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EVALUATION OF THE FORMABILITY OF EN AW-5754 H22 ALUMINIUM-MAGNESIUM ALLOY PERFORATED SHEETS DURING THE SINGLE POINT INCREMENTAL FORMING PROCESS

Ana-Maria BUCUR, Tomasz TRZEPIECIŃSKI, Mihaela OLEKSIK, Delia Rebeca VASILCA, Valentin OLEKSIK

***ABSTRACT:** The present paper aims to study the formability of EN AW-5754 H22 aluminium alloy perforated sheets formed by incremental forming process based on the maximum allowable wall angle. For this study, a variable angle cone frustum trajectory was used, and nine specimens were incrementally formed, corresponding to a 3^2 full factorial experiment. We employed three levels of variation for two parameters: the perforated hole diameter (2.5, 3 and 4mm) and the distance between two holes measured between the perforated edges (2, 3 and 4mm). The results are focused on determining the main strains, the thickness reduction, the height of the part, the maximum allowable wall angle and the maximum value of the forces on the three directions.*

***KEYWORDS:** perforated sheets, aluminium-magnesium alloy, incremental forming, maximum wall angle, main strains, force variation.*

1. INTRODUCTION

The single point incremental forming process (SPIF) has developed a lot in the last 30 years due to the advantages it offers: increased flexibility and reduced forming forces compared to classical sheet metal forming processes [1]. Due to the importance of the process, there is also a large number of published scientific papers that have studied the formability of the SPIF process or the influence of the technological or geometrical parameters on strains, thickness reduction or force variation during the above-mentioned process [2]. Particular attention, especially in the automotive industry, has been paid to the incremental forming of aluminium alloys due to the fact that aluminium provides sufficient strength at a low weight [3].

Research strictly related to incremental forming of perforated sheets is extremely rare, which led to the need for this study. The first research related to the incremental forming process of the perforated sheets was carried out by Kitazawa and all [4]. In this paper, the behaviour of aluminium sheets with a periodic equilateral triangular pattern at SPIF process was analysed. The authors' conclusion was that the global deformation modes show many similarities with the behaviour of solid, non-perforated sheets. Another paper concerns the manufacturing of cranial prostheses from TA1 titanium sheet using the SPIF process. This analyses, based on the simulation using the finite element method, the nodal displacement variation, the wall thickness variation, the geometric accuracy of the obtained part and the formability in different areas of the formed part [5]. The work of Li and all studies the formability of the TA1 titanium perforated sheet at SPIF, reaching the conclusion that formability is primarily influenced by the wall angle [6]. The authors also mention that the fracture that occurs is ductile. Bouzidi and all analysed, based on an experimental study, the springback obtained in the incremental forming process of perforated sheets from AZ31B Magnesium alloy [7].

2. MATERIALS AND METHODS

For conducting the experiments, the EN AW-5754 H22 aluminium-magnesium alloy with a thickness of 0.5 mm was used, an aluminium alloy used for constructing vehicle bodies, rivets, ship building and welded structures. The chemical composition of this alloy includes Mg (2.6% to 3.6%), Mn + Cr (0.1% to 0.6%), Fe (up to 0.4%), Si (up to 0.4%) and Zn (up to 0.2%).

The EN AW-5754 H22 aluminium-magnesium alloy has a density of 2.66 g/cm^3, the elasticity modulus of 68 MPa, a maximum tensile stress of 270 MPa and a minimum elongation of 7%. The specimens measure 245 x 245 mm and were water jet cut. Also, the perforated holes were water jet cut in order to not influence the mechanical characteristics of the material. We created a 3^2 full factorial experiment, with two influence factors (the hole diameter and the distance between two holes measured between the perforated edges), each factor having three levels of variation. The design of experiments is presented in Table 1.

Table 1

The Design of Experiments

No.	Code	Hole diameter [mm]	Distance [mm]
1.	Al_1_var	2,5	2
2.	Al_2_var	2,5	3
3.	Al_3_var	2,5	4
4.	Al_4_var	3	2
5.	Al_5_var	3	3
6.	Al_6_var	3	4
7.	Al_7_var	4	2
8.	Al_8_var	4	3
9.	Al_9_var	4	4

In order to manufacture the parts using the incremental forming process the Kuka KR210-2 industrial robot was used. The 12M Aramis optical system was used for measuring the strain on the x direction, the strain on the y direction, the in plane xy strain, the major strain, the minor strain, the equivalent von Misses strain, the thickness reduction and the maximum part height before the occurrence of the fracture. The Piezotronics PCB 261A13 force transducer was used in order to measure the force variation on the three directions. Figure 1 presents a photo of the experimental layout with the force transducer mounted on the robotic arm of the Kuka robot.

