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NEGATIVE INCREMENTAL FORMING OF SHEET BASED ON INTERVAL MODEL OF HYDRAULIC BULGING CAE ANALYSIS

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Abstract. The quality of incremental forming depended largely on the spatial feed path of tool. Appropriate tool path can equalize the strain distribution across the surface of a part in negative ISF. The forming of bulging presents a process that the shape of part is approached to the final profile from a plate sheet. A novel tool feed path generation method is presented in this paper. A series of inchmeal approximating surfaces can be obtained from hydraulic bulging CAE analysis results, consequently the tool spatial feed path can be generated based each surface. This method approach the final contour of part inchmeal, thus exert the sheet deformation capability in negative incremental forming. The work detailed in this paper focuses on finite element analyses about hydraulic bulging and multi-passes incremental forming using PAM-STAMP software.

1. INTRODUCTION

For the demand of products developing, small-batch trial production is needed in manufacturing industry such as automobile vehicle. Because of the low-cost tooling and flexibility, single-point incremental forming (SPIF) offers a novel alternative to produce customized panel parts [1]. In this process, the final shape formed by the progressive movement of the tool without conventional shapely tools. SPIF is based on partial forming of a metal sheet by CNC controlled tool. The process can include a basic geometry supporting die ("positive ISF") or no dies at all ("negative ISF"), depending on the complexity of the part [2].

In negative incremental forming, a ball roll follows a trajectory on a sheet metal blank, according to a programmed tool path. The sheet is clamped at its periphery on a support frame (Strano 2003) [3]. In positive forming, the central part of the workpiece is supported by a fixed counterpunch (or mandrel) and the tool-workpiece interface is located on the convex side of the shape to be formed. The sheet can be either fixed at the periphery (Park and Kim 2003) by a blank holder or it can be free [3]. The latter case can be considered a direct evolution of the conventional shear spinning process (Wong, Dean, and Lin 2003) [3].

2. THEORETICAL BACKGROUND AND OBJECTIVE

Most investigations of SPIF have concerned applications and formability limits of the process. So far, the investigations lead to the conclusion that the formability of the process can be defined in terms of four major parameters [4]: (i) thickness of the sheet, (ii) size of the vertical step down per revolution, (iii) speed (both rotational and feed rate) and (iv) radius of the forming tool. The influence of the first parameter is commonly explained by means of the sine law $t_f = t_0 \sin\alpha$, where t_0 is the initial

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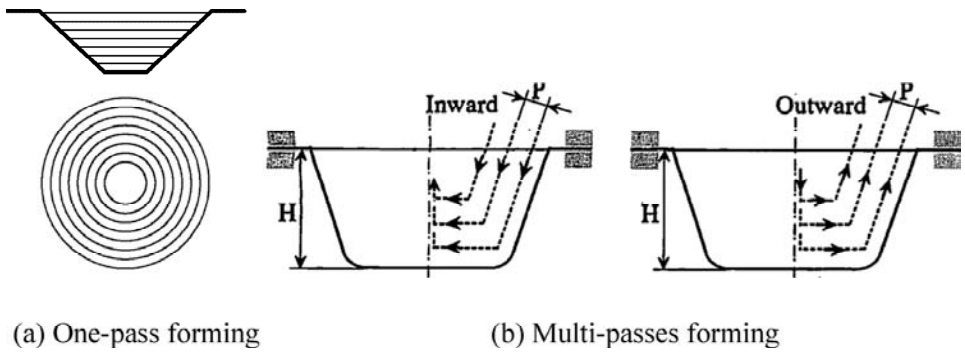

Fig. 1. One-step tool path and multi-passes tool path.

thickness, t_f is the final thickness and a is the vertical slope of conical geometry parts. This law is only employed in parallel section layered one-pass forming (see Fig. 1a) and cannot manufacture the part with vertical wall because of sin90°=0. The method "parallel section layered" is similar shear spinning forming in which tool path generated through parallel slicing the contour of part. It is only one-pass that tool sweep over the surface contour. But the movement of material from the original blank to the final conical shape using several passes in traditional spinning.

To avoid partial thinning and fracture, material of the part must be forming fully and uniformly. Kitazawa [5-7] and Kim and Yang [8] used a pre-form, two-passes or multi-passes forming as a means of equalizing the strain distribution across the surface of a part (see Fig. 1b). Jeswiet and Hagan [9], and Kun Dai [10], Hirt et al. [11-13], also used this same technique, and the result shown that thinning of the sheet during multi-passes forming can exceed the maximum thickness reductions observed in single-pass processing, implying a formability shift.

