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EXPERIMENTAL RESEARCHES REGARDING THE DISTRIBUTION OF THE DEFORMATIONS ON INCREMENTAL FORMED PARTS

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Abstract: *The goal of this research is to present results regarding the variation of the deformations on the surface of the incremental formed parts. The experiments were performed on a custom layout by means of a KUKA industrial robot and the measurement of the sheet metal deformations was done using ARAMIS optical measurement system. The custom layout allows for the measurement of the deformations to take place during the actual forming process.*

Keywords: incremental sheet metal forming, industrial robot, strains, optical measuring system

Introduction

Manufacturing processes of sheet metal parts are widespread among the industrial environment, especially in the automobile and aircraft construction. Processes such as stamping and deep drawing have proven they're value over the years in the manufacture of series products. The high price of the dyes is not justified for manufacturing prototypes or pre-series components.

In recent years the market demanded new approaches regarding the manufacturing of sheet metal parts, especially to the production of prototypes. As researches in this field provide more and more results, new manufacturing solutions emerged, reducing both the cost and the total manufacturing time. Incremental forming is such a solution, which is specialized in manufacturing cheap prototypes or pre-series components at a low cost (Hagan, 2003; Jeswiet, 2005).

Unlike the traditional manufacturing processes of sheet metal parts, rapid changes can be performed during the incremental forming process, due to the simplistic design of the equipment and tools. Although the time required for the manufacture of a product using incremental forming is higher than in traditional processes, the manufacturing of the forming tool is significantly lower.

Incremental forming can be performed using several types of equipment such as specially constructed machines built for incremental forming, CNC milling machines and more recently with industrial robots (Vihtonen, 2008; Sasso, 2008).

Incremental forming has stirred the interest of scientist around the world from the beginning, due to its great potential and applicability in various fields. Different researchers have reported positive results regarding the manufacture of medical implants using the incremental forming process (Ambrogio, 2005; Oleksik, 2009).

Single point incremental forming

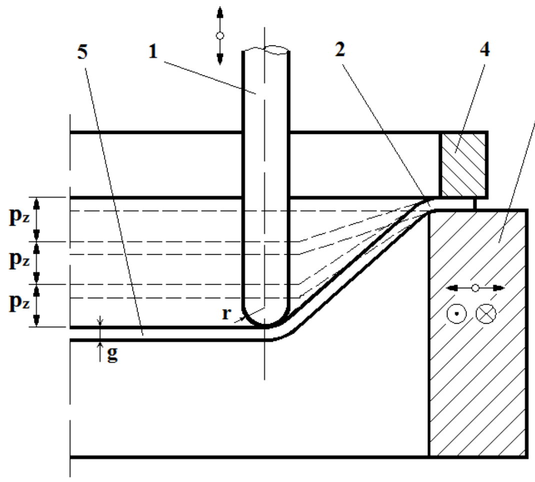
The main characteristic of this manufacturing process is that only a small portion of the sheet metal is in contact with the forming tool at any given time. The work piece surface that comes in contact with the forming tool is directly dependent on the size and shape of this tool.

A brief description of the single point incremental forming process principle is presented in Figure 1. The blank (2) is fixed by means of the blank holder (4) on a support frame (3). In order to obtain the final shape the steel metal part (5), the punch (1) has an axial feed movement on vertical direction, continuous or in steps (p_z - incremental), while the support frame (4) carries out a plane horizontal movement.

Incremental forming enables a higher degree of deformation and the possibility of forming materials with reduced deformation capacity and higher strength (Schafer, 2005).

In spite of its great advantages, the industry is still reluctant to apply incremental forming on a large scale due to two major drawbacks: low shape and dimensional accuracy of the sheet metal parts and sheet metal integrity (Rauch, 2009).

Figure 1: Process principle of single point incremental forming



Some solutions have been identified in order to eliminate the drawbacks mentioned before. One of the most promising is the optimization of the process tool paths (Cofaru, 2008). A large number of research results about incremental forming have been published in recent years, aiming to find out what equipment is best suited for this process and of course what are the most important process parameters both in running experiments and for production (Oleksik, 2010).