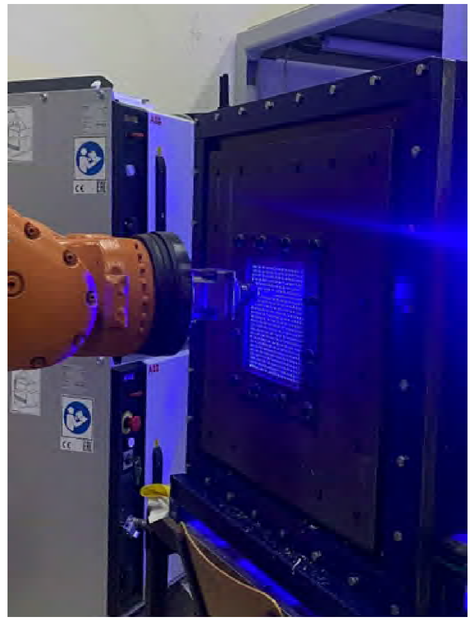

Fig. 1. The experimental layout used

The processed part is positioned vertically to allow the measurement of the strains during the incremental forming process. As we can observe in Figure 1, the blue light necessary for the Aramis optical system is present also on the side of the robotic arm due to the presence of the perforated holes. Before the forming process, the specimen is prepared by painting it with matte, rubbery white paint. After it dries, a diffuse network of black paint speckles is applied. The Aramis optical system will measure the displacement of each feature (black point) and will calculate the strains.

The desired geometry of the formed part is presented in Figure 2. In order to obtain a variable angle cone frustum, a spiral trajectory was used.

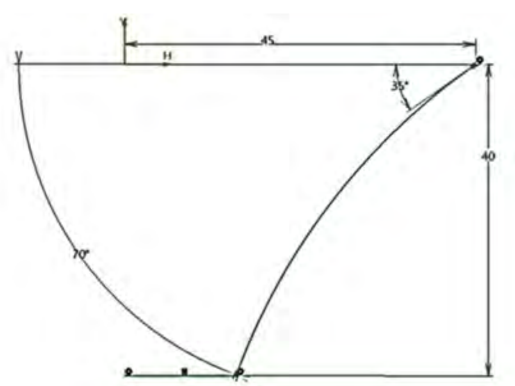

Fig. 2. The desired geometry of the part

The trajectory starts with an angle of 35° and ends with an angle with 70°. Of course, the fracture will occur before the final angle.

3. RESULTS AND DISCUSSION

In figure 3, the manufactured parts obtained are presented. We stop the robot after the first fracture occurs. In order to compare the wall angle for which fracture occurs for perforated sheets, we previously processed a part from a solid, non-perforated sheet from the same material. Of course, we used the same trajectory and the wall angle for which fracture occurs was 52.6 degrees.

The part, after the fracture occurs, is presented in Figure 4. Figures 5-7 present, for the solid, unperforated part the results for the major strain, minor strain and thickness reduction before the fracture occurs.

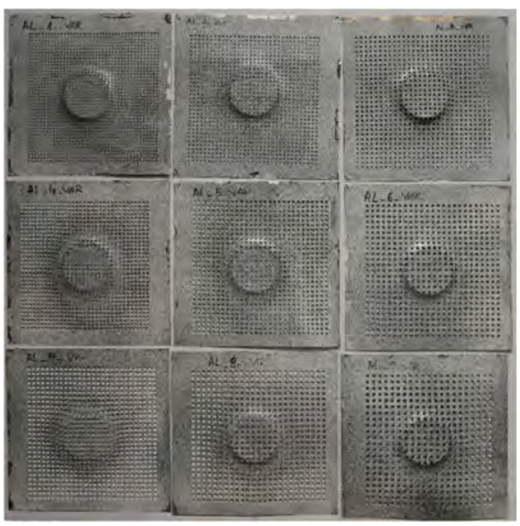

Fig. 3. The perforated sheet after the SPIF process

Fig. 4. The unperforated part after the fracture occurs

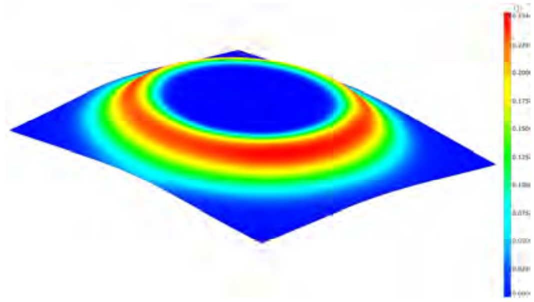

Fig. 5. The major strain before fracture occurs for the unperforated part [mm/mm]

