NUMERICAL STUDY OF A PROCESS STRATEGY FOR IMPROVING GEOMETRICAL ACCURACY IN INCREMENTAL FORMING PROCESS**POPP Mihai-Octavian***Faculty of Engineering, Department of Industrial Machines and Equipment, "Lucian Blaga" University, Sibiu, Romania, mihai.popp@ulbsibiu.ro***OLEKSIK Mihaela***Faculty of Engineering, Department of Industrial Engineering and Management, "Lucian Blaga" University, Sibiu, Romania, mihaela.oleksik@ulbsibiu.ro***RACZ Sever-Gabriel***Faculty of Engineering, Department of Industrial Machines and Equipment, "Lucian Blaga" University, Sibiu, Romania, gabriel.racz@ulbsibiu.ro***RUSU Gabriela-Petruța***Faculty of Engineering, Department of Industrial Machines and Equipment, "Lucian Blaga" University, Sibiu, Romania, gabriela.rusu@ulbsibiu.ro*

Abstract: Incremental forming process is a relatively new process among researchers, which is yet to be implemented in automotive and aerospace industries. The researchers are studying various process strategies and methods to improve the geometrical accuracy of the parts obtained by incremental forming, because the geometry of the parts is one of the key factors holding back the process industrialization. One good method to investigate the benefits of a process strategy is by means of numerical analysis, from which the results obtained can confirm or disprove the gains of the researched strategy. The aim of this paper is to present the advantages of using a fluid under pressure as a supporting die instead of using a conventional fixed backing plate for the single point incremental forming process.

Key words: single point incremental forming, sheet bending, finite element analysis, fluid pressure, geometrical accuracy.

1. Introduction

Single point incremental forming is a process that presents a great potential for automotive industry due to the complex shape parts that can be produced. In comparison with other well-known processes such as deep-drawing, incremental sheet forming is a simple process due to the small number of elements necessary to manufacture different shape parts. Through single point incremental forming it is possible to manufacture sheet metal parts that can be used in automotive industry. The process consists of a clamping device for blank sheets and a punch that follows a toolpath designed by the user.

Despite the fact that incremental sheet forming process presents a series of advantages when compared with other plastic deformation processes, from costs of implementation and its high flexibility, the process involves also a series of drawbacks due to poor geometrical precision of manufactured parts [9].

Researchers have studied these errors of accuracy and tried to categorize them according to the type of parts produced. Oleksik studied in paper [1] the thickness reduction of frustum cone shaped parts with different wall angles, ranging from 45° to 65°. The author also confirmed experimentally that the maximal values of the thickness reduction are accordingly with the sine law, but only after a certain height of the part is reached [6], [7], [8]. From experimental results it can be observed that for a steel sheet, regardless of the wall angle, step on vertical direction, diameter of the punch the thickness reduction was between 30% to 40% of the initial thickness of the sheet which is still not acceptable in many areas of industry and further represents a drawback of single point incremental forming process. Micari et al presented in the

paper [2] three main geometrical errors when taking into consideration the sheet metal forming of a part with a shape of frustum cone. These geometrical errors consists of:

- sheet bending which appears where the punch comes in contact with the blank sheet metal;
- pillow effect, which appears at the center of the cone, being a typical error for this kind of shape;
- sheet springback, also a common geometrical deviation, one of the most obvious problems in incremental sheet forming process which occurs due to the absence of a die when deforming the sheet.

These errors tend to occurs at parts with different shapes and sizes and they are not dependent of the material used or the toolpaths of the punch. Of course, there are cases when some errors are more pronounced than the others are, but this is still not acceptable in automotive industry [4], [5], [8].

During recent years, researchers studied different methods in order to reduce or even to eliminate the drawbacks of single point incremental sheet forming process. In the paper of Khamis [3] the authors summarized the above-mentioned geometrical errors and proposed different strategies to improve the dimensional accuracy of the frustum cone shaped parts. In Figure 1 it can be observed all three common errors which appears after the force of the punch is removed from contact whit the sheet blank. The researchers used an aluminum alloy for the sheet blank with the thickness of 1 mm, wall angle of 45° and a depth of 35 mm for the frustum cone. The major diameter of the part is 90 mm.

Figure 1: Definition of the three main geometrical errors
[2]

2. Concept of the testbench

Given the fact that the sheet bending is one of the highest problems in incremental sheet forming process in terms of geometrical deviation of the shape, the aim of this paper is to propose a strategy in order to prevent this type of error. This error is more obvious at parts with big dimensions and it gets higher as the contact point between the punch and sheet blank is more distant from the fixture of the sheet, which is the case of parts produced for automotive industry, but it is also present at relatively small shape parts.

The strategy proposed by the authors is the usage of a tank filled with pressurized fluid mounted underneath the sheet blank. The pressurized fluid should prevent the sheet blank to bend in the contact area of the punch with the sheet, thus acting like an active die. The proposed equipment for experimental investigation of the single point incremental forming process with pressurized fluid should contain the following: pressurized tank that can withstand a certain pressure; special couplings for the tank with the sheet blank containing sealing elements; a pump or a hydraulic cylinder for pressure build up and pressure holding; pressure relief valves in order to release pressure because the fluid will be compressed by the sheet metal during the incremental forming process and pressure sensors for monitoring the pressure inside the tank, which are also needed for setting the desired fluid pressure.

