EXPERIMENTAL RESEARCHES REGARDING THE INFLUENCE OF GEOMETRIC PARAMETERS ON THE PRINCIPAL STRAINS AND THICKNESS REDUCTION IN SINGLE POINT INCREMENTAL FORMING

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Scopul acestui studiu a fost acela de a investiga prin metode optice influența parametrilor geometrici asupra deformațiilor principale şi a subțierii relative în procedeul de deformare incrementală într-un singur punct. Au fost alese două tipuri de piese: o adâncitură în linie dreaptă şi o piesă de tip cupolă. Parametrii luați în considerare au fost diametrul poansonului şi pasul pe direcție verticală a poansonului. Testele au fost efectuate pe două grosimi din acelaşi material, dar având caracteristici diferite. Concluziile referitoare la influența parametrilor geometrici asupra deformațiilor principale şi subțierii relative pentru cele două tipuri de piese sunt prezentate .

The purpose of this study was to investigate by optical methods the influence of geometrical parameters on the principal strains distribution and the relative thinning in the single point incremental forming process. Two types of components were chosen: a straight grove and a dome part. The parameters which were taken into account are the punch diameter and vertical step. Tests were done on two thicknesses of the same material but having different mechanical characteristics. Conclusions regarding the influence of geometrical parameters and the relative distribution of strains and also thinning of the components are presented.

Keywords: single point incremental forming, experimental research, strains measurement, sheet metal

1. Introduction

Incremental sheet forming (ISF) is a flexible sheet metal forming process with a high potential for small quantity production and for rapid prototyping applications [1]. With this process it is possible to form sheet metal parts without manufacturing specialized dies. There are many variations of ISF, like hammering [2], laser forming [3], incremental forming with water jet [4] or with rollers [5], but the most utilized method is with a solid hemispherical punch. There are two types of incremental forming with a small punch presented in figure 1, single

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point incremental forming (SPIF) and two points incremental forming (TPIF). The process is called SPIF because it is a single contact point between the material and the forming tool, the punch (figure 1a), and TPIF because this case has a second contact point with the male (figure 1d) or female (figure 1c) die, the support post (figure 1e) or with the second intender (figure 1b). In both cases the tool path is controlled by a CNC program. The tool follows the 3D tool path, giving the shape of the part. In this metal forming process the tool produces small localized plastic deformations. The process is very flexible because in order to produce a new part it is enough to change the CNC program.

The latest researches in the area include studies investigating the possibility to form new materials through ISF, like: sandwich panels, which have ductile and largely incomprehensible cores [6], tailored blanks produced by friction stir welding [7] or polymer sheet components [8]. Other research directions is the optimization of tool path in two points incremental forming [9], to increase the geometrical accuracy of the parts by using an offline model based an online sensors based strategy [10], or to investigate the suitable tool and lubricant for pure titanium sheet [11]. There are also researches that used multi-step tool path to obtain parts with vertical walls having 90^0 [12] or to investigate hybrid processes [13] which are a combination of ISF with stretch forming.

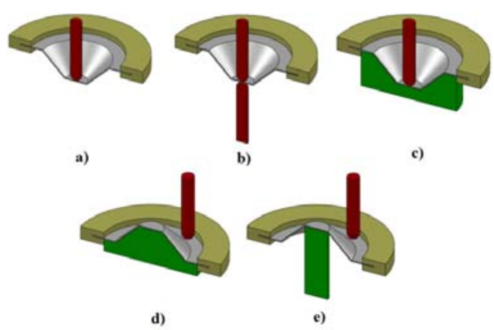


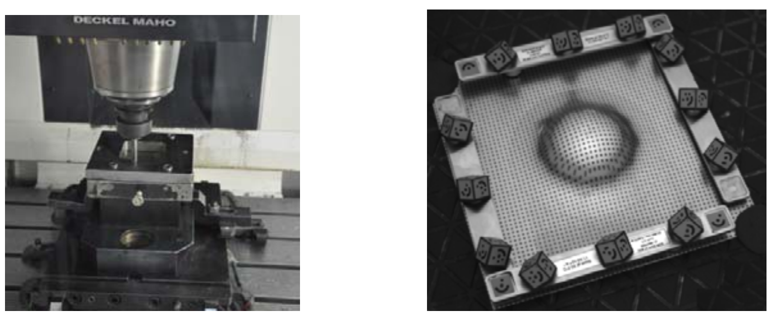
Fig. 1 Incremental forming types with a small intender

