NUMERICAL ANALYSIS OF FORMING PROCESSES REGARDING THE PREDICTION OF PRESS FORCES

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ABSTRACT: A decisive criterion for the selection of the optimal press line within the press shop's layout plan is the required press force. The press force necessary to form the component is defined significantly by the stroke range and the corresponding bottom dead centre. The latter finalises the embossing process commonly used for reinforced structures on body components. The high forces required hereby strongly impact the deformation behaviour of the tool and the press and result in force requirements specific to individual presses. This paper deals with the accuracy of force calculation for forming simulations. In doing so, a reliable measuring setup is introduced for repeatable calculation of the necessary bottom dead centre. An abstract of the established criterion is developed and implemented in a solid forming programme used for high-precision force calculation. This is followed by examinations of the deformation behaviour of tools and presses.

KEYWORDS: forming simulation, press force, tool deformation, bottom dead centre

1 INTRODUCTION

Increasing efficiency in the product development process is achieved through standardisation and the synchronisation of the development and planning processes as well as through the shifting of workloads to the early phases of the product development process (frontloading). The objective is to allow the product to be influenced as early as possible with regard to production technology and economic aspects. Such influence is realised through digital factory techniques (e.g. simulation of production processes) and utilisation of experiences gained in previous projects.

Options for influencing individual body parts with regard to economic aspects and production technology – and thus options for reducing costs – are, for instance, increasing the material utilisation, elimination of process stages and the correct layout of suitable press lines. For example, assigning the optimal product spectrum to the press lines has a substantial impact on the line's productivity.

A decisive criterion for the selection of the optimal press line within the press shop layout plan is the press tonnage.

The continually increasing use of high- and higher-strength steels results in significantly higher required forces and demands a more precise calculation of the required press forces.

The previously used values are based on an embossing force calculation using CAD software [2], the determination of the maximum force in the forming simulation or a depth of experience with similar components. However, examinations have discovered substantial deviations between the calculated and the real values, which are based on insufficient criteria for bottom dead centre, on the use of shell elements during the embossing phase as well as on the fact that tool- and press-specific characteristics were not given consideration. These deviations can lead to substantial costs for changes/replanning where force requirements are underestimated and to high collateral costs where force requirements are overestimated.

2 ANALYTIC PROCEDURE

The press force required for optimal press allocation cannot be correctly calculated by current forming simulations due to the restrictions inherent in model creation. On principle, the required forces should always be defined as the press force, tool force and forming force as depicted in Figure 1.

Here, the forming force is that force which current forming simulations are able to calculate without

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considering elastic boundary conditions and which comprises bending, friction and ideal forming force. The accuracy of the simulation was examined in extensive laboratory tests in order to decouple the individual force proportions from one another.

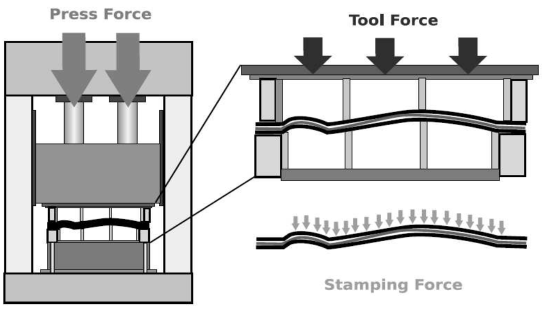

Figure 1: *Definition of required forces to form stamping parts [4]*

The tool force results from the elastic deformation work as well as the friction influences generated by the guides and the draw-bead opening forces and can be calculated using a force-measurement coupling plate. The tool influence was examined by setting up two tools with identical active surfaces but different base designs which facilitated the determination of the influence of the tool's rigidity on the force required and an assessment of the necessity to incorporate this factor in the forming simulation.

The press force also includes friction forces generated within the ram guides and additional deformation work particularly in the interaction between the ram and table rigidity. On mechanical presses, the press force can, for example, be determined through pressure measurements at the overload protection [1].

