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Determination of the bead geometry considering formability and stiffness effect using generalized forming limit concept (GFLC)

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Abstract. Beads are used in deep drawn sheet metal parts for increasing the part stiffness. Thus, reductions of sheet metal thickness and consequently weight reduction can be reached. Style guides for types and positions of beads exist, which are often applied. However, higher stiffness effects can be realized using numeric optimization. The optimization algorithm considers the two-stepped manufacturing process consisting of deep drawing and bead stamping. The formability in both manufacturing steps represents a limiting factor. Considering nonlinear strain paths using generalized forming limit concept (GFLC), acceptable geometries will be determined in simulation. Among them, the efficient geometry which has higher stiffness effects will be selected in numerical and experimental tests. These will be integrated in the optimization algorithm.

1. Introduction

With the progressive development of computer technology in the nineties, demands for lighter and stiffer metal structures have been increased. FEM-based simulation programs were used to identify improved with the help of parameter variations bead patterns for different load cases [1, 2]. The bead length was optimized based on energy, but the implementation of intersection wasn't considered [3]. A different approach is that the direction of bead stamping is determined based on the determined material distribution by topology optimization [4]. One of the first direct beading optimization was introduced that beads must be determined along the trajectories of the first principal stress [5]. Recently, this algorithm have been developed in bead optimization [6]. The existing algorithms for the optimization of beads have not taken into manufacturing processes as well as the geometry of the sheet metal part.

Within this research project, an optimization method will consider the manufacturing and geometry parameters. A failure model is used to predict formability in the bead stamping simulation after the forming simulation as deep drawing.

This paper will introduce that the cross section of bead geometry is determined by using forming simulation, which carries out the two-stepped process. In order to achieve that, the modified Nakajima test [7] is selected as example of the forming simulation to perform the various stress states as pre-forming. The bead stamping process is carried out after that. The formability of the part, which is deformed after two-stepped forming simulation, is predicted considering nonlinear strain paths by using a concept of the generalized forming limit curve (GFLC) [8]. The geometry parameter of bead profile varies to identify the influence on the formability and the stiffness of the part. Some experimental cases of pre-formed part is used to validate the simulation by comparison of strain in pol region.

2. Determination of bead profile

It is simulative investigated which bead profile increase effectively the stiffness of the part without the defect as instability or fracture.

2.1. Bead geometry sample

In order to investigate systematically the influences of the bead geometry on the formability and stiffness of the part, the sample of the bead profile is defined as the normalized geometry function as shown in Fig. 1. The geometry parameters consist of head radius r_h, foot radius r_f, height h, width w and edge angle α. The profile function will be implemented in the optimization program.

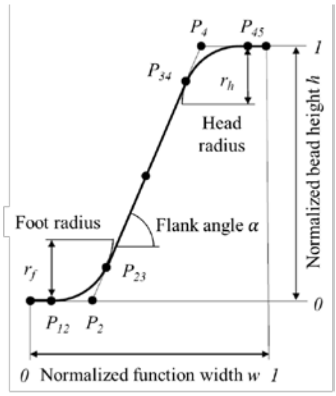

Figure 1. Sample of bead profile with parameterization.

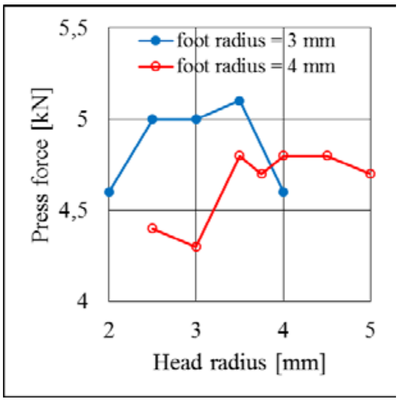

Figure 2. Influence of radii pair.

