ANALYSIS OF THE ALUMINUM FORMABILITY IN THE INCREMENTAL SHEET FORMING PROCESS

ŻABA Krzysztof[1], GŁODZIK Marcin[1], PUCHLERSKA Sandra[1], POCIECHA Daniel[1], NOWOSIELSKI Maciej[1], KWIATKOWSKI Michał[1], LUTY Grzegorz[2]

[1]AGH University of Science and Technology, Cracow, Poland, EU, marglo@agh.edu.pl
[2]PZL Mielec / a Sikorsky Company, Mielec, Poland, EU, g_luty@pzlmielec.com.pl

Abstract

The paper presents preliminary results of the studies of the aluminum alloy sheet formability in the process of Incremental Sheet Forming (ISF). For tests was used aluminum alloy sheet 2024 series. The paper presents laboratory stand and measurement method that have been used to analyze the process. The first studies consist of the mathematical modeling, selection of the optimum process parameters, determining the forces generated in the process and thickness distribution analysis with the photogrammetric method.

Keywords: Single Point Incremental Sheet Forming, Aluminum Alloys, Photogrammetry, FEM

1. INTRODUCTION

Incremental sheet forming (ISF) is a new approach to the problem of the metal alloys forming as well as the composite shell structures. This method is a combination of two extremely different metal shaping techniques: stamping and machining [1], [2].

Incremental sheet forming in the first version called „dieless forming" has been patented [3] in 1967 by Edward Leszak. It consisted on a point sheet metal stamping (single point) using a mandrel or roller, without die. The essence of the method is shown in **Fig. 1**.

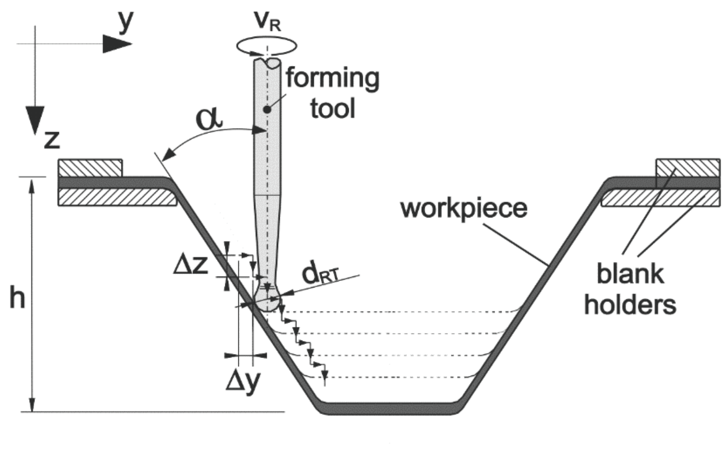

Fig. 1 Essence of single point incremental forming

There are many modifications Leszak's method based on advanced multi-axis CNC machine and robots [4]. The mechanism of deformation remained unchanged, modifications were only tools, dies and holders.

Single point incremental forming with faceplate on a real example is shown in **Fig. 2.** Rotating mandrel deforms the metal sheet in the so-called three-dimensional shape with the so called backfilling.

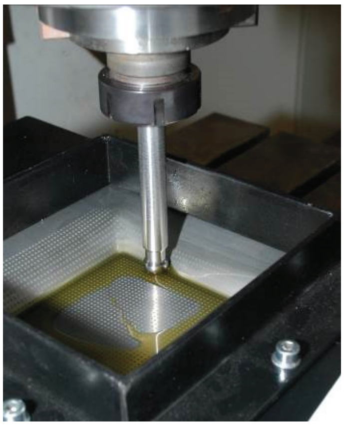

Fig. 2 Single point incremental forming with the faceplate (SPIF) - real view

Another variation of the process is incremental sheet forming with the counter tool that moves along the path of the forming tool and supports a sheet from below [4].

There are solutions that use partial or full die and a movable metal holder. However, such techniques, introduces additional tensile stress due to metal sheet stretching on the die [5].

The aim of the research was preliminary analysis of the aluminum alloys formability in the incremental sheet forming.

2. METHODOLOGY

Preliminary studies realized on 2024 aluminum sheets with a thickness of 1mm in T3 condition (solution heat treatment and ageing). The study of the chemical composition of metal sheet was carried out by Hitachi TM 3000. From the metal sheet was cut samples for tensile test, using a static testing machine Zwick/Roell Z050, equipped testXpert® II program, used for control and data acquisition. Then the sheet was cut into smaller samples with dimensions 250mm x 250mm, for the ISF process. Tool for the ISF process made from powder steel VANCRON 40. Working part of the tool was made in the spherical shape with a diameter of 18mm. In order to verify the shape and size realized measurement using a photogrammetric scanner ATOS III Triple Scan from GOM company (**Fig. 3**).