This paper aims to determine the influence of geometrical parameters (dp = punch diameter and Δpz = vertical step) on the resulting principal strains ($\varepsilon_1, \varepsilon_2$) and thickness reduction (thk) distribution for two types of pieces: dome and straight grove.

2. Determination of strains and thickness reduction

2.1. Parts manufacturing

For the practical experiments of the single point incremental forming samples a DMG Veco 635 CNC milling machine was used. The forming equipment was installed on the CNC machine as can be seen in figure 2 a). It is composed of a bottom plate that has two carriers which support the die, a punch and a retaining ring. Dies have various shapes such as circular, square, triangular and others. For the dome parts a circular die, with the inside diameter of 55.5 mm and 6 mm radius was used. For straight grove parts a square die was used with the inside dimension of 60 mm and 6 mm radius. For both components there were used two types of punches, one with a diameter of 6 mm and another with a diameter of 10 mm and two steps on *z* direction, 0.25 mm and 1 mm. Regarding the movement of the punch, a feed rate of 240 mm/min with a punch rotational speed of 180 rpm was used. Reduction of the contact friction between the punch and the material forming implied the usage of lubricant. The chosen material to produce the parts is a DC04 steel, with two thicknesses of 0.5 and 0.9 mm. The specimens used during testing are cut into squares of 120 mm side length. The mechanical characteristics of the two types of sheets were determined on a tensile test machine Roell RKM & Korthaus 100/20.



a) b)

Fig. 2 a) Experimental equipement used for SPIF and b) Part with coded bars and markers for optic analysis

Table 1.

The mechanical characteristics of materials

Thickness (t) [mm]	Strength coeficient (K) [MPa]	Strain-hardening coefficient (n) [-]	Maximum uniform strain (ε_u) [%]	Anisotropy coeficients		
				r_{00} [-]	r_{45} [-]	r_{90} [-]
0,5	547	0,212	46,82	1,419	1,378	1,716
0,9	524	0,185	47,43	1,345	1,016	1,582

As it can be seen from table 1, both materials have high values for maximum strains; this makes them suitable for incremental forming, because in this metal forming process the required deformations should be high.

In order to measure the principal strains, the samples were electrochemically marked with a network of points before deformation. We used a network of points having a diameter of 1 mm and a 2 mm distance between center points as one can see in figure 2 b). The point network was made on the piece side that does not come in contact with the punch. An optical ARGUS system produced by the GOM company was used to measure the principal strains. Deformations were measured with a 12 mm focal length lens camera.

The pieces were placed on a rotating table. On them there were mounted four encoded bars and 12 markers that allow the calibration of the optical system. After calibration, the pieces are measured by acquiring a set of 20-24 images. To capture these images the camera is positioned perpendicular to the table and a set of image captures are taken after rotating the table with 15-20 degrees.

The program, with which the optical analyzer is equipped, can measure strains (technical strains, logarithmic strains or Green strains) and thickness reduction. In this paper the true strains are presented.

2.2. Strains and thickness measurement for dome parts

To determine the distribution of principal strains, four separate tests - for each material thickness - were carried out. Punch trajectories can be seen in figure 3. The punch executes first a vertical step in the *z* direction and then executes a circular motion in the sheet plane with a certain radius. After each sheet plane circular motion, the punch executes a constant simultaneous motion in *z* and *x* directions; this variable depends on the radius. Dome pieces have an inner radius of 34 mm.