Usually, Pre-forms can be designed by reducing wall angle and artificially large offsetting from original shape (see Fig. 1b), inward mode or outward mode [6]). In fact, that is a forming strategy problem materially. How to obtain the pre-form shapes is the key of the optimization on multi-passes incremental forming path that generated from pre-form shapes. Isometric offset can easily obtain by CAD/CAM software. But it could not used in too deep or steep wall part, because the offset shape of part with vertical wall just have the same vertical angle. So it must be offset artificially unless an intelligent system had been developed. In negative ISF, the surface of part is stretch expanding and the sheet is thinning. Appropriate progressive approaching shape can equalize the strain distribution across the surface of a part. As a negative ISF, the forming of bulging presents the process that is progressively approaching the complex final shape from a plate sheet. Tool path can be generated form approaching surfaces that are obtained from hydraulic bulging CAE analysis results. The aim of this paper is to illustrate a novel method of tool feed path generation that based interval model of hydro-bulging CAE analysis results.

3. MODELING OF MULTI-PASSES TRAJECTORY

3.1. Bulging simulation setup and results

PAM-Stamp 2G software is used to simulate hydro-bulging process. A hat shape part is wanted to manufacture. The diameter of die cylinder wall is 100 mm with 50 mm flange and 50 mm depth. Radius of all round corners is 5 mm. The diameter of

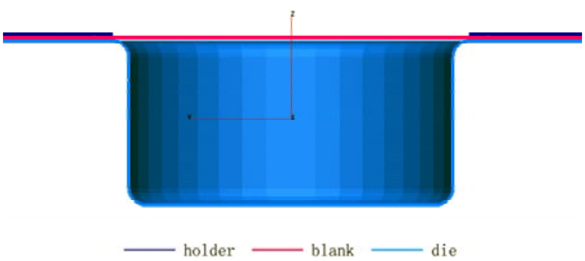

Fig. 2. Models of die and holder and sheet in hydro-bulging process.

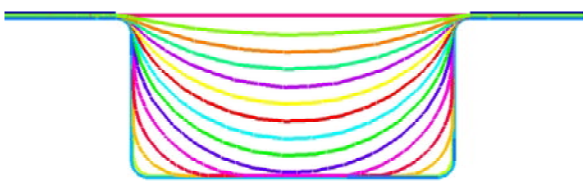

Fig. 3. Interval shape of simulation about hydraulic bulging.

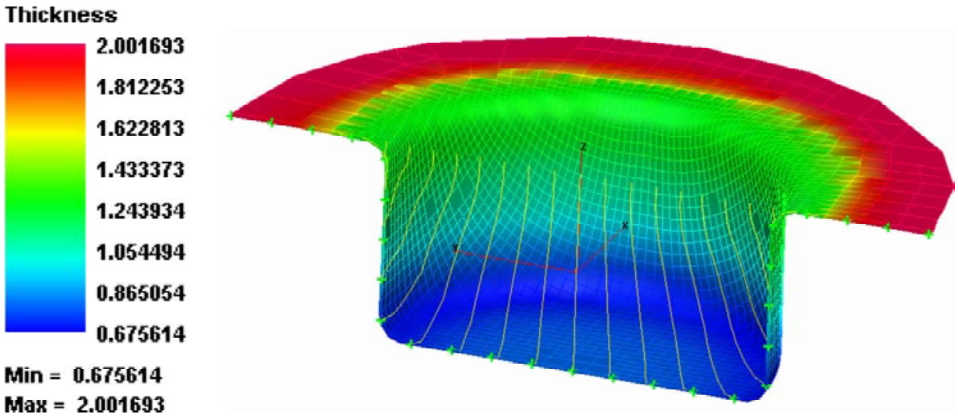

Fig. 4. Thickness distribution and metal follower line in the final shape.

workpiece is 200 mm with thickness 2 mm (see in Fig. 2). To avoid fracture with normal material, a special stress-strain relation model of material is defined to form the process of hydraulic bulging. A special friction state within holder and sheet is defined to avoid metal flow from flange to die, but the friction of die and sheet is set zero, the holder imposes 300 KN force to press the sheet on die. With adaptive meshing, the number of meshes is out of consideration, but the regulation of adaptive meshing must be set. In this bulging simulation, refinement is set automatic with slide radius 5mm and the detection angle criterion is 10° between elements.

Un-formed neutral layer area is 7851.416 mm^2 and formed area is 23858.365 mm^2 on the region of deforming. So the final thickness should equal 0.658 if the deformation and thickness distribution is assumed uniform. After simulation, the results of hydraulic bulging have 14 steps that are illustrated in Fig. 3. The minimum thickness of the final shape is 0.664 mm (see Fig. 4). These results presented that the flange metal has flowed into die and caused the thickness of partial flange is thinning obviously.