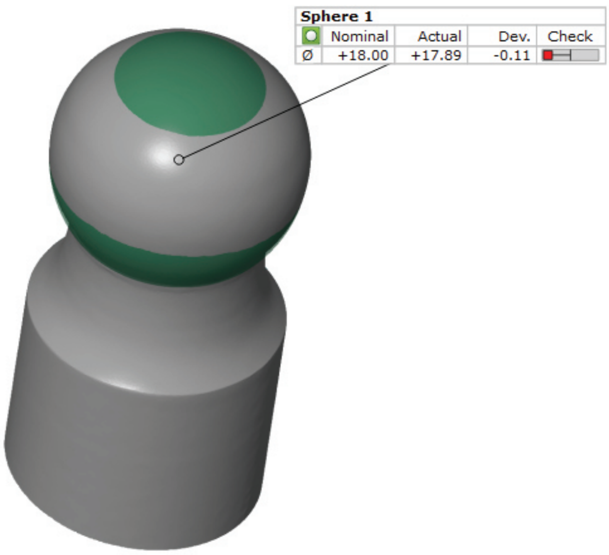

Fig. 3 Digital model of the tool

By using Catia V5 program was designed CAD model of the part. This model was used to generate the tool path in the Edge CAM software (**Fig. 4**)

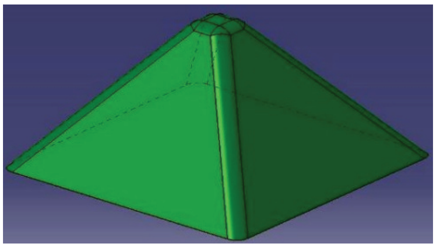

Fig. 4 The digital part model in the program Catia V5

ISF process was carried out on a laboratory stand built on the three-axis CNC machine, controlled by Fanuc software (**Fig. 5**).

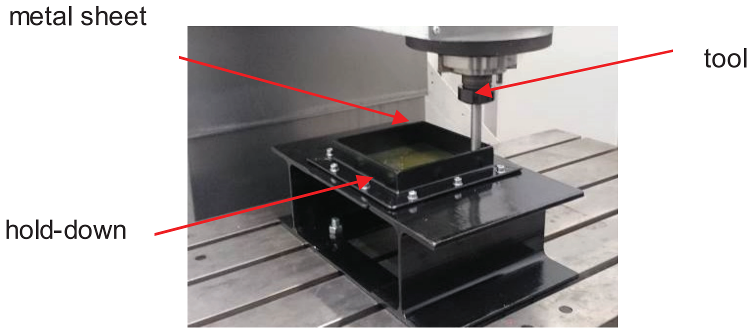

Fig. 5 Laboratory stand to the ISF

Metal sheet was fixed with a steel platen and screws. Feed rate of the forming tool was 600 rpm, rotation speed was 300 rpm, embossing depth was 1mm and the distance from the path of 1mm. The study used lubricant Iloform PN 142. In the process tool pressure force was recorded. During the tests, also recorded temperature distribution on the surface of the formed metal sheet using thermovision camera FLIR to determine thermal effects occurring in the process (**Fig. 6**).

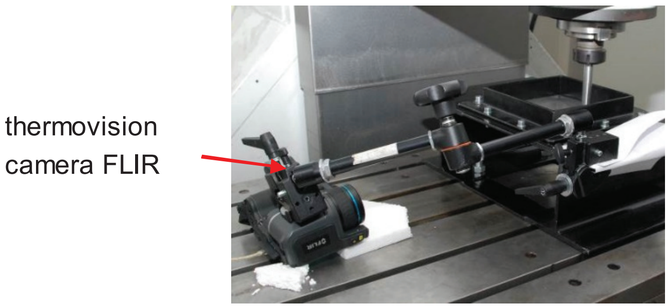

Fig. 6 Laboratory stand to the ISF with thermovision camera

Due to the failed first laboratory tests (cracking of the shaped material) decided to modeling ISF process using commercial Abaqus UFEA software, this allowed to choose optimal parameters for forming. In addition, batch sheets were heat treated by solutioning in 493°C.

In order to verify numerical simulations was carried out laboratory tests again with the changed process parameters, as shown in the test results.

3. RESULTS

The results of the 2024 aluminum alloy chemical composition are shown in **Table 1**.

Table 1 Chemical composition of the 2024 aluminum alloy

Element	Cu	Mg	Si	Mn	Zn	Fe
%	4.880	1.6	0.081	0.609	0.103	0.201

The mechanical properties results of the metal sheets in T3 condition are R_m = 430MPa, R_{02} = 320MPa, A = 22%.

