Sheet-Bulk Metal Forming

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Synonyms
Plate forging

Definition
Sheet-bulk metal forming (SBMF) processes are defined as forming of sheets with an intended three-dimensional material flow as in bulk forming processes (Merklein et al. 2012). As semifinished product, sheets with an initial thickness of 1–5 mm are used and subjected to one or several conventional bulk forming operations. Typical applications of SBMF include the forming of local functional elements on blank parts or the intended and locally restricted alteration of the sheet thickness in order to produce highly functional integrated parts out of sheet metal (Fig. 1) (Mori 2012). Further complexity can be achieved by the combination of SBMF processes with traditional sheet forming operations like bending or deep drawing, which is generally possible for most applications (Merklein et al. 2012). Besides the fabrication of end products, SBMF can also be used to produce tailored blanks with adjusted properties for usage in subsequent manufacturing processes (Tan et al. 2008).

Theory and Application

Classification
According to DIN 8582 (2003), forming processes are categorized with respect to their stress states during the forming operation. This classification is not applicable to SBMF processes due to the fact that characteristics of multiple processes can merge in some cases and due to the missing consideration of the geometry of the semifinished part in question. Kudo (1980) proposed a different approach that enables a general classification of SBMF processes as a function of the semifinished parts in question, the resulting product geometry, and the strain state in relation to the main axis of the part. Standring (1999) proposed another, more detailed classification, which also uses the contact normal vector, as well as the ratio of the contact areas in the forming zone in comparison to the remaining contact area as criteria. However, since both approaches are kept very general, an exact assignment of process characteristics to the process class SBMF is not possible. In order to solve this challenge, Merklein et al. (2011) proposed a classification in respect to the tool motion as is displayed in Fig. 2. According to this
classification, upsetting, ironing, forging, and coining can be assigned to the group of linear tool motion, whereas flow forming, orbital forming, and boss forming processes possess a rotational tool motion. As Fig. 2 depicts, with the exception of orbital forming and boss forming, combinations with conventional sheet forming processes are possible in all cases. Additionally, nearly all process variants allow the selective, local thickening and thinning of the sheet in use. Regarding typical forming forces, big differences between the individual process variants exist. The force demands are generally determined by the size of effective contact area between the tool and the forming zone. In principle, smaller contact areas result in less process forces. Hence, the lowest force demands can be found in incremental forming operations like flow forming or orbital forming.

<table>
<thead>
<tr>
<th>Change in thickness</th>
<th>Linear tool motion</th>
<th>Rotational tool motion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upsetting</td>
<td>Ironing</td>
<td>Forging</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change in thickness</td>
<td>↑</td>
<td>↓</td>
</tr>
<tr>
<td>Combination with sheet forming known</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Forming force</td>
<td>High</td>
<td>Medium</td>
</tr>
</tbody>
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Material Flow
Most applications of SBMF aim to produce parts that possess local functional elements on sheet metal with an element height in the dimension of the initial sheet thickness. Due to the complex three-dimensional material flow necessary for the forming of the singular elements, the stress and strain states during the forming operation are complex and three dimensional as well. In contrast to this, the remaining blank area shows comparatively low two-dimensional stress conditions. The high strains in the forming zone of the elements result in high and locally restricted strain hardening that is surrounded by large areas of low strain-hardened material.

Due to the strain gradient, the material flow tends to be directed away from the functional elements and therefore results in incomplete...
forming. Figure 3 demonstrates this circumstance by means of an exemplary SBMF forging process that enables the forming of two different element shapes on a circular blank. In order to allow proper forming of the functional elements despite this, the material flow for a particular SBMF process has to be considered in detail during the process design, and measures have to be taken to control the material flow as desired. Current research shows that this can be achieved either by means of geometrical flow restrictors (Koch and Merklein 2013) or by a local modification of the friction between the workpiece and the tool as demonstrated by Löffler et al. (2015).

**Tribology**

Tribological conditions are of major importance in SBMF processes, due to their influence on the process quality and accuracy (Merklein et al. 2012). Hence, detailed knowledge on the friction behavior is important to allow proper tool and process design by means of FE simulations. In order to determine the required friction factors and friction coefficients, laboratory friction tests are utilized. However, since SBMF processes possess both characteristics of conventional sheet and bulk forming operations, the tribological conditions during SBMF operations are of high complexity and cannot be represented by one friction test alone (Hetzner et al. 2012). Tribological conditions vary locally in dependence of the stress and strain conditions present at the contact surface in question. For this reason, the combined usage of the three friction tests shown in Fig. 4, strip drawing, ring compression, and pin extrusion, has been proposed in order to represent the dominant stress and strain states during SBMF processes. Both the ring compression test and the pin extrusion test have been adapted for this purpose by Vierzigmann et al. (2013) to meet the conditions of SBMF.

**Tooling**

Due to the complexity and locally varying stress and strain conditions during SBMF operations, the requirements on tool design and load capacity are demanding. Especially forging processes result in very high tool contact stresses as has been demonstrated for example by Nakano (2009). Furthermore, forming of asymmetrical parts leads to inhomogeneous tool loading and increased horizontal forces. An example for an asymmetrical product and the corresponding tool system is displayed in Fig. 5. Furthermore, since tool load in the forming zone of the elements can be as high as in conventional cold forging that show values up to 2750 MPa, tool systems for SBMF have to be reinforced in many cases in
order to increase the load capacity and prolong tool life. For the same reason, the use of modern powder metallurgical high strength steels and innovate tool design, like non-circular reinforcements, are oftentimes necessary (Merklein et al. 2012).

**Modeling**

Since material flow and the resulting stress and strain conditions, as well as the tribological interaction between workpiece and tool, are complex and locally varying, process design by use of FE simulation is advisable. However, the modeling of SBMF operations currently presents a challenge due to limited computational capacity. Asymmetrical products prevent in part the exploitation of symmetries in order to reduce model size and therefore increase the number of necessary finite elements. Furthermore, the three-dimensional stress and strain states, which lead to the forming of the functional elements, require volumetric finite elements and fine meshing. If the same element strategy is used for the remaining blank area, a very high number of integration points will be necessary, which, in turn, will make the calculation difficult.

A powerful strategy to overcome this problem is the use of adaptive modeling based on the dual weighted residual method, which enables the local modification of the numerical mesh (Becker and Rannacher 2002). This way, it is possible to heighten the mesh efficiency in respect to the numerical demands without distinctly reducing the solution precision. Since SBMF processes typically possess high areas of contact between the workpiece and tool, efforts
have been made to apply the model adaptivity on friction problems as well, in order to further reduce calculation time (Rademacher 2015).

Besides the simulation of material flow and tool load, damage criteria have to be deployed to effectively use the forming potential in a given process. However, the conventional forming limit diagram cannot be utilized since the plane stress assumption cannot be applied to SBMF processes. In order to overcome this challenge, a topic of current research is the adaption of alternative damage models for the purposes of SBMF. For example, Soyarslan et al. (2014) have shown that this is possible for the Gurson model, as has been successfully demonstrated by means of a process where a w-shaped punch penetrates in the edge of a sheet metal with a thickness of 2 mm (Fig. 6).

Cross-References

▶ Cold Forging
▶ Sheet Metal
▶ Tailored Blanks

References