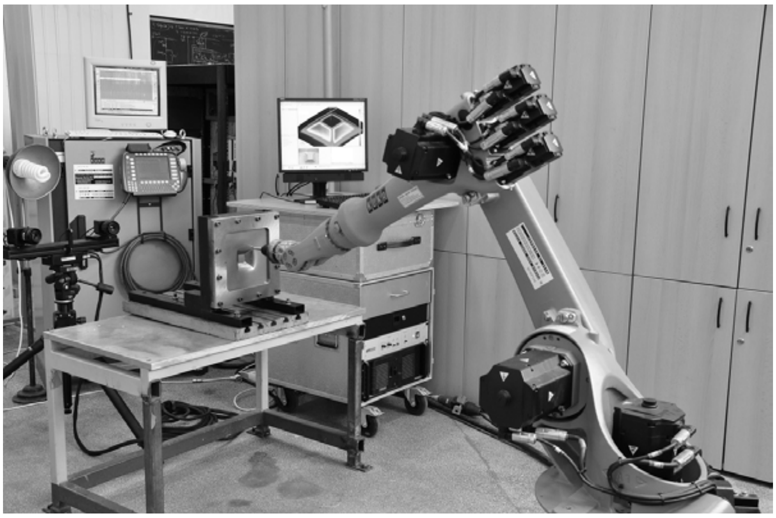
In the first articles regarding the incremental forming process, the experiments were performed with the help of specially designed machines or CNC milling machines, in recent years a large number of articles were published in which the authors have conducted experiments using industrial robots (Schafer, 2005; Meier, 2009).

Experimental layout

The custom layout used for the single point incremental forming experiments consists of six degrees of freedom anthropomorphic robot KUKA KR 6 (Figure 2), a custom blank holder, a custom tool holding unit and the forming tool. The KUKA KR6 robot has great flexibility and is suitable for both point-to-point and continuous-path controlled tasks.

ARAMIS optical measurement system is used as an extensometer in order to measure the strains. The system consists of two high resolution cameras and the computation system. ARAMIS uses a diffuse network of points applied on the surface of the metal sheet and is able to measure the displacements between these points during the deformation process and thus it can determine the strains.

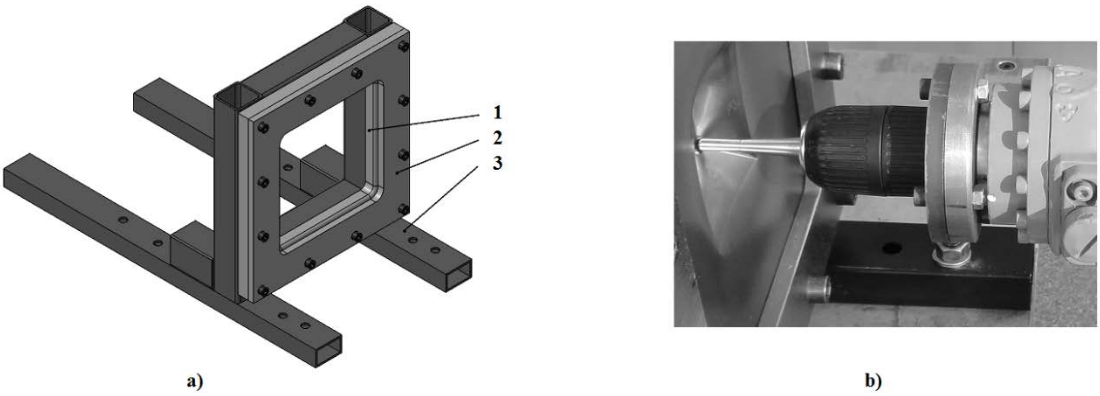
Figure 2: **Experimental layout used for incremental forming**



The position and the orientation of the blank holder (Figure 3, a) were chosen in this manner in order for the optical measurement system ARAMIS to be able to measure the strains during the actual incremental forming process. The sheet metal is fixed in a vertical position, exposed in front to the industrial robot, and in the back to the optical measurement system. The blank holder consists of a support frame (1), the holding frame (2) and the support frame (3).