A comparison with the simulation thus raises three questions.

- How accurately do current programmes calculate the force requirement based on stroke?
- When is bottom dead centre reached in practice and in the simulation?
- How can the tool- and press-specific parameters be taken into account?

3 FORMING FORCE

The force required for the forming of a component – the overall total forming force F_T – consists of the proportions bending force F_B, ideal forming force F_I and friction force F_F.

$$F_T = F_B + F_I + F_F \qquad (1)$$

Bending force was determined by performing tests using a top-hat profile. With this type of swage bending with binder, the process itself eliminates stretch-forming proportions while the use of drawing film, drawing grease and displaced binder substantially reduces friction proportions. The matrix radius is 10 mm. In total, five different materials were tested at two material thicknesses of 1.2 and 2.0 mm. However, depending on the software, the subsequent simulation deviated from the experiments significantly, in some cases by up to 100%.

The ideal forming force was determined by conducting tests using hydraulic bulging at 200 mm diameter, which eliminated the friction proportion and also facilitated as low a bending proportion as possible. Three different materials at two different material thicknesses were examined. To allow a comparison, the forming degree was recorded via a matrix grid in addition to the displacement height. For the further comparison, flow curves were extrapolated using the collected data [5]. In addition, material thickness, geometry and main forming degree were incorporated in the comparison. The subsequent simulations were performed using the software Pam-Stamp 2G 2007. A good level of consistency with the experiments was determined. (Fig. 2)

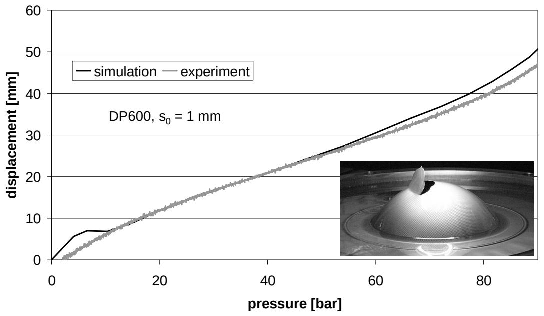

Figure 2: *Comparison of bulge test experiment and simulation*

No additional tests were conducted for the comparison of the friction values as a high number of tests have already been performed in this regard in the past and friction force ultimately has a negligible influence on the required forces for reinforcement embossing and the final embossing of the radii. (Fig. 3)

Finally, a multitude of tests were conducted for embossing using various numbers and shapes of reinforcements owing to the high force/travel gradient. Here also, five different materials at two material thicknesses were used.

Current commercially used simulation tools for blank forming do not offer satisfactory representations of the force curve for embossing. This can be explained by the restrictions in discretisation. The use of shell elements results in simplifications of the tension state in favour of calculation time.

Consequently, the stretch-forming production process embossing is to be recorded using an R&D tool from solid forming and employing volume elements. Figure 7 illustrates that the force curve when using volume elements deviates only marginally from the real-force curves up to shortly before bottom dead centre.

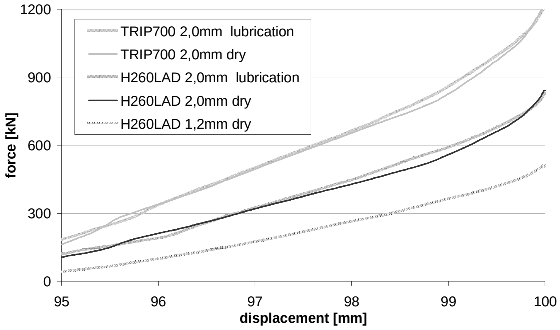

Figure 3: *Force curves for embossing varying parameters*

The deviations occurring shortly before bottom dead centre is reached can be attributed to the use of rigid tools and the lack of an abortion criterion for real tool closure.

The results arrived at allow the conclusion that the calculation of the force requirements throughout the deep drawing process can be depicted well for larger bending radii. To calculate the force required for embossing, good results are achieved through the use of a solid forming programme as of a few millimetres ahead of bottom dead centre.

