IOP Conference Series: Materials Science and Engineering

Experimental Investigation on the Single Point Incremental Forming of AlMn1Mg1 Foils using Flat End Tools

To cite this article: Sherwan M. Najm and Imre Paniti 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **448** 012032

Experimental Investigation on the Single Point Incremental Forming of AlMn1Mg1 Foils using Flat End Tools

Sherwan M. Najm[1,3, b)] and Imre Paniti[2,1, a)]

[1] *Department of Manufacturing Science and Engineering, Budapest University of Technology and Economics, Hungary, H-1111 Budapest, Műegyetem rkp. 3.,*
[2] *Institute for Computer Science and Control, Hungarian Academy of Sciences*
H-1111 Budapest, Kende u. 13-17., Hungary
[3] *Northern Technical University, Iraq*

a) Corresponding author: imre.paniti@sztaki.mta.hu
b) sherwan@manuf.bme.hu

Abstract. Single Point Incremental Forming (SPIF) is one of the main and most used variants of Incremental Sheet Forming (ISF), a flexible rapid prototyping technique in the sheet metal sector. In this paper, the effect of flat end tools on SPIF with variable wall angle geometry was studied under different process parameters. Experiments on AlMn1Mg1 sheets with 0.22 mm initial thickness are carried out by a CNC Milling Machine. Geometry measurements of the formed parts carried out on a coordinate measuring machine (CMM) are also presented.

Keywords: Single Point Incremental Forming, Formability, AlMn1Mg1, flat end tools

1. Introduction

Single Point Incremental Forming (SPIF) is one of the most important types of Incremental Sheet Forming (ISF) due to the flexibility and capability to change the experimental parameters to achieve the desired shape. In fact, the main advantage of SPIF is the ability of rapid design by changing factors affecting the process, like sheet thickness, tool radius, tool speed, tool feed and type of lubricant used. This makes SPIF one of the most important methods of manufacturing prototypes before starting mass production. One of the most important factors is the tool geometry which is affecting the other related parameters especially the formability and the maximum forming angle in SPIF.

T. McAnulty et al, mentioned that seven articles indicate that increasing tool diameter led to increasing the formability and ten articles proved the opposite of that, and six articles agreed to the fact that the best tool diameter had adjusted for the highest formability since all the tools were solid hemispherical [1]. There are three different types of forming tools that are used in SPIF; spherical, ball bearing in the concave cavity with free movement on the forming sheet surface and the flat end tool [1]. These tool names are based on the end of the tool without relation to the shank of the tool.

There were many discussions on this topic, especially in earlier studies on the effect of shape and size of the forming tool. According to a study of Y.H. Kim and J.J. Park [2], a hemispherical-head tool is less efficient - in connection of formability - than a ball tool. They used an aluminium 1050 sheet with 0.3 mm in thickness in their experiments and obtained the best formability with ball tool of 10 mm in diameter. By applying a ball tool the decreased friction between the tool and formed sheet caused better formability than in the case of hemispherical tool [3]. In [4] the authors claimed that the geometrical accuracy of a product is better when a flat end tool is used instead of a hemispherical one. Furthermore, a flat end tool in some cases showed a better result in term of formability, and needed less force to form the sheet than the hemispherical end tool [4]. Failure occurs easily with the decrease of the contact area between the tool end and the formed sheet due to the high localized stress generated, which led to lack of required plasticity for the formability [5]. In SPIF, Sheet thickness, the diameter of forming tool and the interaction between them having a significant effect on the forming wall angle limit [6]. Best surface roughness was obtained with a 10 mm tool diameter which explicated to the biggest contact between the tool and the formed sheet [7]. Geometrical accuracy can be increased by decreasing the diameter of the tool and the step size [8].

Furthermore, it is claimed that formability in SPIF increases with friction and by applying smaller tool diameter [8].

In this paper, three tools with different corner radius are used to investigate experimentally the best flat tool corner radius in SPIF for achieving maximum forming depth and best accuracy of profile geometry. Profile measurements are carried out with a coordinate measuring machine (CMM), and thickness distribution of the plate along the wall of the product is examined with a Digital Micrometre. AlMn1Mg1 sheets with 0.22 mm are used to form a truncated cone with variable wall angle by a CNC milling machine. In all cases machine oil as lubricant was applied.

2. Material Properties

AlMn1Mg1 with the chemical composition in Table 1 had been used for the experiments. Tensile testing was used to measure the mechanical properties of the sheet in (0, 45, 90)^0 of the rolling direction, the mechanical properties are listed in the Table 2. Material properties are given by Széchenyi István University.

