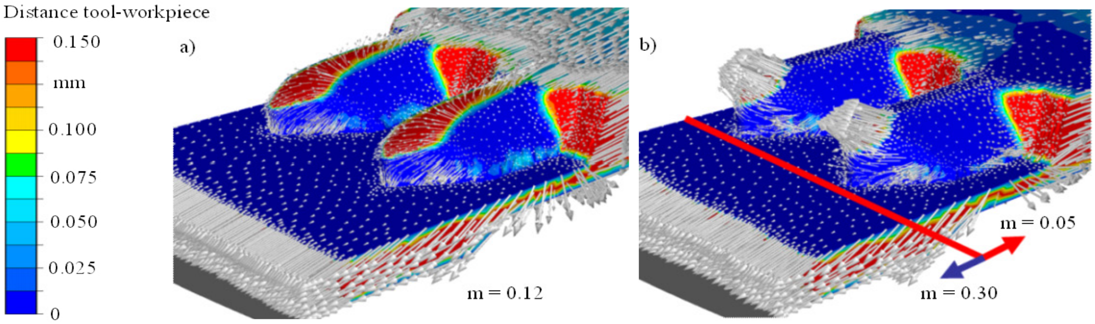

Fig. 1. FE-simulation of the material flow, represented by velocity vectors, with a global friction factor (a) and a local adapted friction factors (b)

To be able to provide process adapted tribological conditions tailored surfaces will be used. The general aim is to adjust the tribological conditions within the SBMF processes to the individual requirements of a certain forming operation. For its realization, process adapted semi-finished parts might be generated with geometrically determined and undetermined structures. Groche et al. describe in [8] the effect of reducing friction in bulk metal forming by implementing lubrication pockets.

2. Experimental setup

2.1. Friction tests

The strip drawing test is well established for the determination of the friction coefficient μ according to Coulomb in sheet metal forming. For the investigations in this paper a self-built double sided flat strip drawing test was used. Within the strip drawing test a specimen is clamped with a defined normal force F_N between two flat friction jaws and then drawn between them with a certain drawing speed while the friction force F_F is measured for determination of friction coefficient μ. The friction jaws have a length of 100 mm and a width of 50 mm while the specimens have a length and a width of 500 mm and 30 mm. All tools for the friction tests were made of the high-speed tool steel 1.3343 (HS-6-5-2C) and used in hardened condition (61 ± 2 HRC). The specimens for the investigations are made of DC04 having a sheet thickness of 2 mm.

The pin extrusion test has been chosen as test method because its forming conditions are close to those which appear when variants are formed out of the sheet plane. The process of pin extrusion can be seen as a combination of an upsetting and a forward extrusion process. In a pin extrusion test, a pin is generated out of specimen surface by pressing two upsetting dies together, while one of them has a cavity in the center, with a diameter of 1.5 mm and a shoulder radius of 1 mm. The specimens have a diameter of 20 mm. According to the tribological conditions a specific pin height is resulting for a defined punch stroke of 1 mm. Further information on the development of tool design can be found in [5]. Fig. 2 shows a schematic drawing and the principle of the test. The higher the friction gets between the specimen and the dies, the more the material flow in radial direction is restrained, resulting in an increasing material flow towards the pin cavity and thus to a larger pin height. As a direct identification of a friction factor is not possible, the numerical identification of the friction factor is done by modeling the test with the FE-software simufact.forming 9.0. As the DCE test is well known [6] and no results are presented within this paper, the third test of the chosen test methodology is not described in detail.

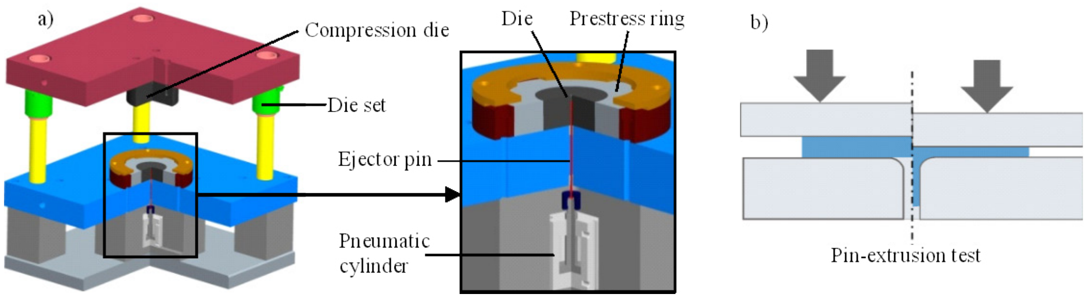

Fig. 2. Schematic drawing of pin extrusion test (a) and principle of the test (b)

2.2. Lubricants

As mentioned before, locally varying tribological conditions are predominant in SBMF, thus suited lubrication systems have to be determined. Because of the different load conditions in sheet and bulk metal forming many lubrication systems have been developed for the different process needs. On the one hand there are the demands of easy and steady application, resistance against being squeezed out, and on the other hand the environmental aspect has to be taken into account [4], thus lubrication systems with hazardous chemicals, e.g. chlorinated additives or phosphate have to be avoided. For the present investigation a deep drawing oil (Ometa IHV 36) and an extrusion oil (Dionol ST 1725-2) were chosen as representative lubricants. Also a water based non-poisonous lubricant with wax particles and high viscosity (Beruforge BF 150 DL) was selected, according to the trend towards environment friendly lubricants. The general aim of the lubrication tests is to provide suitable lubricants for SBMF that show good performance in sheet and bulk metal forming operations.

