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Common defects of parts manufactured through single point incremental forming

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Abstract. Single point incremental forming is one of the most intensely researched die-less manufacturing process. This process implies the usage of a CNC equipment or a serial robot which deforms a sheet metal with the help of a relatively simple tool that follows an imposed toolpath. As every cold metal forming process, besides the many given advantages it has also some drawbacks. One big drawback in comparison with other cold metal forming processes is the low accuracy of the deformed parts. The aim of this research is to investigate the sheet metal bending mechanism through finite element method analysis. The results shows that the shape of the retaining rings has a big influence over the final geometrical accuracy of the parts manufactured through single point incremental forming.

1 Incremental forming – general remarks

Incremental sheet metal forming (ISF) process is part of plastic deformation processes and can be performed either at room temperature (cold deformation) or at various high temperature (hot deformation) depending on the type of material used for sheet blank. In comparison with other plastic deformation processes, ISF process is quite unique because of its simplicity since it is a “die-less” process and it only involves the sheet metal blank fixed by two retaining rings and a simple tool in form of a hemispherical punch that follows a toolpath imposed by the user as in Figure 1 [1].

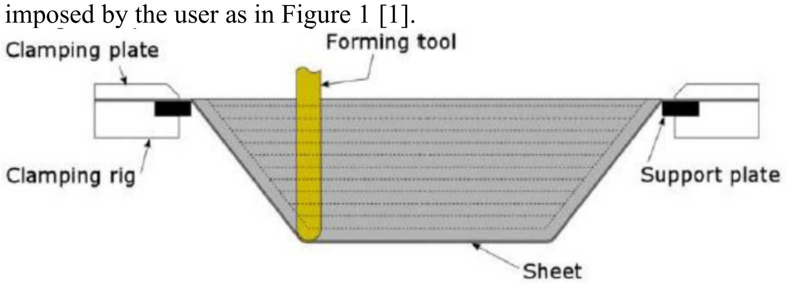

Fig. 1. Incremental forming principle [1]

Nowadays, the products from various industries must fulfil the customer requirements, and the geometrical accuracy of these products must be in certain limits imposed by current

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standards. Therefore, in recent years, industrial engineers are searching for new processes and methods to develop products more efficient, less time consuming and with cheap parts involved in the process. This is a great opportunity for processes such as incremental sheet metal forming to receive all the attention from researchers due to some advantages it poses over other classic deformation processes [2,3,4].

ISF process can be performed with either a CNC machine or with the help of a serial or parallel structure robot, thus bringing another advantage for industry implementation especially for automotive industry where big power plants are already using lots of serial robots on the production line [5]. Besides all these advantages of the process, unfortunately there is still one important drawback, which is the low geometrical accuracy of the parts produced, so the current standards cannot be yet fulfilled, thus the process is still in development phase. Many researchers focused on the main factors which causes the parts produced through ISF to be uncompliant and highlighted through various papers the areas of the parts produced with the highest geometrical errors, like Essa in paper [6-12].

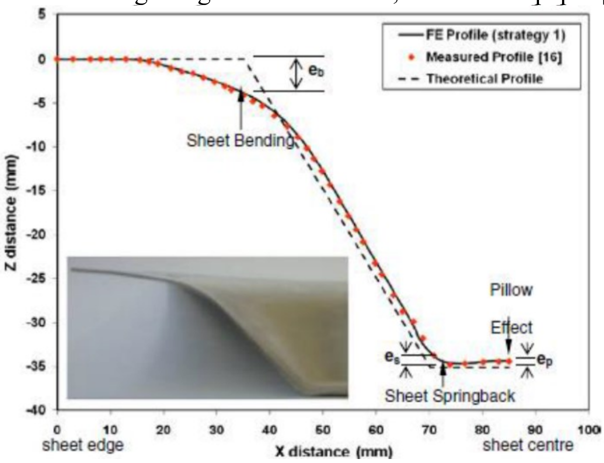

Fig. 2. Common defects of parts manufactured through SPIF [6]

To summarize all the research workload from last years, the research direction was to investigate as many methods to improve geometrical accuracy as possible by changing a few factors which could lead the process to a step further for its industrial implementation [7]. As seen in Figure 2, the author identifies three main areas where defects appear:

- in the proximity of the contact between sheet metal blank and tool in form of sheet bending error;
- at the bottom of the formed shape where springback occurs;
- in the centre of the part where pillow effect appears after the tool is removed.

The aim of this paper is to investigate the behaviour of the sheet metal blank deformed through single point incremental forming process, with focus on the sheet metal bending error. Also a mathematical model is proposed in order to evaluate the maximum deviation between the CAD profile of the part and the actual profile obtained through finite element analysis method in relation to the distance between the initial contact of the tool and retaining rings [13-20].