3.2. Paths of multi-passes

Export each step shape of blank to a STL file and import each file that contains a surface of interval model into POWERMILL. POWERMILL is powerful software of CAM that is produced by DELCAM Company, which can process the STL format file. After choosing proper parameters about negative incremental forming, NC code file can be generated and exported in ASCII format.

In POWERMILL software, machining strategy is selected as “3D offset finish machining” and the distance between rows is set 5 mm. It is must offset half of thickness toward inner that surfaces exported form bulging results are neutral layers. But thickness is varies about profile of part, 1 mm offset uniformly is only to do so and that would be caused deviations of path and shape. Of cause, offset the ball end tool 1 mm outside is practicable if not offset the interval model surface. In this paper, the diameter of ball tool is set 22 mm in POWERMILL software, and the tool is defined 20 mm diameter in PAM-STAMP simulation, so the surfaces needn’t offset. Finally, NC code can be generated after all parameters are set and no error. Treat NC files and transform into IGES files with curve, which described the trajectory of tool in a one-pass process.

To verify the forming feasibility of these trajectories, simulation is needed to investigate the deformation behavior of multi-step. PAM-STAMP 2G software is also used to fulfill this mission. After transform every interval model to an IGES file, it will be used in PAM-STAMP as a path of tool in simulating. The curves of path are helical and composed by many straight-line segments. Fig. 5 is showing a trajectory curve that had imported into PAM-STAMP.

The blank is defined as SPCC in material with thickness of 2 mm. Ball tool with diameter of 20

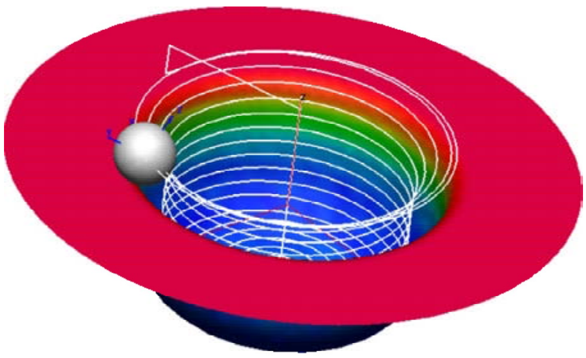

Fig. 5. Helical multi-passes trajectory and ball tool in PAM-STAMP.