3. Results of friction tests

The strip drawing tests were performed with a drawing speed of 100 mm/s and surfaces pressures of 10 MPa and 20 MPa respectively. The application of the lubricants on specimen was manually done while the amount of lubricant (5 - 10 g/m²) was controlled with a pipette and homogeneously distributed with a paint roller. The results of the strip drawing test can be seen in Fig. 3 (a). In all cases, friction coefficients are below $\mu = 0.1$ and nearly independent of surface pressure. The lubricant BF 150 DL, originally developed for bulk metal forming, leads to the lowest friction coefficients. It can be assumed, that the wax particles in lubricant BF 150 DL lead to constant separation between tool and specimen within the mixed lubrication condition during the test.

The pin extrusion test was performed on a hydraulic press of the type LASCO TSP 1000 in speed controlled modus with a punch speed of 2.5 mm/s. For a repeatable upsetting distance of 1 mm an end stop was used. The determination of friction factor was done by measuring the total height at the top of the extruded pin on the specimen after the test and comparing it with specimen height evaluated within the FE-simulation for different friction factors. The lubricant BF 150 DL leads to the lowest friction factor, followed by drawing oil IHV 36. The highest friction factor is obtained when extrusion oil ST 1725-2 is used, as to be seen in Fig. 3 (b).
Summarizing the results of the first friction tests for the different load conditions in SBMF it can be concluded that BF 150 DL shows the lowest friction values in a strip drawing test as well as in a pin extrusion test. Thus, it can be expected, that these results will be approved in the upcoming DCE tests. It could also be shown, that the resolution of the pin extrusion test is high enough to show differences between small tribological changes, like different lubricants. Thus, the pin extrusion test is suited for investigation and qualification of tailored surfaces that are described in the next chapter.

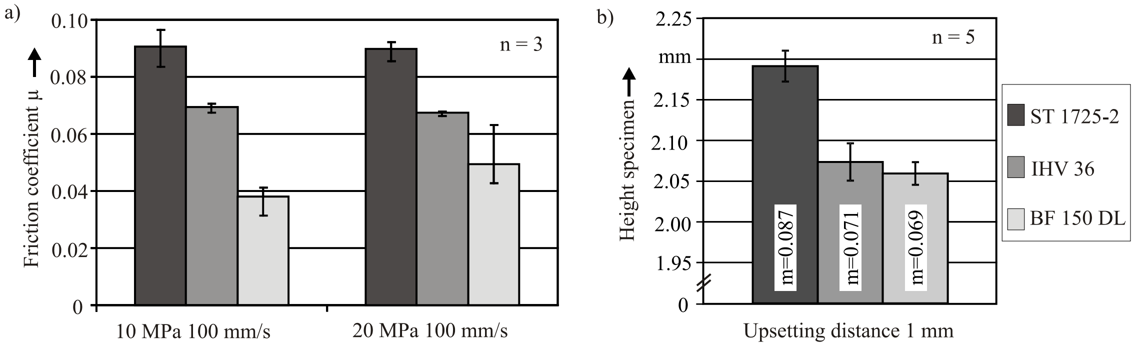

Fig. 3. Results of strip drawing test (a) and pin extrusion test (b)

4. Surface structuring by micro coining for realization of tailored surfaces

The aim of tailored surfaces is to provide specimen or semi-finished products with local adapted surface topographies, resulting in different frictional conditions, to extend the forming limits of processes in SBMF. The idea of process adapted surfaces is already well known in sheet metal forming were it is state of the art to use semi-finished products that are textured planar by rolling for improvement of deep drawability and paintability in the automotive sector [9]. As investigations in [8] have shown, the defined application of lubrication pockets on the surface of specimens leads to a decrease in friction in bulk metal forming. For SBMF, the aim is to decrease or increase friction by structuring only certain areas. One possibility to generate defined lubrications pockets on specimens is micro coining. Micro coining has the advantage, towards direct structuring techniques, like laser structuring, that the micro coining die has only to be manufactured once and can be used for the production of many specimens. The micro coining die for this investigation is manufactured by Micro Electrical Discharge Machining (μEDM) out of a steel block with an outer dimension of 30.0 mm x 30.0 mm, using a SARIX SX-200. The die has a coining area of 21.5 mm x 21.5 mm with 324 cylindrical micro punches. As punch geometry, to generate blind holes, a diameter of 300 μm, a height of 50 μm and a distance of 1170 μm between the centers of two punches was chosen. These parameters are leading to a surface coverage ratio of 5 %. After the manufacturing process the micro coining punches were characterized quantitatively by using the confocal white light microscope NanoFocus µSurf Custom. Deviating from the desired diameter 300 µm of the structures only an actual average value of 274 µm was reached. The desired height of the micro coining punches of 40 µm was reached well with an actual height of 40.3 µm. The reason for the lack in diameter of the structures has to be seen in an incorrect parameterization of a software based erosion process concerning the erosion gap between the tool electrode and the workpiece that will be avoided in the next tests.