3. Numerical investigation of the proposed strategy

The purpose of this paper is to research the strategy suggested by the authors to improve the dimensional accuracy of the parts produced by single point incremental forming and for this we will perform two analyzes with finite elements: one in which the common single point incremental forming process will be simulated and one in which the improved process will be reproduced. In order to reach the purpose of this work, both analyzes will aim to achieve a frustum cone with a wall angle of 55° and a depth of 22mm.

The analysis by means of the finite elements method will be carried out with the help of the ABAQUS / EXPLICIT program. For the modeling of the two analyzes, an assembly consisting of the

following parts will be used: two retaining rings modeled as being discrete rigid, a tool that is also discrete rigid and the sheet metal as a deformable body. The size of the sheet metal used in this model is 200 x 200 mm and has a thickness of 2 mm.

Figure 2: SPIF simulation parts

The sheet metal is made of an aluminum alloy AlMg1SiCu. The chemical concentration of this alloy is: 0.4 – 0.8% Si, 0.7% Fe, 0.15 – 0.4% Mn, 0.8 – 1.2% Mg, 0.04 – 0.35% Cr, 0.25% Zn and 0.15% Ti. The mechanical characteristics of this material according to the EN755-2 standard are presented in the table below:

Table 1: Mechanical properties

Yield stress Rp0.2 [MPa]	Tensile strength Rm [MPa]	Elongation A [%]
110	150	16

The sheet metal is meshed with S4R elements and this means that is a shell element with 4-node, quadrilateral, stress-displacement. In the same time because are considerate to be discrete rigid the two retaining rings and the tool are meshed with R3D4 that is a rigid element with 3-node and a triangular facet.

In the case of the analysis that simulates the proposed strategy, it must be determined the pressure that will be applied against the tool. This pressure has to be applied on the sheet metal without causing tensions in the material. Thus, prior to the analysis performed for this research paper, a simulation is done with the same sheet metal used in the other two analysis, which in this case is fixed on all the edges and on its surface is applied a pressure as an amplitude so that it can be determined the maximum pressure at which tensions start to appear in the material. After performing this analysis, it was observed that the maximum pressure which can be applied on the sheet metal is 2 bars.

After comparing the results obtained from the two analysis with and without pressurized fluid, an improvement in the dimensional accuracy can be observed in the case of the strategy proposed. In Figure 3 are presented all the differences between the deformed shape obtained with the pressurized fluid, which is represented with red color, and the deformed shape obtained without pressurized fluid, represented with blue color. The significant difference between the two shapes of the part are in the upper area where it can be observed an improvement in the sheet bending effect. The pillow effect can be observed in both cases in the bottom area of the frustum cone, but unfortunately, in the case of the simulation with pressurized fluid it is more pronounced due to obvious reasons.

Figure 3: Comparison between the deformed shape with pressurized fluid and the deformed shape without pressurized fluid

Figure 4 shows the profile plots obtained by FE analysis and the theoretical profile. From this plot it can be observed that the profile of the part in the case of pressurized fluid is much closer to the theoretical profile than the case without pressurized fluid, but the sheet metal starts to bend in the other direction in comparison to the normal incremental forming process. This effect of reverse sheet bending is caused by the pressurized fluid which is applied on the second surface of the sheet metal and can be overcome by a more precise determination of pressure level of the fluid.

Figure 4: Profile plots obtained from FE compared with the desired shape

4. Conclusions and discussions

The proposed strategy for improving geometrical accuracy of the parts produced through single point incremental forming process has proved to be a success. The numerical investigation of the process when using pressurized fluid showed that the profile obtained is closer to the theoretical profile of the part. The most obvious geometrical error that the strategy is able to correct is the sheet bending effect in the area where the punch comes in contact with the blank sheet metal. Nevertheless, the pillow effect at the bottom of the frustum cone has higher values, but this drawback can be avoided by using different toolpaths for the punch.

In conclusion, the pressurized fluid which acts like an active die can be a viable solution for replacement of the annular back ring that is used in most cases of single point incremental forming. One must take in consideration that the annular back ring can reduce the geometrical error even further than the proposed strategy, but if we take into account one of the most important feature of this process – it's high flexibility and capacity of producing complex shape parts, then in this case it becomes harder and harder to produce a back ring as the complexity of the shape increases, thus using a fluid as an active die would fit to every shape and size of parts.

Further research will aim to validate the proposed strategy also with complex shape parts.

Acknowledgments

This research presented here was partially financed by a grant of the Romanian Ministry of Research and Innovation CCCDI-UEFISCDI, project number PN-III-P1-1.2-PCCDI-2017-0446/ nr. 82 PCCDI/2018, within PNCDI III, project title: "Smart manufacturing technologies for advanced production of parts from automotive and aeronautics industries".

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