TABLE 1. Chemical Composition

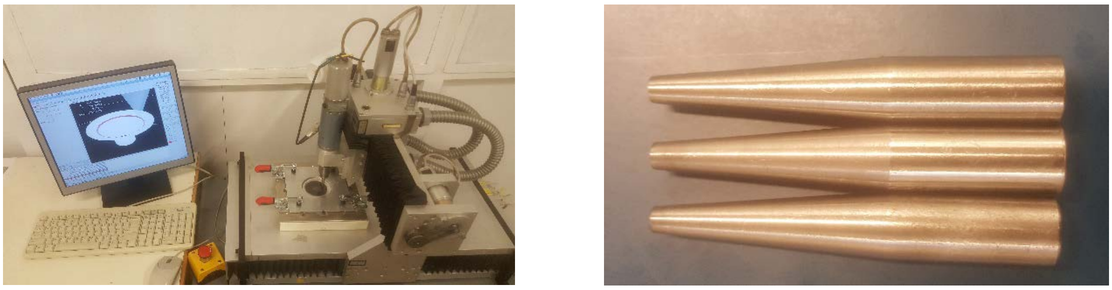
Al	Si	Fe	Cu	Mn	Mg	Zn	Cr	Ni	Others
96,90	0,201	0,448	0,212	0,807	1,260	0,071	0,022	0,006	0,073

TABLE 2. Mechanical Properties

Direction	Rp0,2, MPa	Rm, MPa	Ag, %	A50, %	n5	r10
0^0	88,3	183,0	16,44	16,88	0,297	0,554
45^0	90,0	155,5	9,27	10,45	0,266	0,580
90^0	86,3	170,3	12,48	12,95	0,268	0,594

3. Experimental

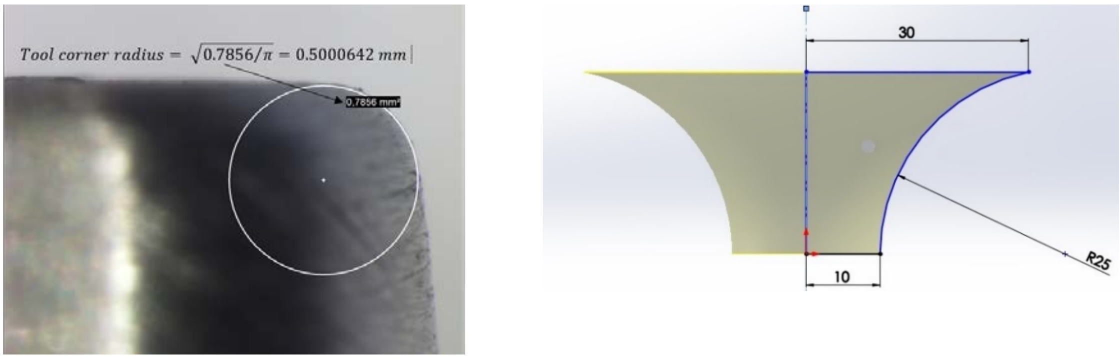
Rieckhoff CNC milling machine with LinuxCNC real-time controller was used for the experimental part as shown in Fig. 1 (a). Flat steel tools with 2 mm end radius and different corner radius (0.1 mm, 0.3 mm and 0.5 mm) for the experiments are shown in Fig. 1 (b).



(a) **(b)**

FIGURE 1. (a) Set-up of the experiments, (b) SPIF Tools with different corner radius

Fig. 2 (a) shows the magnified image of the tool with corner radius 0.5 mm and the radius calculation from the obtained magnified area of the circle, while Fig. 2 (b) illustrate the designed shape of the truncated cone with an increasing wall angle. All parameters were fixed to identify the influence of the tool corner radius on the forming depth, geometry accuracy, and pillow effect (as defined in [9]). Inwards spiral strategy with analogical tool rotation were performed, the experiments were carried out with step size: 0.01 mm, feed rate: 1500 mm/min and spindle speed: 3000 Resolutions Per Minute.