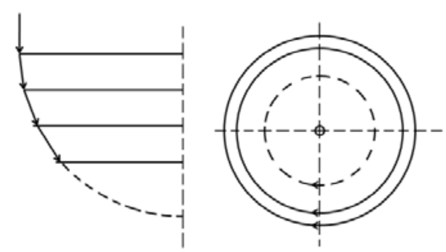


Fig. 3 Trajectories for dome parts

With decreasing punch diameter lower minor strains are achieved, but the major strains and relative thinning are increasing. By increasing the step, the major strains and relative thinning decrease but this also increases the minor strains.

Maximum values for the major strains and relative thinning are obtained in the A1 (for 0.9 mm sheet) and A3 (for 0.5 mm sheet) cases, where there is a punch of 6 mm and a vertical pitch of 0.25 mm. Also, in these cases, minor strains have minimum values, as it can be seen from table 2.

Maximum values for minor strains are obtained in the cases of A6 (for 0.9 mm sheet) and A8 (for 0.5 mm sheet), were there was used a 10 mm punch and pitch of 1 mm. In these cases we obtained minimum values for major strains and relative thinning.

Table 2.

The experimental results for principal strains and relative thinning

Case	dp [mm]	t [mm]	Δpz [mm]	ε_1 *max* [%]	ε_2 *max* [%]	*thk* [%]
A1	6	0.9	0.25	0.774	0.0733	0.921
A2	6	0.9	1	0.753	0.152	0.872
A3	6	0.5	0.25	0.956	0.0831	0.972
A4	6	0.5	1	0.875	0,147	0.92
A5	10	0.9	0.25	0.712	0.091	0.794
A6	10	0.9	1	0.649	0.16	0.747
A7	10	0.5	0.25	0.916	0.0944	0.897
A8	10	05	1	0.765	0.1508	0.861

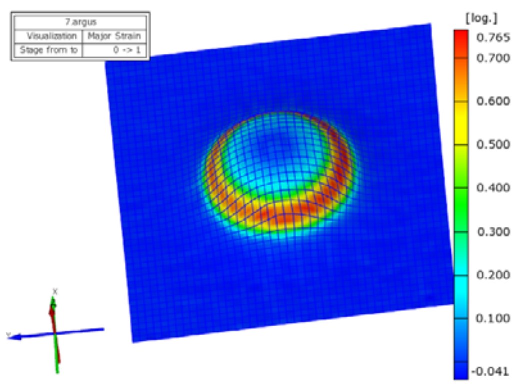


Fig. 4 Major strains for dome parts for the A8 case (10 mm punch diameter, 0.5 mm material thikcness and 1 mm vertical step)

As recognizable from the figure 4 the major strains have maximum values in the area of the punch movement in the sheet plane. The major strains are greater in the area where the punch executes the first vertical steps. Variation of the minor strain is presented in figure 5. Minor strains of maximum values were obtained within the penetration area of the punch into the material.

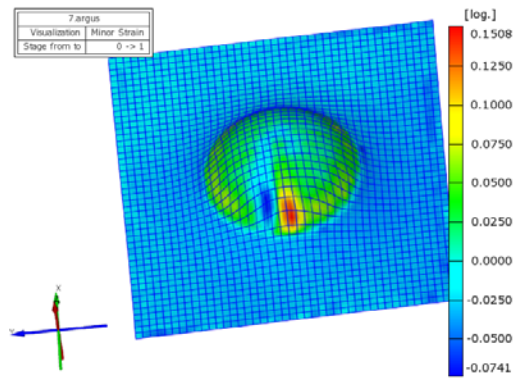


Fig. 5 Minor strains for dome parts for the A8 case (10 mm punch diameter, 0.5 mm material thikcness and 1 mm vertical step)