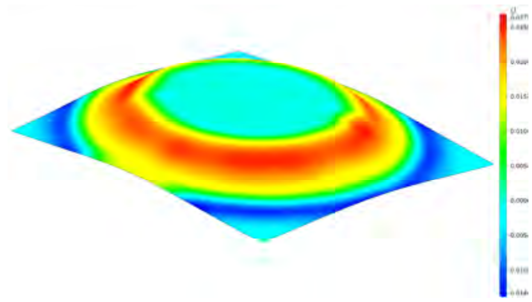

Fig. 6. The minor strain before fracture occurs for the unperforated part [mm/mm]

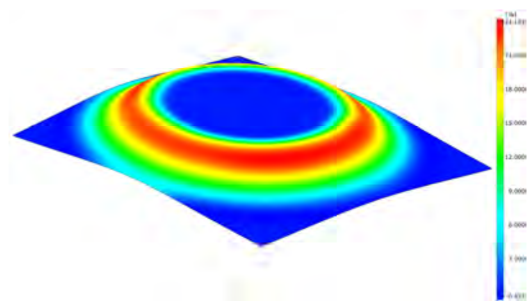

Fig. 7. The thickness reduction before fracture occurs for the unperforated part [%]

For experiment no. 3 (Al_3_var) the part after the fracture occurs is presented in Figure 8. Figures 9-11 present the same results as the unperforated part: major strain, minor strain and thickness reduction.

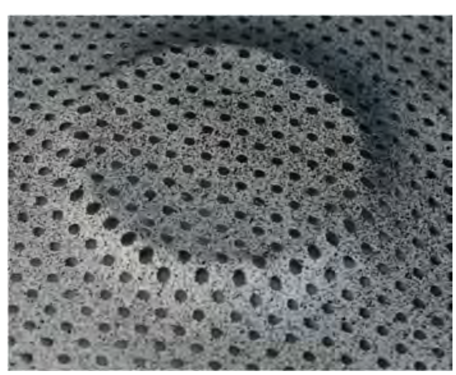

Fig. 8. The perforated part after the fracture occurs

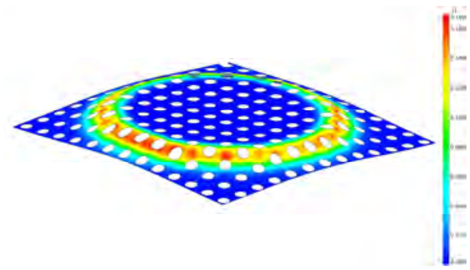

Fig. 9. The major strain before fracture occurs for the perforated part (case3) [mm/mm]

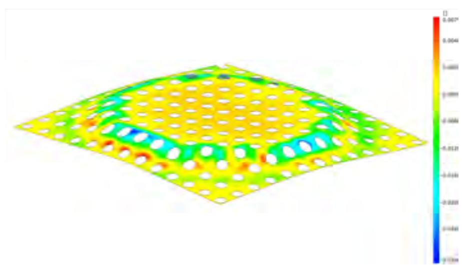

Fig. 10. The minor strain before fracture occurs for the perforated part (case3) [mm/mm]

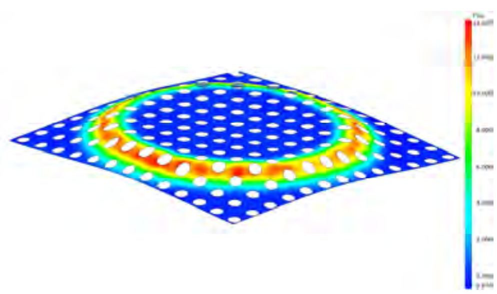

Fig. 11. The thickness reduction before fracture occurs for the perforated part (case3) [%]