The forming tool is a punch with a diameter of 10 mm, supported in a specially constructed tool holding unit (Figure 3, b) witch is attached to the industrial robot. Using this tool holding unit, tools with different diameters can be changed quickly and easily between experiments.

Figure 3: a) **Custom blank holder ; b) Custom tool holding unit**



Experimental Study

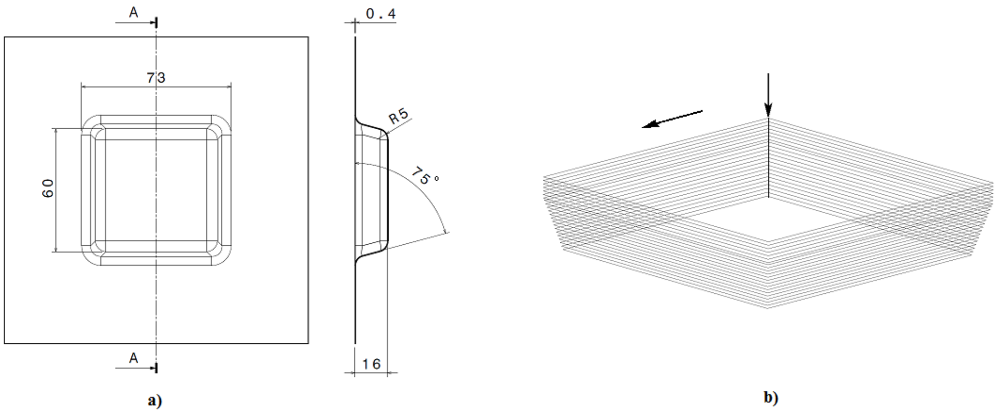
The trajectory of the forming tool attached to the KUKA KR6 industrial robot was programmed and tested using DELMIA software package. DELMIA is able to create a virtual environment in witch the movements of the industrial robot can be simulated and tested. If the simulation is satisfactory, the program code needed for the robot to function correctly can be generated with a specific function of the software. DELMIA uses an internal compiler and depending on the version of DELMIA, it needs a particular version of java installed on the PC. The compiler creates two files and both have to be transferred to the KUKA KRC01 controller in order to use the robot properly.

In order to measure the deformations on the incremental formed parts, ARAMIS measurement system needs to be calibrated using a special calibre. The area in witch the measurements can be performed without errors is approximately 96 mm x 96 mm. The recommended distance between the sheet metal and the cameras of the optical measurement system is approximately 1000 mm. The steel sheets used for incremental forming experiments need to be cleaned and painted with white mate paint in order to avoid reflections. After the white paint dries off, a fine network of black points needs to be applied on the steel sheets so that ARAMIS can measure the strains during the forming process.

The surface of the steel sheet that will come in contact with the forming tool needs to be lubricated in order to reduce the friction forces. Because the steel sheet is in a vertical position, additional lubrication is required during the forming process.

For the experimental study a truncated pyramid shaped part was chosen. The dimensions of the part are presented in Figure 4, a. The trajectory of the forming tool needed to shape the truncated pyramid part is presented in Figure 4, b. The material of the sheets is similar to DC04 grade of steel and has very good deformability properties.

Figure 4: a) Dimensions of the incremental formed part; b) forming tool trajectory



The geometrical data that are characteristic to this type of experiment are presented in Table 1.

Table 1: Geometrical data that are characteristic to incremental forming process

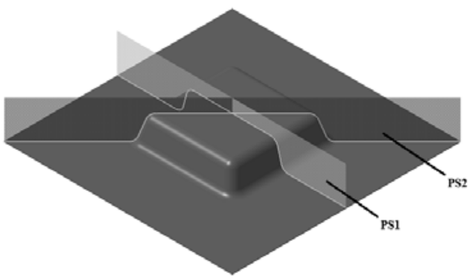
Geometrical data	Dimensions [mm]
Size of the steel sheets	250 x 250
Thickness of the steel sheets	0.4
Diameter of the forming tool	10
Incremental step size	0.25
Height of the shaped part	16
Angle of inclination of the walls	75°

Experimental results

During the incremental forming process ARAMIS measurement system is set to take photographs of the painted side of the steel sheet once every 4 seconds. At the end of the experiment, the photographs are analyzed and the surface of the part is generated in a three-dimensional environment. ARAMIS provides the tools in order to visualize the principle and secondary strains, the thickness reduction and the displacements in the steel part in all the stages of the forming process.