The results of preliminary trials of forming metal sheets were unsuccessful. There was a cracking on the metal sheet (**Fig. 7**) after 11% of the forming in accordance with the program.

a) b)

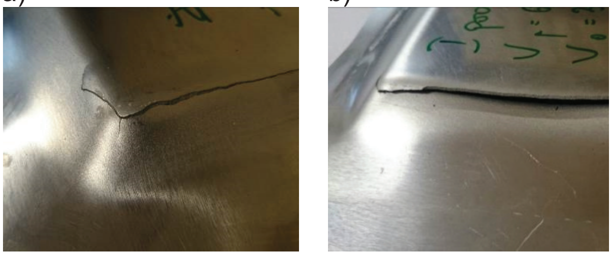

Fig. 7 Damaged product by crack of the material; a) crack in the corner of the part, b) crack along the edge of the part

The next step was numerical analysis of the ISF for selection optimal parameters and to determine the maximum value of stress during deformation. **Fig. 8** shows first step in the process of the tool depth in the metal sheet of 1mm and the tool offset about 20mm. During single step in the forming material are reaching locally stress value of 500MPa.

a) b)

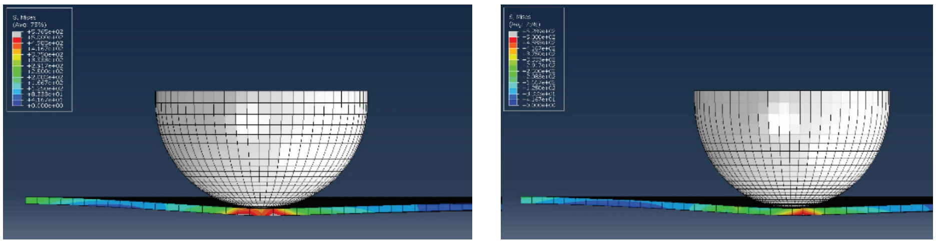

Fig. 8 The results of numerical simulation of the first step of the process; a), b) the next steps tool movement

The results of the numerical analyzes also indicate that the material is pulled out from the platen with a force of approx. 43N (**Fig. 9**).

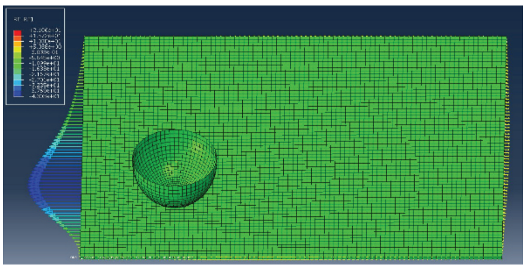

Fig. 9 Forces analysis the ISF

The results of measuring the deformation force in ISF is shown in **Fig. 10**.

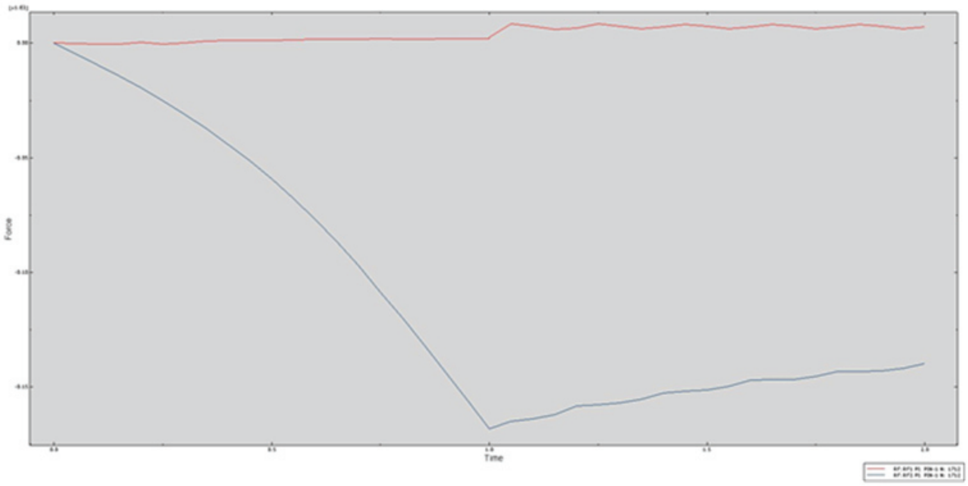

Fig. 10 Force in function of time in two axes of tool movement

The diagram shows two curves. Blue curve shows the course of force in an axis parallel to the axis of the tool, which is, the depth of the tool in the metal sheet. This force is approximately 150 N. The red curve represents the course of force in an axis perpendicular to the tool axis. The movement of the tool in a recessed plate produces a much lower strength.