If, in the case of solid parts, the distribution of main strains and thickness reduction is relatively uniform on the wall of the part, in the case of perforated parts a concentration of them is observed in the area of perforated holes, especially in the area where the fracture occurs. In any case, it can be seen from the main strains and thickness reduction analysis that both in the case of non-perforated parts and in the case of perforated parts, there is a state of biaxial stretching on the wall part area. Only in the area where the fracture occurred negative values of minor strain observed. Analysing the results presented previously, it is easily observed that, for all strains measured, and for thickness reduction, the value obtained in the case of perforated parts are lower than in the case of full, non-perforated parts. Thus, the maximum value of major strain obtained in the case of the unperforated part is 0.254 mm/mm compared to 0.169 mm/mm in the case of the perforated part. The maximum value of the minor strain is 0.027 mm/mm in the case of the unperforated part compared to 0.007 mm/mm in the case of the perforated part. However, an increase in the minor compression strain before fracture occurs is also observed here up to the value of -0.029 mm/mm. For thickness reduction, the maximum value in the case of non-perforated parts reaches 24.19%, while in the case of perforated parts the maximum value is 14.01%. However, it should be noted that the fracture occurs at a smaller angle in the case of all perforated parts.

In the sequence of figures 12-17, the variation of the forces on the three directions is presented in the case of solid, non-perforated parts, respectively in the case of perforated parts for case 3.

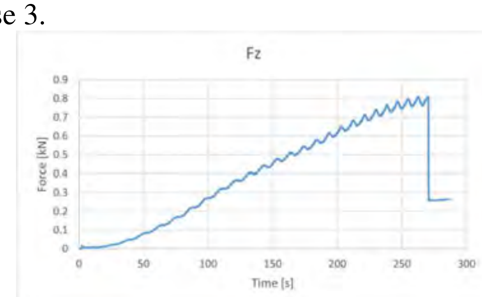

Fig. 12. The vertical force variation (Fz) for the unperforated part [kN]

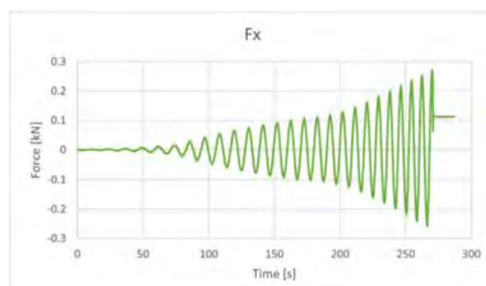

Fig. 13. The horizontal force variation (Fx) for the unperforated part [kN]

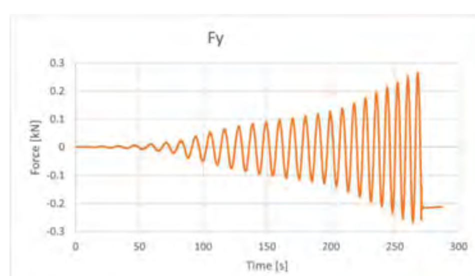

Fig. 14. The horizontal force variation (Fy) for the unperforated part [kN]

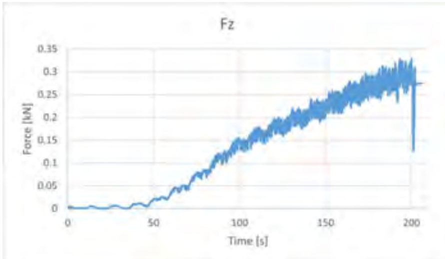

Fig. 15. The vertical force variation (Fz) for the perforated part (case3) [kN]

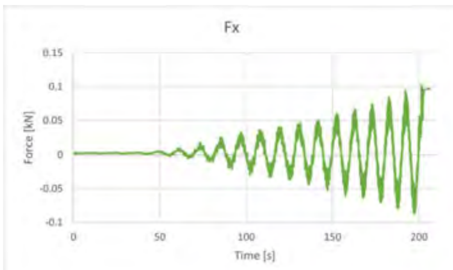

Fig. 16. The horizontal force variation (Fx) for the perforated part (case3) [kN]

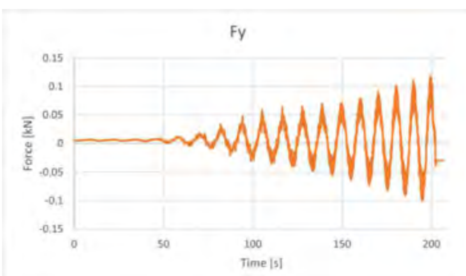

Fig. 17. The horizontal force variation (Fy) for the perforated part (case3) [kN]

Exactly as in the case of main strains and thickness reduction, the maximum values of the forces in the case of solid, non-perforated parts are higher than in the case of perforated parts. The lower value of the forces, in all three directions, is due firstly to the presence of the perforated holes and secondly to the fact that in the perforated parts the fracture occurred at a smaller angle and depth than in the non-perforated parts. On the other hand, lower forces also led to smaller major strain, minor strain and thickness reduction values in the perforated parts. In the contour graph in Figure 18 we have presented the way in which the wall angle value before the fracture occurs is influenced by the hole diameter and the distance between the edges of the perforated holes and in Table 2, the results obtained for the wall angle value before the fracture occurs for all the nine cases.