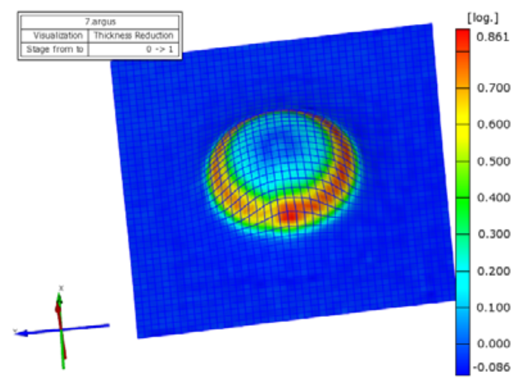
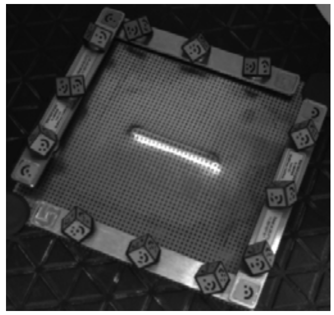


Fig. 6 Thickness reduction for the A8 case (10 mm punch diameter, 0.5 material thikcness and 1mm vertical step)

Variation of the thickness reduction is shown in figure 6. As it can be seen from the figure, the relative thinning reached a maximum in the area of the punch penetration into the material.

2.3. Strains and thickness measurement for straight grove parts

To determine the distribution of principal strains and the relative thinning there were used a set of eight separate parts, four for each thickness of material. Punch trajectories for straight grove parts are presented in figure 7 b) and in figure 7 a) is presented the part during the strains measurement.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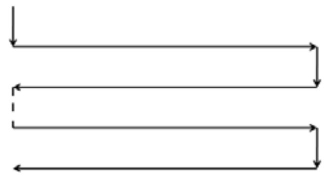
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Fig. 7 a) Part with coded bars and markers for optic analysis and b) punch traiectories for dome parts

Table 3.

The experimental results for principal strains and relative thinning

Case	dp [mm]	t [mm]	Δpz [mm]	ε_1 *max* [%]	ε_2 *max* [%]	*thk* [%]
B1	6	0.9	0.25	0.285	0.166	0.451
B2	6	0.9	1	0.334	0.145	0.398
B3	6	0.5	0.25	0.256	0.1806	0.457
B4	6	0.5	1	0.264	0,1737	0.355
B5	10	0.9	0.25	0.241	0.125	0.364
B6	10	0.9	1	0.258	0.1105	0.3
B7	10	0.5	0.25	0.222	0.1395	0.422
B8	10	0.5	1	0.236	0.109	0.309

Punch penetrates with a vertical step of 0.25 or 1 mm in the z direction and then executes a movement of 40 mm in the *x* direction. When it reaches the end it penetrates whit a step in *z* direction and comes back on the *x* direction with 40 mm. Manufactured parts have a height of 6 mm. The utilized punches have the same dimensions as in the case of the dome parts. In table 3 the results obtained during the tests are presented.

As it can be seen from the table the vertical step, has the greatest influence on the strains distribution. With a smaller vertical step the major strains are smaller, but one can also notice higher minor strains and relative thinning. With an increasing punch diameter, the values for major and minor strains and relative thinning are also increasing.

Maximum values for major strains are observed in cases B2 (for 0.9 mm sheet thickness) and B4 (0.5 mm sheet thickness) for a 6 mm punch and a vertical step of 1mm. Maximum values for minor strains and thickness reduction are observed in cases B1 (for 0.9 mm sheet thickness) and B3 (for 0.5 mm sheet thickness) for a vertical step of 0.25 mm a punch diameter of 6 mm. Minimum values for major strains are obtained in cases B5 (for 0.9 mm sheet thickness) and B7 (for 0.5 mm sheet thickness) for step of 0.25 mm and a 10 mm punch diameter. For minor strains and thickness reduction the minimum values are obtained in cases of B6 (for 0.9 mm sheet thickness) and B8 (for 0.5 mm sheet thickness) for a vertical step of 1 mm and 10 mm punch diameter.