2 Numerical investigation model and results

Many researchers used besides the two retaining rings which their role is to get the sheet blank fixed, an additional supporting plate mounted near the area where the punch comes in contact with the blank, in order to overcome the drawback of the sheet bending error. This comes somehow in contradiction with the “die-less” nature of the process and this method is suitable only for parts with the same shape and size. For this reason, our purpose in the present paper is to numerically investigate the deformation of a part with the shape of a frustrum cone with the dimensions presented in Table 1, without the help of any supporting plate in order to respect the “die-less” nature of the process and to be in concordance with the complex shaped parts which are used nowadays in automotive car body parts, where this process is most suitable for.

Table 1. Investigated frustrum cone characteristic.

Shape characteristics	Values
Shape initial radius	90 [mm]
Frustrum cone depth	16 [mm]
Toolpath strategy	Continuous spiral
Vertical step	1 [mm]
Wall angle	65°

In order to evaluate the sheet bending it was necessary to be considered a variable distance d between the part initial radius and the retaining rings, thus both retaining rings were modeled as a square shape as can be seen in Figure 3. The dynamic simulation was performed with the help of finite element analysis software package, ABAQUS/EXPLICIT version 2020. The material used was an AlCu4PBMgMN aluminum alloy also known as EN AW 2007, according to the DIN EN 573-3 standard has the following chemical composition: 0.8% Si, 0.8% Fe, 3.3-4.6% Cu, 0.5-1.0% Mn, 0.4-1.8% Mg, 0.1% Cr, 0.8% Zn, 0.2 Ti, 0.8-1.5%Pb and 0.15% other elements. The mechanical properties of EN AW 2007 aluminum alloy are presented in Table 2 according to DIN EN 754-2 standard and its ultimate tensile strength (Rm) is 340 N/mm^2.

Table 2. Mechanical properties of the aluminum alloy

Material	Yield stress Rp0.2 [MPa]	Tensile strength Rm [MPa]	Elongation A [%]
AA2007	220	340	8

The sheet metal blank used was considered as a deformable part and the initial thickness is 0.6 mm with 5 integration points. The dimension of the blank is 250x250mm. Both retaining rings are appraised as discrete rigid parts, thus, in order to control the boundary condition needed, a reference point was assigned for each one. The reference point of the lower retaining ring is considered encaster and that of the upper ring is pressed towards the lower one so that the sheet blank should be tightened between them and should no slip.

The inside of the upper retaining ring has the dimension of 200x200mm, but in the case of the lower retaining ring it is smaller 190x190mm and the outside of both is 300x300mm. For this simulation, the tool is a rigid part and has a diameter of 8 mm.

In case of simulations where the number of elements is small, the running time is short, so in our case there are less than 45000 elements distributed according to the Table 3, thus the running time should also be small.

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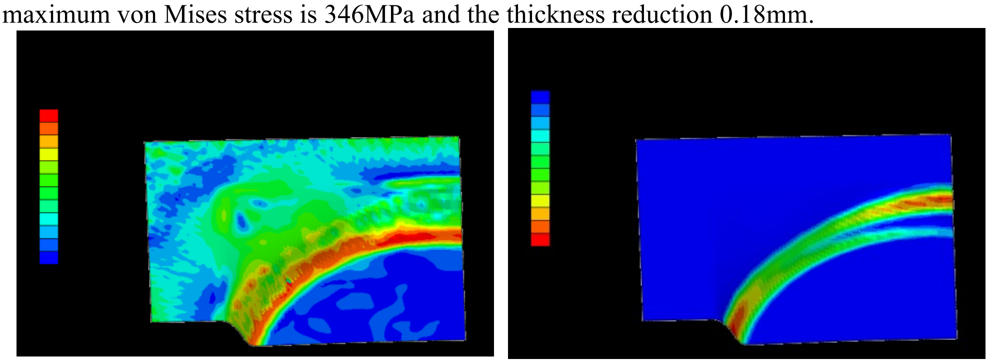
Table 3. Element types and number of elements

Parts	Upper retaining ring	Lower retaining ring	Sheet blank
Element Type	R3D4	R3D4	S4R
Number of elements	8200	8782	27900

After performing this finite element analysis, it can be observed in Figure 3 that the maximum von Mises stress is 346MPa and the thickness reduction 0.18mm.

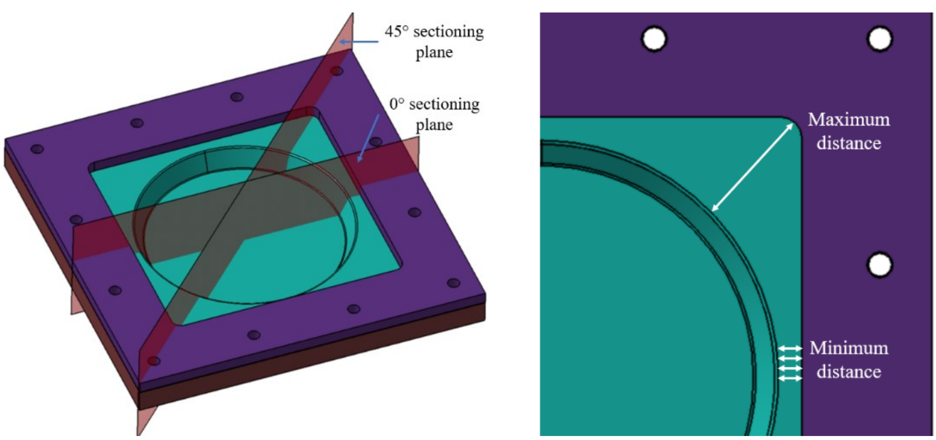


a. b.