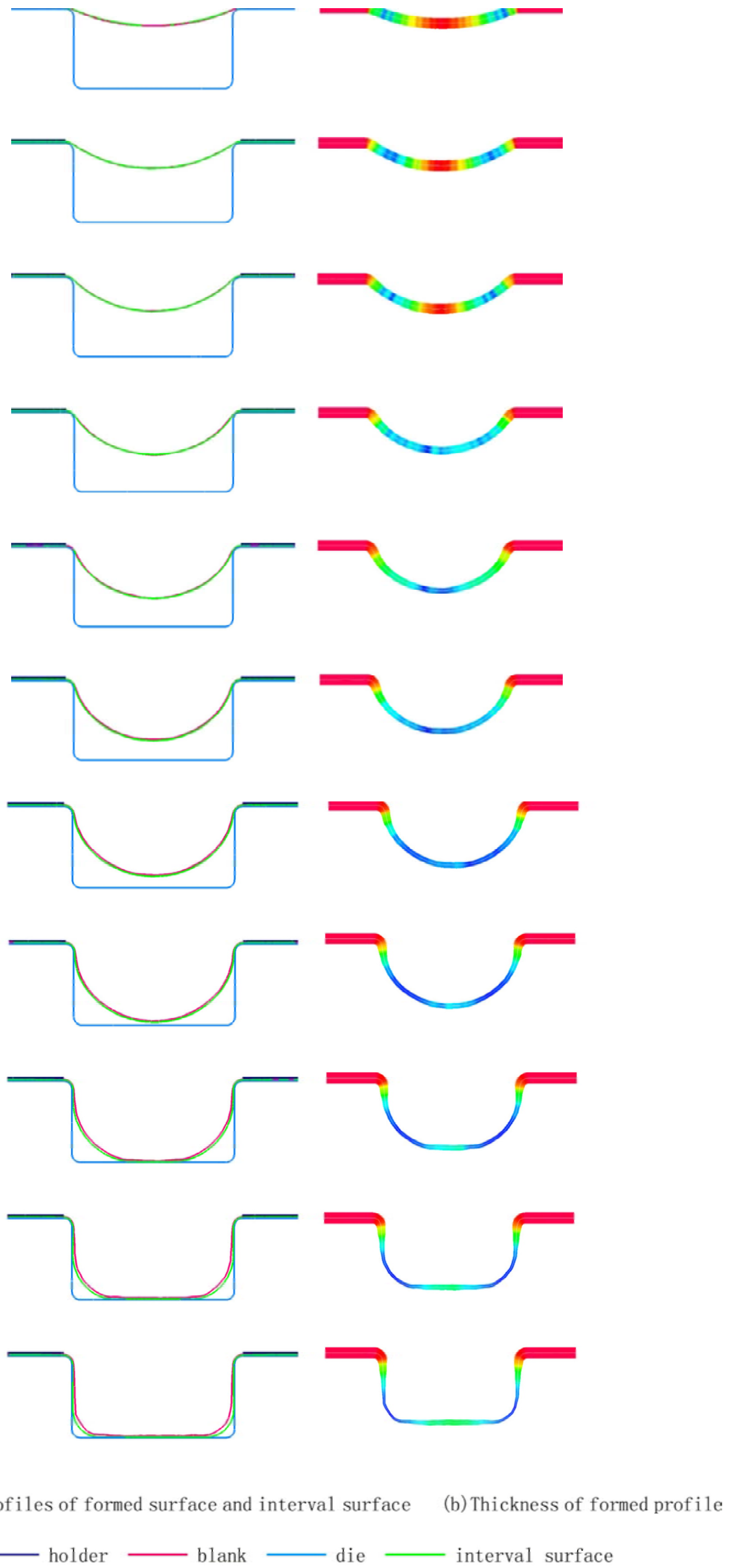

Fig. 6. Multi-passes section profile and thickness of simulation.

mm and holder force of 300 KN are defined in PAM-STAMP. Even the software guide recommended kinematical speed of tool is 10 m/s, but it can be accelerated compute and reduce time remarkably and no effect on the results if the speed is set 100 m/s. As the same reason, friction coefficient between roll tool and blank is set zero, so do holder and blank too. The friction coefficient between die and blank is set 0.12.

4. RESULTS AND DISCUSSION ON THE FEM OF MULTI-PASSES INCREMENTAL FORMING

Simulation starts from the second bulging interval surface because the first one deformation is so indistinctive that needn't form. The forming strategy is set inward in step 1-3, and outward in step 4-7, inward in step 8-11(see Fig. 6). As the diameter of ball tool is 20 mm, the radius of part (5 mm) cannot be manufactured, and last two interval models were not simulated.

In step 1-3, the bottom of part is unformed almost. So in step 4, tool is formed begin with bottom (see in Fig. 7). The thickness of bottom altered from 1.93 mm to 1.38 mm. The metal flow line of step 4 is show in Fig. 8.

In step 1-3, the thickness change is unapparent and the blank is formed in accord with its relative interval model surface. From step 4, variance is obvious between formed surface and interval model surface. As neutral layers offsetting generated the

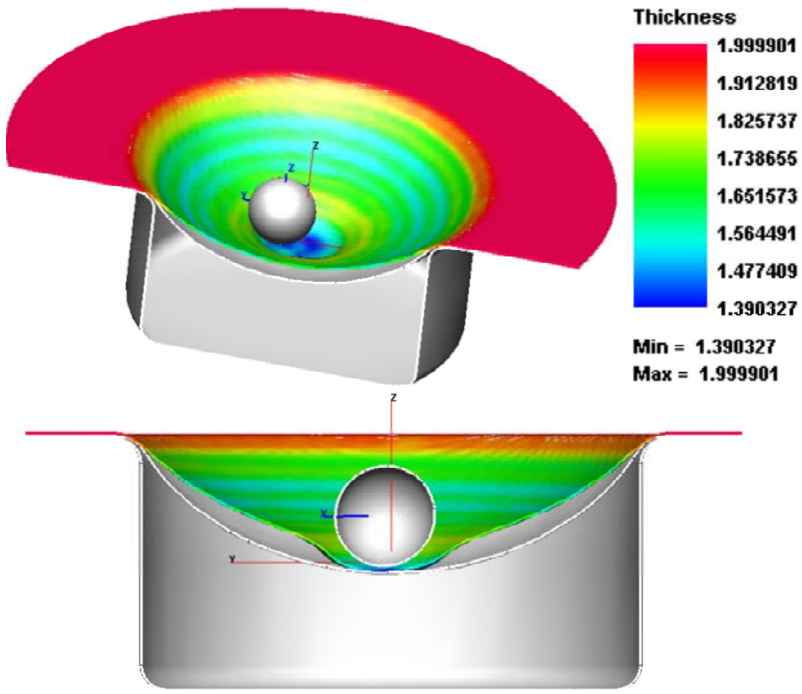

Fig. 7. Deformation of bottom of 4th step.