4 TOOL CLOSURE

In practice, bottom dead centre is usually determined visually. Statements can be made regarding tool closure, for example by creating a blueing print, by comparing the target and the actual status of selected radii, by measuring the remaining drawing gap using lead fragments and by stamping a bottoming marker on the component (Fig. 4).

All currently employed methods suffer from subjectivity and thus from a lack of reliability when determining bottom dead centre. Furthermore, statements regarding tool closure are merely qualitative – the discrete point of time cannot be determined. It is therefore necessary to define a criterion for as precise a determination as possible of the time of tool closure and the acting forces. The most commonly employed method is the use of the bottoming marker (BM). Owing to the durability and the simplicity of documentation, this method is used in series production. Because of its proliferation in the press shop, the BM is to be used as the basis for the development of a quantitative criterion.

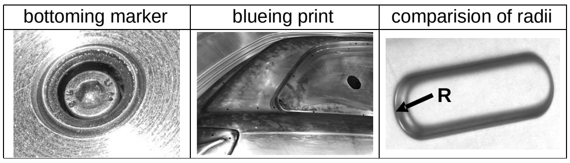

Figure 4: *Three options for determining bottom dead centre in practice*

To develop a method that will be suitable for series production, the force at the BM is to be measured using a force gauge. To this end, a miniaturised force gauge has been designed which will replace the standardised spacer disc beneath the BM. Thus, only a small additional bore for cable routing is necessary.

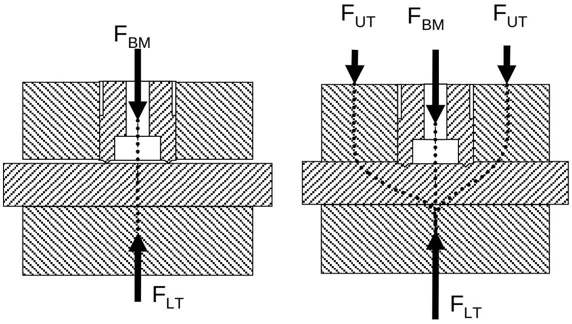

Figure 5: *Force flow through bottoming marker*

Laboratory tests using a tensile/pressure test device are to establish a characteristic criterion within the force curve, by which the discrete time of tool closure can be determined with the greatest possible accuracy. The force curve changes at the point of complete engagement as forming closure occurs in the tool, thus resulting in a closed-loop force flow (Fig. 5).

The measurements on the test stand are performed with varying blank quality, material thickness and BM shut height in order to determine all factors influencing the force curve and the ideal embossing force. A strong dependence on blank quality and BM shut height is apparent. Therefore, the ideal embossing force cannot be used as a criterion for bottom dead centre as the material and the BM shut height vary.

This means that a criterion is sought that displays the greatest possible independence of the stated factors.

The laboratory tests demonstrate that the force increase/time curve can be subdivided into characteristic phases. One of these phases is tool closure. Extensive tests using the tensile/pressure test device have shown that the qualitative force/time curve is independent of material, material thickness and BM shut height. The defined criterion determining bottom dead centre via the force increase was subsequently validated and verified using real tools (Fig. 6).

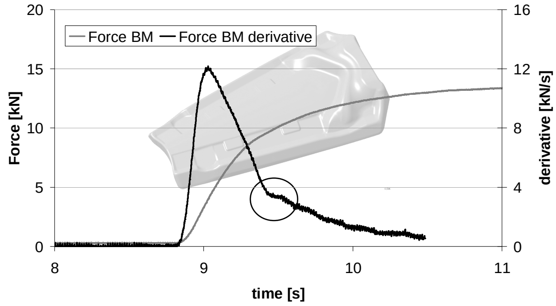

Figure 6: *Validation using real component*

In regard to the required punch force, the precise determination of bottom dead centre in simulations of blank forming processes is as important as the determination in practice.