Based on the results, decided that it should significantly improve conditions for deformation in the ISF. The first step was to increase the formability of metal sheet through solution heat treatment. As a result of this treatment substantially reduced the strength properties of material to the level of R_m = 300 MPa; R_{02} = 150 MPa and an increase in plastic properties to the level of A = 25%.

Furthermore, the depth of the tool during each pass, and the distance between paths was 0.5mm. The rotational speed of the tool and the feed rate was chosen as much as possible to minimize friction between the tool and the material. The rotational speed was 11 rpm and tool feed speed of 300 mm/min. With such a tool speed matched, tool is rolling on the metal sheet, thus eliminating efface of the material.

During the process, the temperature was recorded using a FLIR thermal imaging camera. This study is justified by the fact that the solutioned 2024 alloy very quickly naturally ageing in room temperature. The part forming from solutioned alloy in room temperature is possible after 20 minutes after solution heat treatment. The process temperature can accelerate the aging process. The study showed that in the final phase of the process, which is about 11 minutes, the maximum local temperature sheet is about 80°C. **Fig. 11** shows the thermographic photo at the beginning and the final stage of the process.

a) b)

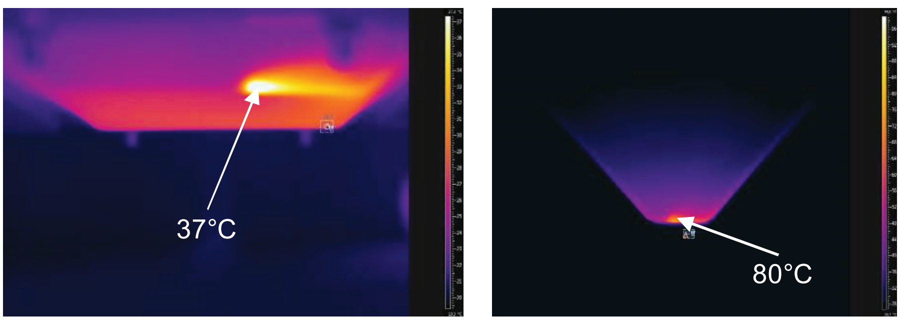

Fig. 11 Thermographic photos of the process; a) elevated temperature at the point of contact metal sheet with the tool, b) the temperature distribution of the forming part

The final product is characterized by an acceptable surface quality assessed visually (**Fig. 12**).

a) b)

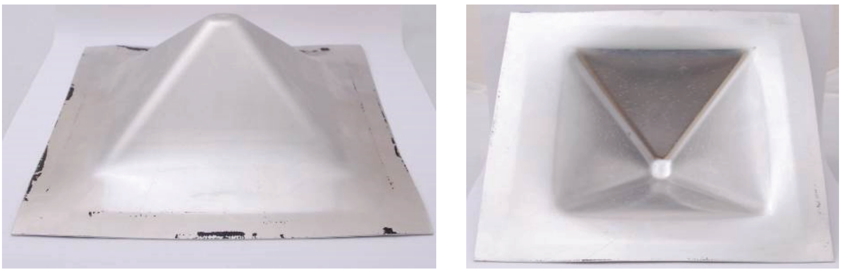

Fig. 12 The product obtained in ISF; a) isometric view, b) plan view

The resulting product has been photogrammetric scanning to identify the wall thickness distribution. **Fig. 13** shows the map of the wall thickness distribution. Analysis showed that the maximum thinning is 30% and is highest in the periphery of the bottom of the stamping.

a) b)

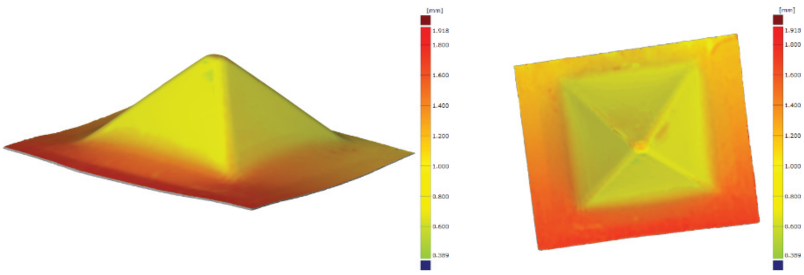

Fig. 13 Wall thickness distribution of the product; a) isometric view, b) plan view

4. CONCLUSION

Preliminary studies of the process have shown that the formability of aluminum alloy 2024 can be increased significantly by providing a tool for minimizing the friction material by adjusting the rotational speed to the feed so that the tool went through the material. Furthermore, studies have shown that a major problem in this process is non-uniform change in wall thickness. Further study of this process will be aimed at identifying critical parameters to change the thickness of the wall and the search for such a construction solution to minimize this effect to an acceptable level.

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