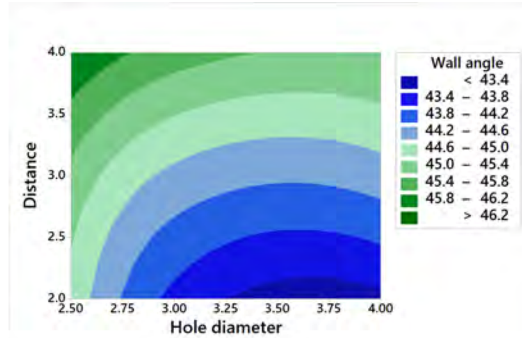

Fig. 18. The contour plot of Wall angle versus Hole diameter and Distance

Table 2

The values of the wall angle before fracture occurs

No.	Code	Wall angle before fracture [deg]
1.	Al_1_var	44.9
2.	Al_2_var	45.3
3.	Al_3_var	46.2
4.	Al_4_var	43.7
5.	Al_5_var	44.5
6.	Al_6_var	45.6
7.	Al_7_var	43.3
8.	Al_8_var	44.4
9.	Al_9_var	45.4

It can be noticed that the maximum value of a wall angle before the fracture occurs is obtained in the case presented by us (case 3), that is, in the case where the hole diameter is equal to 2.5 mm and the distance between edges is 4 mm. The minimum value of the angle before fracture occurs is obtained for case 7, where the hole diameter is equal to 4 mm and the distance between edges is 2 mm. It can also be observed that, in all nine cases, the wall angle value before the fracture occurs is lower for the perforated parts than for the non-perforated part (52.6°). This indicates that perforated holes produce a decrease in formability for all cases analysed even if the major strain, minor strain and thickness reduction values are lower.

4. CONCLUSION

Analysing the results presented previously, it can be concluded that the presence of perforations leads to a decrease in the wall angle value before the fracture occurs and, implicitly, to a decrease in formability in the case of perforated parts.

We can also note that the value of the wall angle before the fracture occurs and implicitly the formability increase with the decrease in the hole diameter of the perforated holes and with the increase in the distance between the edges of the perforated holes.

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EVALUAREA DEFORMABILITĂȚII TABLELOR PERFORATE DIN ALIAJ DE ALUMINIU-MAGNEZIU EN AW-5754 H22 ÎN TIMPUL PROCESULUI DE DEFORMARARE INCREMENTALĂ ÎNTR-UN SINGUR PUNCT

Rezumat: Procesul de deformare incrementală necesită cercetări suplimentare înainte de a putea fi implementat pe scară largă în industrie, deoarece există anumite dezavantaje nerezolvate. Înțelegerea comportamentului materialului necesită cunoașterea diagramei limitei de rupere, permițând implementarea unui model analitic care prezice momentul ruperii acestuia. Această lucrare prezintă un model teoretic al procesului de deformare incrementală într-un singur punct, validat ulterior prin teste experimentale specifice. Procesul de validare își propune să stabilească o corelație între constatările experimentale și predicțiile analitice, facilitând aplicarea eficientă a procesului de deformare incrementală în industrie.
Lucrarea de față își propune să studieze deformabilitatea tablelor perforate din aliaj de aluminiu EN AW-5754 H22 deformate prin deformare incrementală pe baza unghiului maxim admisibil al peretelui piesei. Pentru acest studiu, a fost utilizată o traiectorie de trunchi de con cu unghi variabil și s-au deformat incremental nouă specimene, corespunzând unui experiment factorial complet de tipul 3^2. Am folosit trei niveluri de variație pentru doi parametri: diametrul găurii perforate (2.5, 3 și 4 mm) și distanța dintre două găuri măsurată între marginile perforate (2, 3 și 4 mm). Rezultatele sunt axate pe determinarea deformațiilor principale, a subțierii relative, a înălțimii piesei, a unghiului maxim admisibil al peretelui și a valorii maxime a forțelor măsurate pe trei direcții.

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