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PATH-DEPENDENT PLASTICITY AND 3D DISCRETE FORMING

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Key words: Discrete die, sheet metal forming, non-proportional strain path change.

Summary. *The reconfigurable character of a small scale discrete die is used to obtain an optimally formed 3D workpiece after a sequence of individual forming steps. In general, the sheet metal is subjected to subsequent strain path changes in the imposed forming sequence. Experiments with the discrete die are used to validate the results of the numerical procedure and it is shown that the use of different strain paths can yield superior products compared to products which are manufactured in one single forming operation.*

1 Introduction

From an industrial perspective, considerable research efforts have focussed on the optimization of processing parameters such as blank design, restraining forces and blank-holder pressure in order to obtain products without defects (rupture, wrinkle) and in order to deal with elastic springback effects. Several optimization procedures in combination with inverse approach finite element methods are known, e.g. aiming for minimum plastic work or a homogeneous thickness reduction. In this study, a recently developed engineering concept, known as Discrete Die Forming, is used of which the first concept was introduced more than fifty years ago, initially designed for large scale (sheet) metal forming. Using a geometrically reconfigurable die, precious production time can be saved since a range of different product shapes can be made without changing tools. Additional cost-saving is realised because the manufacturing of expensive rigid dies becomes obsolete. Many small-lot forming applications may benefit from this technique, where traditional dies remain too expensive.

2 Optimum forming

The advantages of a reconfigurable forming tool are investigated because besides the ability of producing various different products, another approach can be followed using an adjustable tool. The main focus will be on the manufacturing and properties of products that have equal surface shape geometries but different internal stress and strain distributions. The forming experiments are combined with the ARGUS photogrammetry technique and the SVD routine (rigid body motion correction) for determining the surface

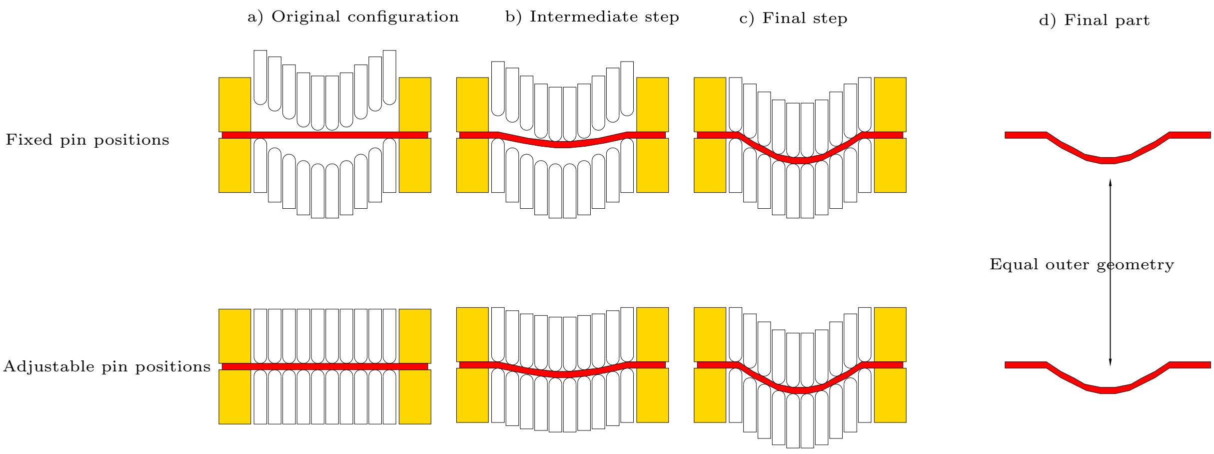

Figure 1: *optimum forming and multi-point deformation.*

geometry and the magnitude and direction of major and minor strains.

The adjustability of the SSDD prototype which is shown in figure 2 on the right, is applied to generate a sequence of forming operations that normally would require a complete set of rigid tools. The choice of subsequent forming steps determines the strain distribution at the end of the process where the surface shape is the same for all specimens. The strains are monitored at several intermediate forming steps and at the end of the forming process. Ideally, the strain distribution should be tuned to the product requirements. This could be done by means of numerical procedures in which product shape and internal strain distribution can be predicted as a function of the externally applied boundary conditions.
The possibilities of a reconfigurable tool are illustrated in figure 1, where the discrete die is shown in a rigid and adaptive deformation mode. In the deformation sequence at the top of figure 1 (top), the relative pin positions are fixed. The stress and strain distribution of products made with this process are comparable to a process in which a rigid die would have been used. In the adaptive deformation process on the bottom of figure 1, the pin positions are changed continuously, which results in a different internal stress and strain distribution. In the next section, a brief summary will be given of the work that already has been done in the field of optimum forming and also some preliminary results of the current work will be presented.

3 Experimental results

Parts may fail (tear, wrinkle) during the manufacturing process because of formability limitations. In our experiments we used 0.2 mm thick steel sheet. It appeared that single step forming into a parabolic geometry was not possible; the sheet cracked, as shown on the left in figure 2.