As Figure 7 illustrates, an abortion criterion in regard to die filling is required. A basis for this is provided by the previously conducted examinations for the practical determination of bottom dead centre.

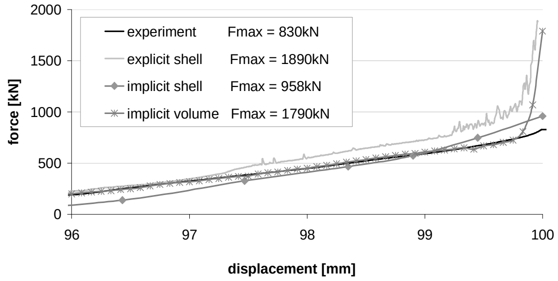

Figure 7: *Maximum force for various FEM programmes*

An initial approach is to geometrically integrate the BM into the simulation model (Fig. 8). However, this bears the disadvantage that the BM's diminutive dimensions necessitate a high mesh resolution for the component, in turn increasing calculation time. Also, cutting processes during the intrusion of the BM into the workpiece are only insufficiently depicted by the simulation leading to a corruption of the determined bottom dead centre in the simulation. Additionally, the geometric integration is only suitable where the workpiece is discretised by volume elements, thus ruling out the use of many blank simulation tools.

This means that a substitute model must be used as an aid. As the ideal embossing force in dependence of the material and the BM shut height has already been established by the laboratory tests, the minimum tension required for the complete forming of the BM can be determined.

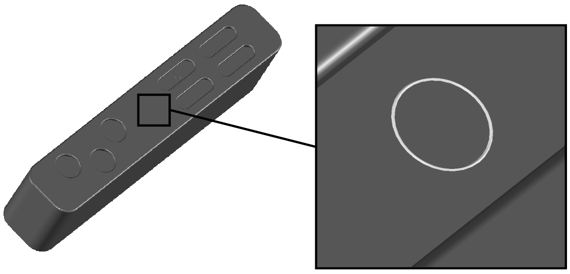

Figure 8: *Geometric integration of the BM into the simulation model*

Further examinations demonstrated an almost entirely linear interrelation between the ideal embossing force and the BM shut height. In consequence, the tension required for complete forming of the mark depend solely on the material. Instead of the geometric integration of the BM, a volume element has been placed in the die as a substitute model (Fig. 9). Volume elements offer the advantage of being able to depict all tension states.

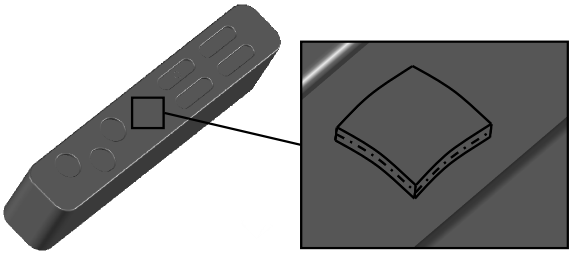

Figure 9: Substitute model

With the aid of the substitute model, the standard contact tension acting on the integrated volume element can be selected as the abortion criterion. If this standard contact tension exceeds the minimum tension value determined via relation (2), the abortion criterion has been met.

$$\sigma_{\min} = \frac{F_{embos}}{A_{BM}} \tag{2}$$

Figure 10 shows the curve for standard contact tension for the volume element. In benchmark tests, the abstract abortion criterion demonstrated a clear improvement in regard to the required forming force as determined in the simulation. Current abortion criteria, most of which are based on the principle of distance measurement, cannot guarantee that the simulated bottom dead centre is equivalent to the actual one.

Furthermore, initial examinations have demonstrated a necessity to integrate elastically modelled tools. Here, the force-controlled simulation has proven to be favourable, meaning that the corresponding criterion results in a clear improvement in regard to the determination of the required force – and corresponds to the bottoming marker used in practice.