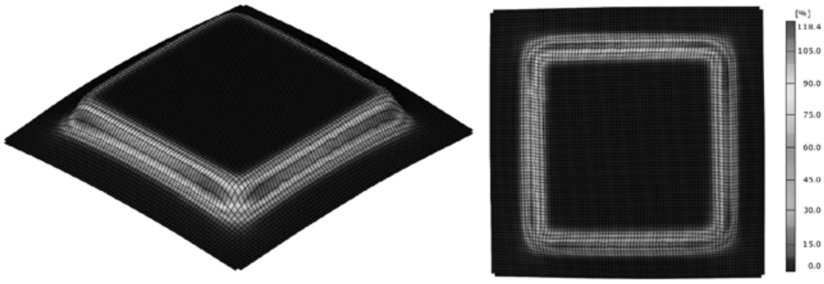
In order to graphically display the variation of the strains and the thickness reduction on the surface of the incremental formed parts, the 3D model of the part was sectioned by two planes (Figure 5).

Figure 5: Sectioning planes



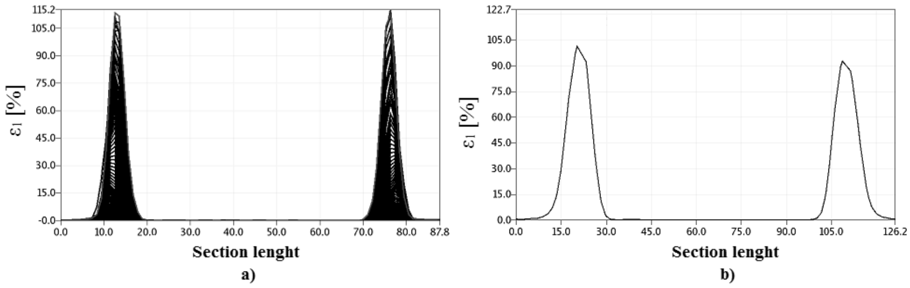
The distribution map for the major strains is presented in Figure 6. The maximum value of 1.184 for the major strains was attained on the faces of the truncated pyramid shaped part.

Figure 6: Distribution map for the major strains



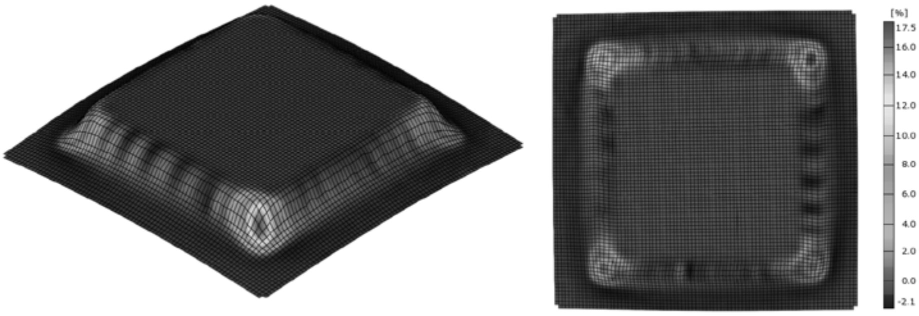
The variation of the major strains for the PS1 section is presented in Figure 7, a. The strain variation for the PS2 section is presented in Figure 7, b.

Figure 7: a) Major strain variation for PS1 section; b) Major strain variation for PS2 section;



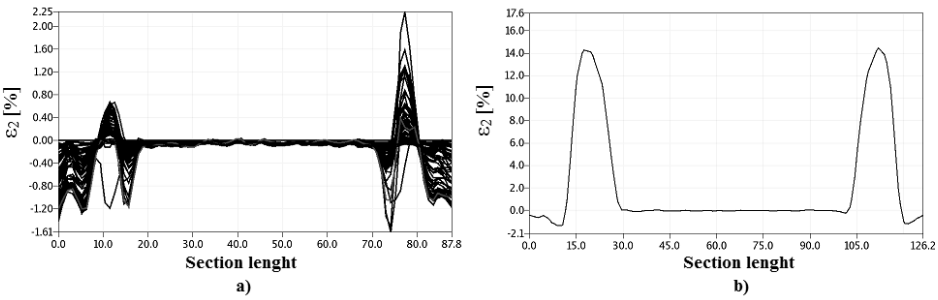
The distribution map for the minor strains is presented in Figure 8. The maximum value of 0.175 for the major strains was attained on the corners of the truncated pyramid shaped part.