(a) **(b)**

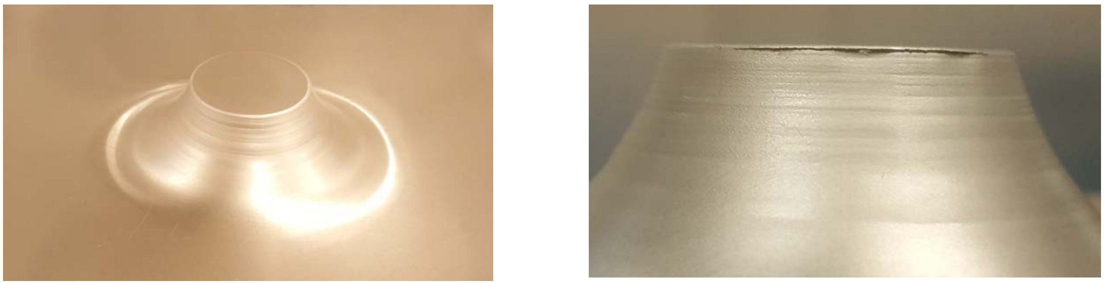
FIGURE 2. (a) magnified image of the tool with 0.5 mm corner radius, (b) Section view of the test geometry

The result of the Pillow effect of the formed parts and the cone profile in the Z-direction were measured using a Mitutoyo CMM. Fig. 3 (a) shows the CMM measurement setup. A digital micrometer was used to measure the thickness distribution for each formed part along the cone depth, as shown in Fig. 3 (b).

(a) **(b)**

FIGURE 3. (a) Measurement setup with Coordinate Measure Machine, (b) Digital Micrometre for thickness measurement

Three sets of experiments with the result showed in Fig. 4 (a) were carried out. Fig. 4 (b) shows the crack propagation appeared on the formed part.

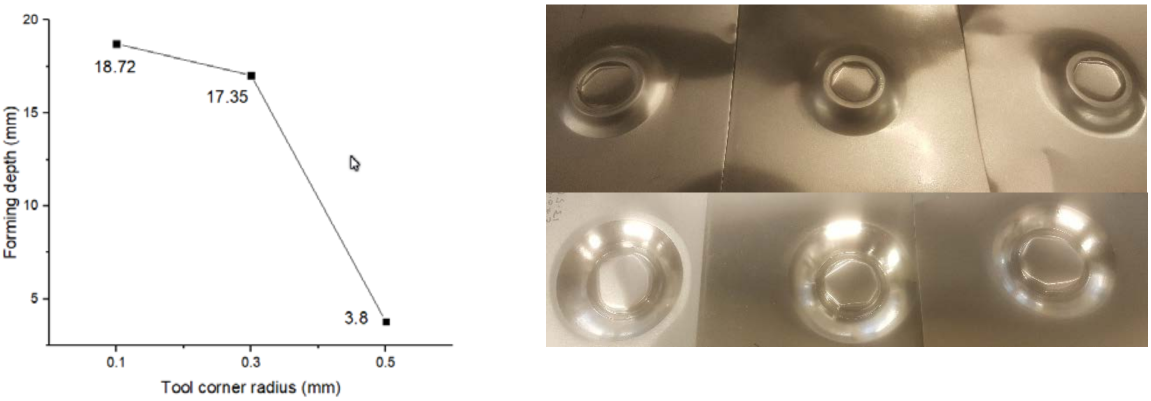


(a) **(b)**

FIGURE 4. (a) Formed product, (b) Crack appearance on the base of the cone

4. Result and Discussion

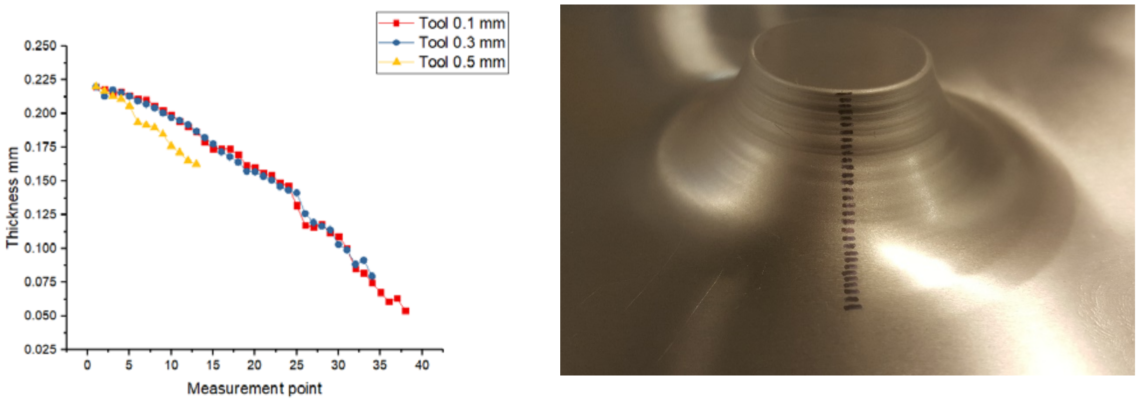
The maximum depth and formability was achieved with the 0.1 mm tool corner radius, so it can be concluded that forming depth increases with the decrease of the flat tool corner radius. The tool with 0.3 mm corner radius also showed good formability but slightly less than the smallest one. Fig. 5 (a) shows the relation between forming depth and tool corner radius. A new phenomenon occurred in the formed part using 0.5 mm corner radius since the sheet was neither formed nor downed from the inside. Forming depth decreased while pillow effect increased in this case. Due to the small step size (0.01 mm) the tool returned to the same formed zone several times. The previous mentioned deformation mechanism with the tool rotation in the same zone caused the flow and streching of the material and lead to an increase of the Pillow effect Fig. 5 (b) shows the undesired formed part with increased Pillow effect.