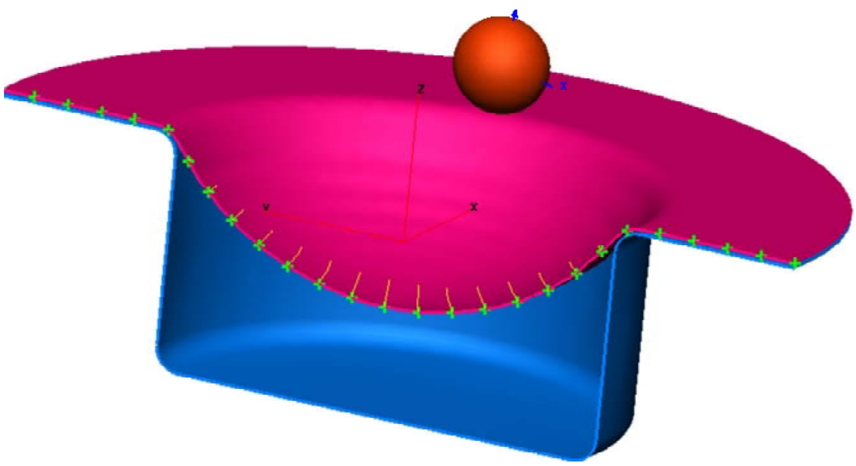

Fig. 8. Metal follower line of 4th step.

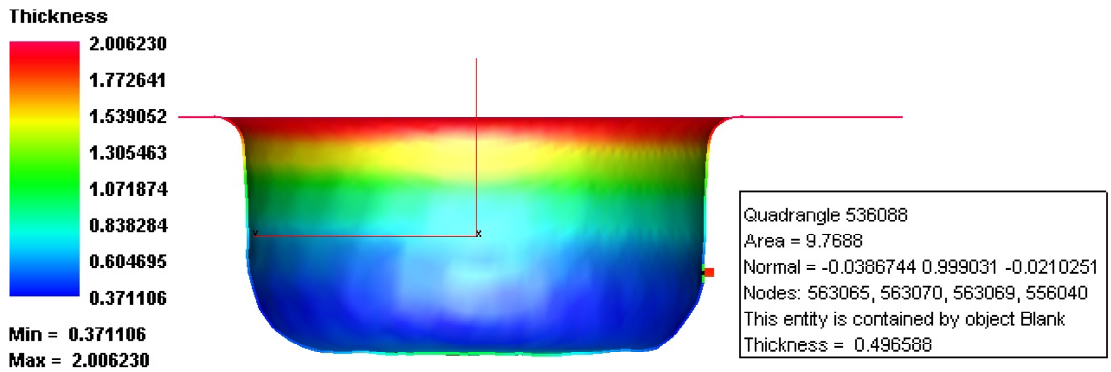

Fig. 9. Distribution of thickness and a mesh normal of wall in final shape.

paths, the deviations of thickness cause that the shape is not concordant with its relative interval model surface. In addition, the spring back is not compensated in hydraulic bulging simulation, and then these spring deformations cause some deviations too.

Finally, minimum thickness after multi-step incremental forming is 0.37 mm at the corner of bottom. Wall angle is almost 90° and depth of vertical wall is almost 30 mm to flanger (a mesh with red mark is showed in Fig. 9). The vertical wall thickness varies from 0.5 mm to 1.55 mm by closing to flange in simulation. It is nearly zero under conventional processing when the angle is 90°, according the sine law.

5. CONCLUSIONS

To obtain and verify internal models approaching the final shape, deformation behavior of sheet metal in hydro-bulging process and negative incremental forming were investigated using finite element software PAM-STAMP 2G. Approaching surfaces of complex part can be obtained easily by this method. Compared to parallel section layered single-step forming, it allows producing vertical wall without leading to part failure even in steep wall. The final thinning of sheet during multi-passes forming can exceed the maximum thickness reductions in single-step forming.

The results obtained are summarized as follows:

(1) Flowing trend of the sheet metal can be controlled by Multi-passes tool path in a certain extent. Proper forming strategy can produce a sheet part no fracture even though with steep wall.

(2) The NC program generated from CAM software based interval model surface of hydro-bulging simulation can used to manufacture multi-passes incremental forming with complex shaped part.

(3) After formed, deviations from the goal surface are resulted in the thinning of sheet non-uniformly and the springback in hydraulic bulging simulation stage are not considered.

(4) Using PAM-STAMP software can simulate complex tool path and forming behaviors to obtain useful information like realities.

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