Figure 8: Distribution map for the minor strains



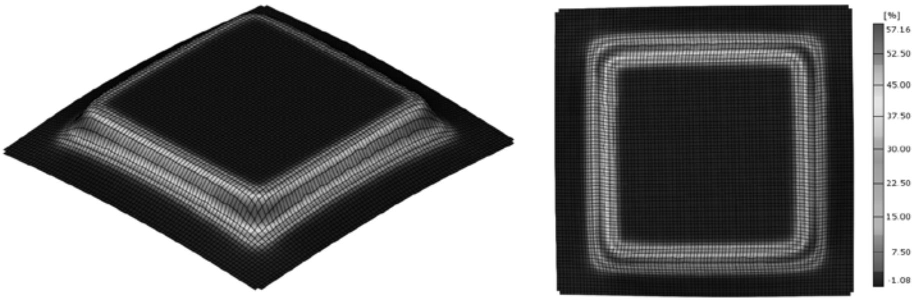
The variation of the minor strains for the PS1 section is presented in Figure 9, a. The strain variation for the PS2 section is presented in Figure 9, b.

Figure 9: a) Minor strain variation for PS1 section; b) Minor strain variation for PS2 section;



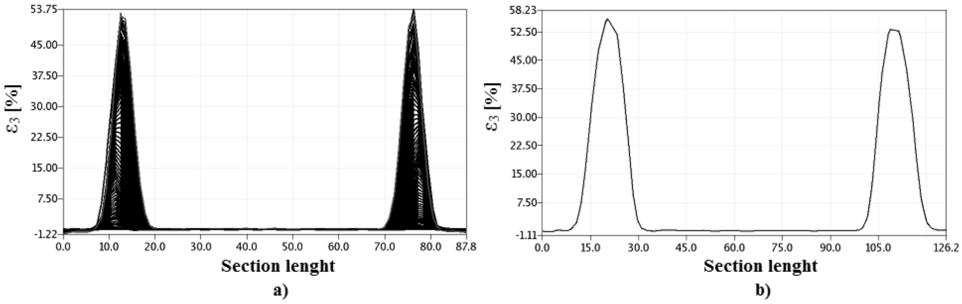
The distribution map for the thickness reduction is presented in Figure 10. The maximum value of 57.16 % for the thickness reduction was attained on the corners of the truncated pyramid shaped part.

Figure 10: Distribution map for the minor strains



The variation of the thickness reduction for the PS1 section is presented in Figure 11, a. The variation of the thickness reduction for the PS2 section is presented in Figure 11, b.

Figure 11: a) Thickness reduction variation for PS1 section; b) thickness reduction variation for PS2 section;



6. Conclusions

As the graphics of the variation of the major strains (Figure 8) were analyzed, it can be concluded that the peak values registered are along the PS1 section. The maximum values were registered on the faces of the truncated pyramid shaped part directly on the trajectory of the forming tool. The values of the major strains along the PS2 section have a similar variation, but the maximum registered values are lower than on the PS1 section. Comparing the graphics of the variation of the minor strains (Figure 10), it can be seen that the peak values were registered along the PS2 section. The maximum values for the minor strains were registered on the corners of the truncated pyramid shaped part. The thickness reduction (Figure 12) has a similar variation to the major strains, but the peak values were registered along the PS2 section. The maximum values for the thickness reduction were registered on the corners of the truncated pyramid shaped part.

The experimental results had shown that ARAMIS measurement system is an excellent tool for measuring strains on the parts during the incremental forming process.

Future work will cover a study of the variation in time of the strains during the incremental forming process.

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