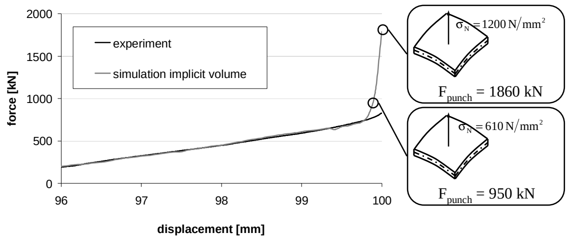

***Figure 10:** Force curves of experiment and simulation using Femutec Forging SFM 8.0*

5 TOOL DEFORMATION

Experiences from tool and die and the press shop have shown that tools in some cases require significantly different forces for component embossing when used on different presses. These discrepancies demand detailed examination of their causes as they can result in substantial problems if the forces are insufficient at start of production. This also leads to the necessity of taking tool- and press-specific characteristics into account in the forming simulation when calculating the required force.

To examine the influence of the presses, complete measurements according to DIN 55189 including additional table and ram deformation were performed. In the following, the results of the measurement of a 1,000-t hydraulic press, simulated under elastic boundary conditions, are compared. Here, only the deformation of the table proved to be a decisive factor.

Simulations using the entire press frame proved to be difficult as the press at times displayed asymmetrical behaviour contrary to the design drawings. In order to make a simple-parameter substitute model for the mounting available, the sliding bolster was mounted on a press bed, the behaviour of which was adapted via geometry and E-modulus to the measurement values resulting from the loading test (Fig. 11) [3].

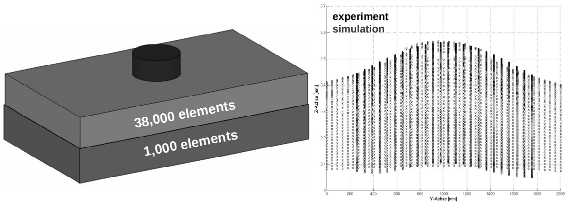

***Figure 11:** Parameterised table model in LS-DYNA and comparison of simulation and experiment*

Finally, measurements were performed using a longitudinal chassis beam tool. To determine the deformation beneath the tool, additional measuring bars equipped with eddy-current sensors were inserted into the grooves. The simulation showed a very high correspondence to the experiment (Fig. 12). It was possible to verify the significantly increased force required for the establishment of a uniform contact pressure image through a force-controlled simulation and a corresponding “read-out criterion”. The increased force requirement results from the use of the tool on a press with a substantially higher rigidity. The interplay of the highly rigid ram and relatively soft table results in substantial additional deformation work.

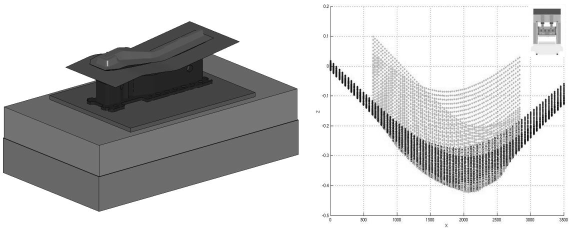

***Figure 12:** Punch on press table, contact behaviour of punch retainer and table*

6 CONCLUSIONS

The force required during the deep drawing phase when manufacturing body components can be depicted sufficiently by the forming simulation. Increasing deviation must be expected with an increasing share of small bending radii.

A significantly more accurate calculation of the maximum force required for embossing just before bottom dead centre is reached can be achieved in the simulation by using a solid forming programme. A future concern will be the implementation of algorithms suitable for mapping shell elements on volume elements.

An accurate and reliable determination of bottom dead centre is possible through the integration of a force gauge underneath the bottoming marker. Integration of an abstract bottoming marker in the forming simulation leads to clearly improved results.

Measurements show a substantial impact of tool and press on the maximum force required. Taking table and ram bending into account facilitates a more accurate press-specific calculation of the force required.

Further examinations will now focus particularly on the integration of substitute models into the forming simulation to allow for elastic boundary conditions so that these methods can be used in production planing.

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