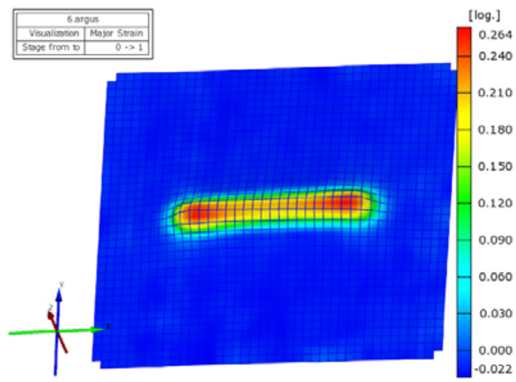

Fig. 8 Major strains distribution for straight grove parts for the case of B4 (6 mm punch diameter, 0.5 mm material thikcness and 1 mm vertical step)

As it can be seen from figure 8, major strains have maximum values along the punch displacement on the *x* direction, with a maximum reached at the initial area of punch penetration in *z* direction.

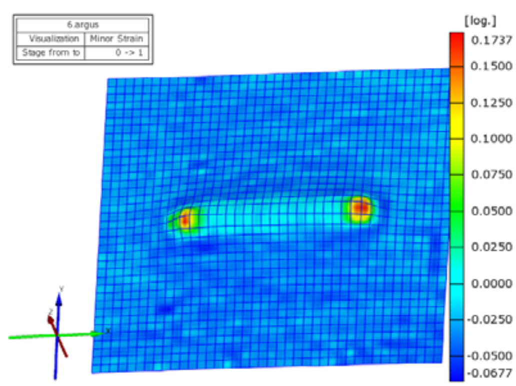

Fig. 9 Minor strains distribution for straight grove parts for the case of B4 (6 mm punch diameter, 0.5 mm material thikcness and 1 mm vertical step)

The minor strains, depicted into figure 9, have maximum values in the areas where the punch moves on *z* direction. Figure 10 presents the variation of thickness reduction. As it can be seen from the figure, thinning is at its maximum in the areas of the punch penetration in *z* direction.

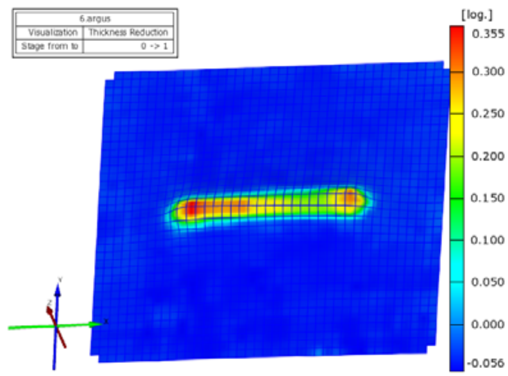

Fig. 10 Thickness reduction for case B4 (6 mm punch diameter, 0.5 material thikcness and 1 mm vertical step)

3. Conclusions

The main conclusions on the influence of geometrical parameters on the principal strains and thickness reduction in parts manufactured with the single point incremental forming method are the following.

In the case of dome parts, by the increasing the punch diameter and the vertical step pitch values there are observed lower values concerning the major strains and thickness reduction and greater values for minor strains.

In the case of the straight grove parts, by increasing the punch diameter there are obtained lower values for major and minor strains as well as for the thickness reduction. By increasing the vertical pitch value~~,~~ the major strain has higher values, but, in the same time, minor strain~~s~~ and thickness reduction have lower values.

In the future we want to extend the analyses of strains and relative thinning distribution through experiments on other types of parts, for example on a cone frustum, pyramid frustum or more complex geometry parts by taking into account others important parameters like: material thickness, angle of the part wall (for the cone and frustum parts) or different material types for the same thickness.

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