(a) **(b)**

FIGURE 5. (a) Forming Depth in relation to tool corner radius, (b) Undesired formed part

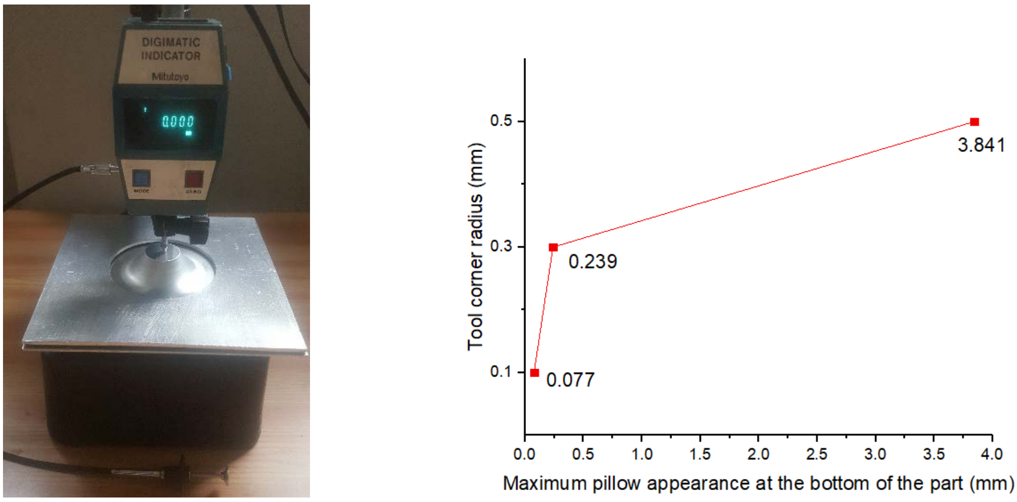
Fig. 6 (a) shows the thickness distribution which indicates that the thickness was continuously decreased from the beginning to the highest plasticity until the end of the process. The elastic-plastic behavior decreased and finally the material faced instability. Fig. 6 (b) shows the thickness measurement points on the part.



(a) **(b)**

FIGURE 6. (a) Thickness distribution, (b) Thickness measurement points on the part

The pillowed Surface at the bottom of the part was measured by a Digimatic dial indicator (gage) as shown in Fig. 7 (a). The effect of the tools realized in the deviation from the ideal geometry at the bottom (Pillow effect) is presented in Fig. 7 (b). The results are also summarized in Table 3. The results showed that the minimum deviation from the Pillow effect was obtained by the smallest corner radius of the tool, while the biggest corner radius leads to maximum deviation in connection with the Pillow effect. It follows that decrease of the tool corner radius is directly proportional to Pillow effect decrease.



(a) **(b)**

FIGURE 7. (a) Digital gage (Digimatic Indicator), (b) Result of the Pillow effect

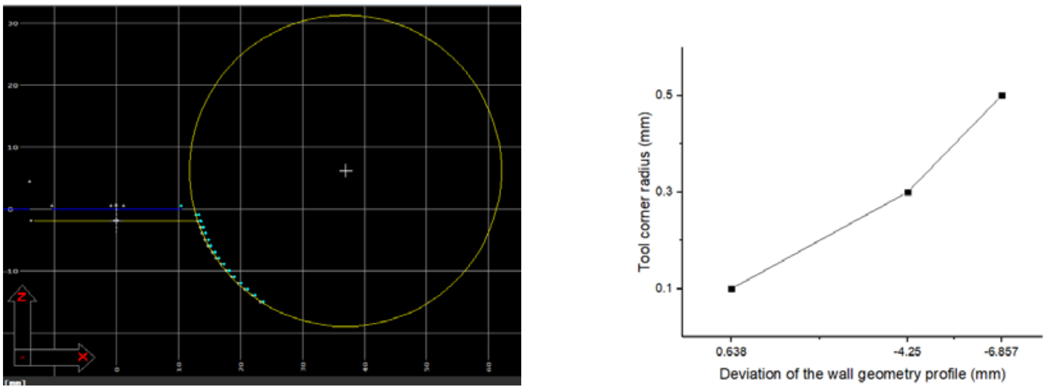
TABLE 3. Pillow effect at the bottom of the parts