2.2. Simulation

As mentioned above, the simulation tool AutoForm [9] is used to carry out the modified Nakajima simulation and bead stamping. The materials of HC260LAD and AA6016 are used. A half-spherical punch and a blank holder of the modified Nakajima have diameter of 400 mm and inside diameter of 430 mm, respectively. The modified Nakajima and bead stamping are carried out. The small punch presses on the top of the part after bead stamping. The pressed force identifies the buckling stiffness of the parts.

Table 1. Parameter level

h [mm]	r [mm]	w [mm]	α [°]
15	5	35	35
14	4	37,5	37,5
13	3	40	40
12	2	42,5	42,5
11		45	45
10			47,5
			50

2.3. Parameter study

The defined geometry parameters are five. The influence of the relation between the head and foot radius on the stiffness of the part is investigated. The head radius varies in cases of that the foot radius is fixed as 3 and 4 mm, respectively. The Figure 3 shows a result of the influence, that the high bead forces are calculated when the radii have no big difference each other. This means that the head and foot radius can be regarded as a same radius to obtain the high stiffness. Consequently, the number of the parameters can be reduced to simplify the study.

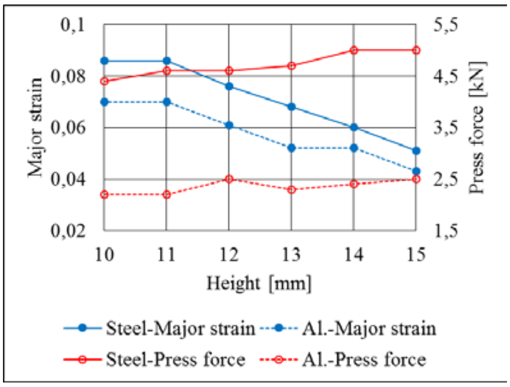

Figure 3. Influence of height.

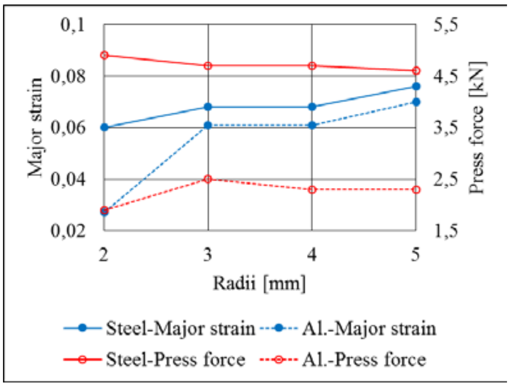

Figure 4. Influence of radii.

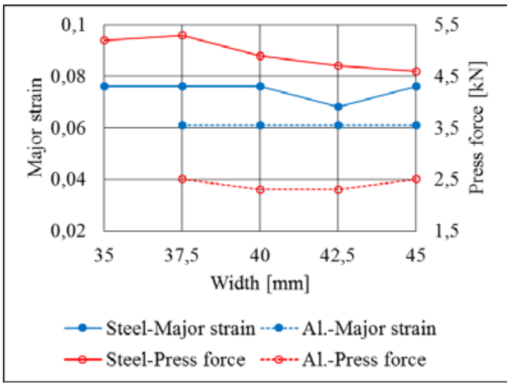

Figure 5. Influence of width.

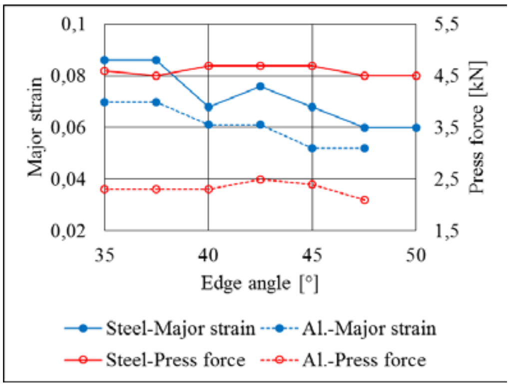

Figure 6. Influence of edge angle.