For the coining experiment a universal testing machine Walter&Bai FS-300 with an upsetting set up was used (Fig. 4 (a)). The depths of the micro coined lubrication pockets according to the applied surface pressures can be seen in Fig. 4 (b). The surface pressures are defined by the ratio of applied force and the sum of the real front areas of micro punches. It can be seen that there is almost a linear correlation between pressure and depth, even though the scatter in pocket depth of 10 to 15 µm is quite high. The reason for the scatter has to be seen in a poor adjustment when mounting the upsetting setup leading to a slight tilting angel between the upsetting dies. This fault is to be eliminated in future by using a spherical calotte. The correlation between surface pressure and pocket depth gives the possibility to generate different depths of lubrication pockets by choosing a certain surface pressure. Thus, there is no necessity for producing a micro coining die for each desired pocket depth. This fact is important, as beside various depths also different geometries of lubrication pockets, such as spherical ones, are to be investigated for SBMF towards their influence on tribological conditions, leading to a high number of needed micro dies. As it is well known [10, 11] that the geometry of the lubrication pocket, especially the flank angel of the pockets, has an important influence on the tribological conditions. A SEM-picture of a single lubrication pocket (a) micro coined with a surface pressure of 2000 MPa and a cross-sectional profile (b) of the pocket are shown in Fig. 5.

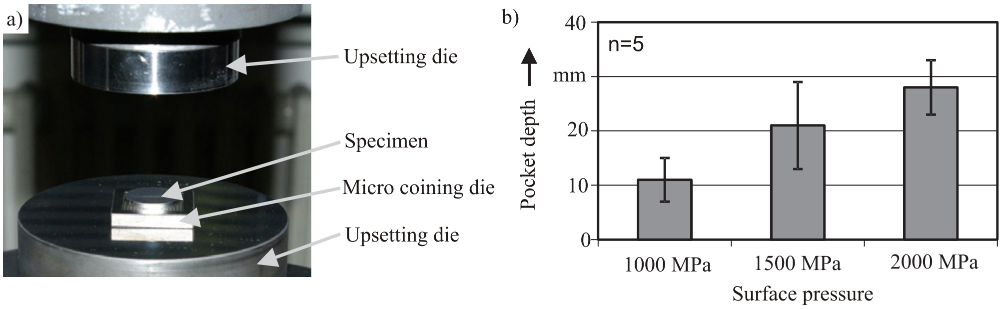

Fig. 4. Micro coning setup (a); achieved depths of lubrication pockets according to surface pressure (b)

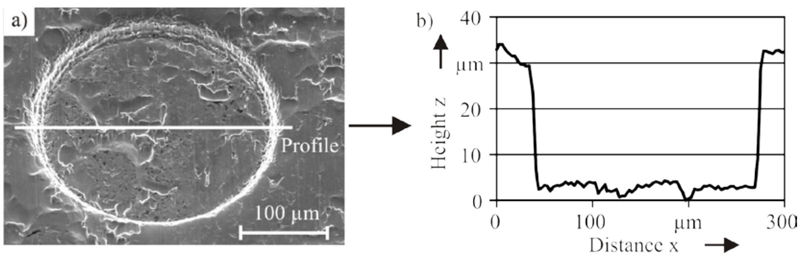

Fig. 5. SEM-picture of single lubrication pocket (a) and cross-sectional profile (b)

The SEM-picture and the profile illustrate that lubrication pockets can be manufactured uniformly and accurate by micro coining. This fact is important, because only if the coining process results in a precise pocket geometry it is possible to identify the influence on frictional conditions resulting from defined variation of the pocket geometry, for example different flank angles.

5. Summary and outlook

Within this paper it was shown that the investigation of tribological conditions in SBMF is of major importance for advancing this new process class. In first tests for finding appropriate lubrication systems for SBMF the lubricant Beruforge BF 150 DL indicates good results for low as well as for high surfaces pressures. Furthermore, the possibility to generate tailored surfaces by micro coining and first results of micro coining are presented. In next steps, the tailored surfaces with different geometries and depths of lubrication pockets will be generated by micro coining and investigated towards their influence on the tribological conditions. By enhancing the idea of tailored surfaces it is the aim to provide process adapted tribological conditions to be able to influence the material flow to form complex functional parts with SBMF that today cannot be produced with traditional forming processes.

Acknowledgements

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