Fig. 3. (a) von Mises stress distribution and (b) thickness reduction

3 Analytical model

In Figure 4 (a) there can also be seen two sectioning planes from which the profiles of the part were extracted after the numerical simulation was performed, and these planes were chosen in such a way that both the minimum and maximum distance d between the shape of the frustrum cone and retaining rings was contained in the profiles.



a. b.

Fig. 4. (a) Sectioning planes for frustrum cone part and (b) variable distance d

The minimum distance dmin is 1 mm and the maximum distance dmax was calculated about 40.35 mm. In order to evaluate the sheet bending defect, after performing the numerical simulation, two profiles were plotted with the help of 0° and 45° sectioning planes which contains both the minimum and maximum distance d, as in Figure 5. From these profiles we were able to extract the sheet bending error ϒ in both cases, thus being able to assume a linear dependence between the distance d and sheet bending error ϒ. For minimum distance we obtained an error ϒ1 as 0.57 mm and for ϒ2 4.06 mm. One must take into account that these values are approximative values due to the fact that it depends on how fine the mesh of the sheet metal blank was done, because the values of the error ϒ were extracted as coordinates of the mesh nodes.

The equation of the linear dependence is calculated with following formula:

$$\frac{y - y_1}{y_2 - y_1} = \frac{x - x_1}{x_2 - x_1} \quad (1)$$

By replacing the variables with our distances and sheet bending errors, we obtain:

$$\frac{\Upsilon - \Upsilon_1}{\Upsilon_2 - \Upsilon_1} = \frac{d - d_1}{d_2 - d_1} \quad (2)$$

$$\frac{y - 0.57}{4.06 - 0.57} = \frac{x - 1}{40.35 - 1} \quad (3)$$

By assuming that it is a linear dependence between sheet bending error and the variable distance of the initial contact and supporting rings, we can determine the value of sheet bending error ϒ for any variable distance d as seen below and in Figure 6:

$$\Upsilon = 0.0887 \cdot d + 0.4813 \quad (4)$$

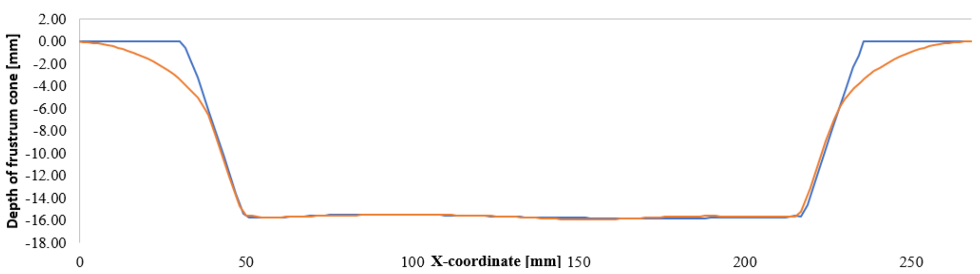


Fig. 5. Profiles of EN AW 2007 aluminum alloy at 0° and 45°

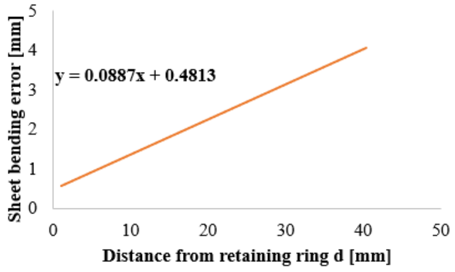


Fig. 6. Linear dependence of ϒ defect over distance *d*

4 Results and Discussion

In this paper it is presented a simple method for quantitative evaluation of one of the main drawbacks of the single point incremental forming process. This method is approximate due to the limitations of precisely determination of nodal mesh coordinates and due to the fact that it relays on a numerical simulation which in fact it is an approximation of the real experiment. Nevertheless, from this paper we can conclude that the distance between the contact point of punch with sheet blank and supporting rings has a big influence over the sheet bending defect and as long as this distance increases the higher the sheet bending error increases. This must be taken into account when large parts with complex shape may be produced through SPIF process. Many researches provided a method to overcome this drawback by adding an additional supporting plate underneath the sheet blank, but this method limits the production of different shaped parts, or by using for every part a different supporting plate, but this will significantly increase the cost of production.

Further research must be proposed to verify the behavior of different types of materials and if the linear dependence is followed if other process parameters are varied like wall angle, vertical step, toolpath strategy and depth of part.

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