The four parameters are investigated in several levels by the precondition that the two radii are identical. The change of the parameters is shown in Table 1. The parameters in shadow are defined the reference case. Every parameter is changed to investigate the influence on the formability and the stiffness when other parameters are set the reference case as constant.

Results of the influences of height, radii, width and edge angle are shown in Figure 3-6. It is obvious that the height and the radii are proportional to the stiffness and in inverse proportion to the formability. This means, that the limited bead geometry makes also the high stiffness of part. However, cases of the width and the edge angle show a different aspect. The variation of the width has no significant influence on the formability and the stiffness. The parts have more high stiffness when the edge angles between 40 and 45° are used. For that reason, the width and the edge angle can be regarded as constant geometry parameter.

2.4. Geometry as function of major strain

The available bead profiles must be determined by depending on preforming. Therefore, the height and identical radii of profiles are simply defined as linear function of major strain from the preforming simulation (Figure 7-8).

3. Validation

In order to validate the simulation results, major strains of biaxial preformed parts are measured by ARGUS measurement system [10]. The major and minor strain values on the top are compared to that from the simulation. The biaxial preforming is carried out with strokes of 60, 70 and 80 mm. The material of AA6016 is used in this validation. The major strain from the simulation has values of 0.052, 0.063 and 0.077 in cases of strokes of 60, 70 and 80 mm, respectively. The measured major strain has values of 0.060, 0.071 and 0.083 in cases of strokes of 60, 70 and 80 mm, respectively. The simulation results have been underestimated about 10 % in comparison to the experiment. But, the differences are shown as constant. This means, that the simulation is not accurate but precise. In this work, the material parameters were not identified, but implemented material parameters from AutoForm were applied to this study. While draw beads were carried out by rectangular draw bead geometry in the experiment, they were simplified as line force in the simulation. These can make inaccurate the simulation results. The bead profile can have intentionally less dimension based on the current results after the determination from major strains.

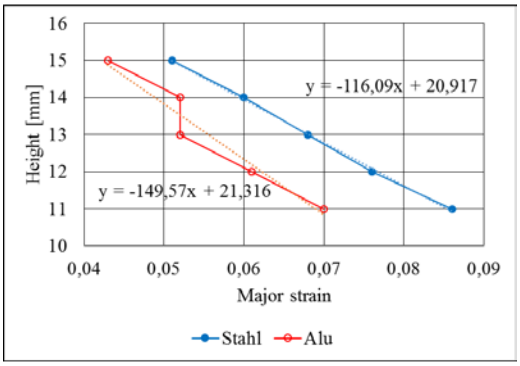

Figure 7. Height function of major strain.

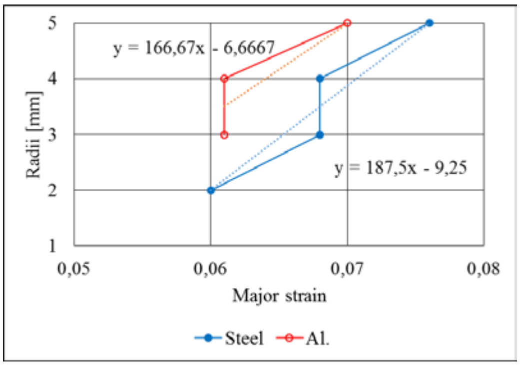

Figure 8. Radii function of major strain.

4. Conclusion

In this paper, how the limited bead profile is determined numerically and the partial validation are introduced. The bead profile can be defined as a function of major strain based on GFLC. The simulation precision was validated by comparison of the strain values from the biaxial preformed parts. Although the validation was carried out only in that case, the determination of limited bead profile from the simulation is reliable.

In the future, other material HC260LAD and other stress states of preforming are going to be examined, and the instability and failure will be confirmed in bead stamping, whether the simulation considers nonlinear strain path right by using GFLC. Moreover, the manufacturing feasibility is going to be also investigated in various bead path and the processing parameters. At the end, the bead process will be optimized under considering of part formability and manufacturing feasibility.

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