The example illustrates what optimum forming can do. By using different, non-

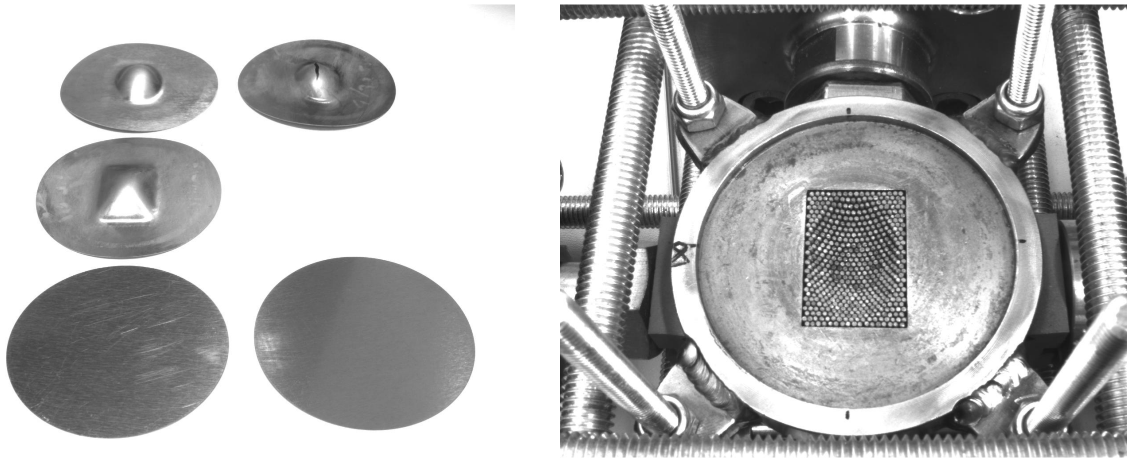

Figure 2: *One- and two-step defomation process. On the top left the sample can be seen on the left without defects whereas the sample on the right is torn completely. On the right a detailed image of the discrete die prototype.*

proportional loading paths, it is possible to make products that cannot be made in one single operation. Even when this is possible, however, different loading paths will result in different final stress and strain distributions for products which are geometrically equal (outer surface). This might present great benefits for products which are subjected to a cyclic or thermal load; their lifetime can be significantly enhanced when the same product is produced in a different way, using different/multiple intermediate deformation steps.

4 Numerical Results

It is observed that the final thickness at the center of the one-way manufactured sample is smaller compared to the two-way manufactured workpiece. Although the final ratios between major and minor strains are about the same, it is observed that the evolution of the ratio (major strain divided by minor strain) is completely different. For the two-way manufactured sample, the ratio increases continuously whereas the ratio for the one-way manufactured sample goes through a minimum halfway the process. In figure 3, the side views of the two- and one-way manufactured samples are shown with the total equivalent plastic strain distribution. A different strain distribution is clearly observed. The thickness reductions for both samples, obtained through the numerical simulations, correspond well to the experimental values obtained with the photogrammetry method.

5 Conclusions

- A reconfigurable forming device has been developed which is used for making a wide range of different sheet metal parts.
- Forming experiments have been conducted with the discrete die, in which two geometrically equal workpieces have been fabricated along two different deformation

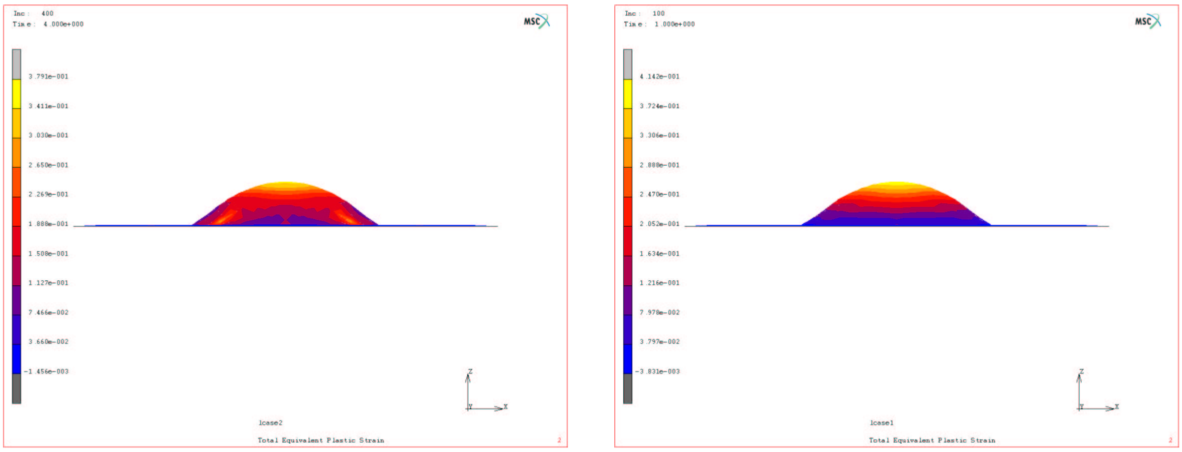

Figure 3: *Sideview of two- and one-way manufactured workpiece with the total equivalent plastic strain distribution, respectively.*

paths. Experimental stress/strain distributions of both samples compared well to numerical results.

- The reconfigurable discrete die offers the possibility to deform the workpiece material along a proportional strain path. The different optimum forming strategies and possibilities of the discrete die within this context are subject of the current research activities.

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