Tool corner radius [mm]	Max. deviation caused by pillow effect [mm]
0.1	0.077
0.3	0.239
0.5	3.841

The geometry profile (circumferential) was measured with a CMM at the edge of the cone depth of the formed part downward to the edge of the base of the cone (see Fig. 8 (a)), deviations from the ideal profile are given in Table 4. Fig. 8 (b) also shows the effect of the tool regarding to the profile geometry. The results highlighted that the smallest corner radius of the tool gives the best geometrical accuracy, by decreasing spring-back.

TABLE 4. Profile deviation

Tool corner radius [mm]	Achieved profile radius [mm]	Deviation [mm]
0.1	50.638	0.638
0.3	45.75	-4.25
0.5	43.143	-6.857



(a) **(b)**

FIGURE 8. (a) profile geometry points from CMM, (b) Deviation of the profile geometry

5. Conclusion

As a result of the experiments the flat tool with 0.1 mm corner radius showed the best results from all measured parameters of the formed part (forming depth, thickness distribution, pillowed surface and final geometric accuracy) and this result decreases by increasing the corner radius of the flat end tool. Finally, a new ratio can be defined in micro SPIF (where initial sheet thickness is below 0.5 mm) regarding corner radius of a flat tool and initial thickness.

6. Future work

More experiments are needed with different flat tool parameters to investigate other parameters of the formed part.

Acknowledgement

This research has been supported by the GINOP-2.3.2-15-2016-00002 grant on an “Industry 4.0 research and innovation center of excellence”; and by EPIC grant No. 739592. The authors would like to thank the staff of the Laboratories of Department of Manufacturing Science and Engineering, Budapest University of Technology and Economics, Hungary. The authors also thank Dr. Miklós Czampa Assistant Professor, Head of Laboratory for his help.

References:

[1] T. McAnulty, J. Jeswiet, and M. Doolan, “Formability in single point incremental forming: A comparative analysis of the state of the art”, *CIRP J. Manuf. Sci. Technol.*, vol. 16, pp. 43–54, 2016.

[2] Y. . H. Kim and J. . J. Park, “Effect of process parameters on formability in incremental forming of sheet metal”, *J. Mater. Process. Technol.*, vol. 130–131, no. 3, pp. 42–46, 2002.

[3] Y. Kumar and S. Kumar, “Advances in Material Forming and Joining”, pp. 29–47, 2015.

[4] X. Ziran, L. Gao, G. Hussain, and Z. Cui, “The performance of flat end and hemispherical end tools in single-point incremental forming”, *Int. J. Adv. Manuf. Technol.*, vol. 46, no. 9–12, pp. 1113–1118, 2010.

[5] B. Cawley, D. Adams, and J. Jeswiet, “Examining tool shapes in single point incremental forming”, *Proc. NAMRI/SME*, vol. 41, no. August 2012, pp. 114–120, 2013.

[6] S. Gatea, H. Ou, and G. McCartney, “Review on the influence of process parameters in incremental sheet forming”, *Int. J. Adv. Manuf. Technol.*, vol. 87, no. 1–4, pp. 479–499, 2016.

[7] S. A. Nama, N. S. M. Namer, and S. M. Najm, “The Effect of using Grease on the Surface Roughness of Aluminum 1100 Sheet during the Single Point Incremental Forming Process”, vol. 1, no. 1, pp. 1–4, 2014.

[8] F. Maqbool and M. Bambach, “Dominant deformation mechanisms in single point incremental forming (SPIF) and their effect on geometrical accuracy”, *Int. J. Mech. Sci.*, vol. 136, no. December 2017, pp. 279–292, 2018.

[9] Hussain, G., L. Gao, and N. Hayat. "Forming parameters and forming defects in incremental forming of an aluminum sheet: correlation, empirical modeling, and optimization: part A." Materials and Manufacturing Processes 26.12, pp. 1546-1553, 2011.