DETERMINATION OF THE MAXIMUM FORMING ANGLE OF SOME CARBON STEEL METAL SHEETS

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Abstract: The maximum forming angle is the most used criterion to express the material formability limit in the case of single point incremental forming (SPIF) process. By knowing this angle, it is possible to asses if a particular part could be obtained by SPIFing a certain material with a certain thickness. In this paper two geometries of part and three thicknesses of metal sheet were tested, in order to determine the maximum forming angle. The chosen material was the DC01 carbon steel, due to its good malleability and ductility properties and large industrial applicability.

Keywords: maximum forming angle, SPIF process.

1. INTRODUCTION

Nowadays, fast-moving competitive markets force the production community to design and manufacture more customised products, with well defined properties, in a shorter time, by lower costs. Within this context, rapid prototyping is highly desirable because the manufacturing of functional prototypes speeds up the time to market. But even rapid prototyping and particularly the rapid prototyping for sheet metal components, implies high costs because the available methods, as Selective Laser Sintering (SLS), Selective Laser Melting (SLM), Three Dimensional Printing (3DP), Rapid Solidification Process (RSP) and many others require expensive tooling and machinery.

Nevertheless, some rapid prototyping techniques, without dedicated tools, for sheet metal have been developed. One of them is the single point incremental forming (SPIF). Unlike many other sheet metal forming processes, SPIF does not require any expensive dedicated dies or punches to form complex shapes. Instead, it uses a small tool to form a sheet metal blank, clamped around its edges in a very simple rig, mounted on the worktable of a three-axis CNC milling machines (Figure 1). The sheet is progressively formed into a final part by moving the tool along successive contours which follow the part geometry. Besides the advantage of simplicity and low costing, the SPIF process allows higher limits of formability, compared to classical forming limits observed in conventional forming processes [1-3]. The forming limit in SPIF is widely expressed by researchers as the maximum forming angle, Φ_{max}, which is the maximum values of the angle of the wall part obtained without occurrence of cracks in sheet metal blank [4,5]. By knowing this angle, it is possible to asses if a particular part could be obtained by SPIFing a certain material with a certain thickness. Thus, thickness of the sheet has a great influence on spifability because it directly affects the maximum forming angle [6-8]. Assuming that only in-plane strains occur, the volume constancy leads to a relationship between the wall thickness of part after forming (t_1) with the wall angle (Φ) and the initial wall thickness (t_0) known as the sine law: $t = t_0 \sin(90-\Phi)$ (see Figure 2). Large angles in forming create thinner cross sections and a thinner material is more likely to initiate a crack,

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since it must sustain a higher stress [7]. Thus it is expected that thicker sheets should have higher forming angles than thinner ones [9].

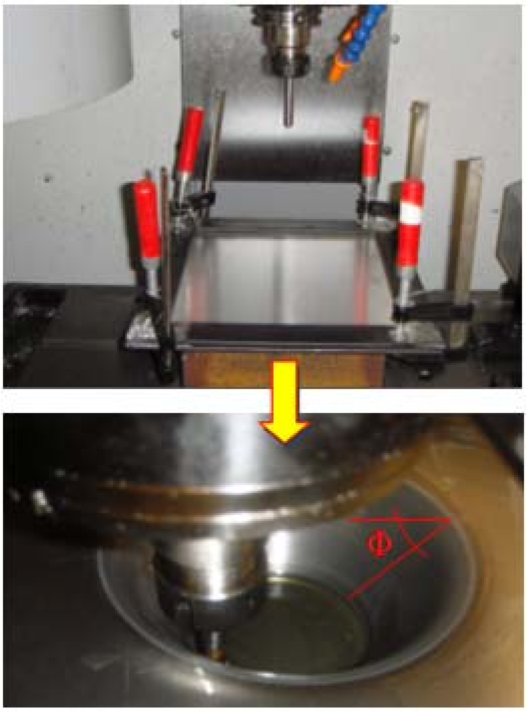

Fig. 1. The forming rig and the formed part [1].

The aim of this paper is to determine the maximum forming angle for the DC01 carbon steel (EN 10130/06), a material with large industrial applicability and good properties of malleability and ductility which make it adequate to be processed by SPIF. Since the maximum forming angle depends on the sheet thickness, according to the sine law, three thicknesses of sheet metal blank were tested (0.8 mm, 1 mm and 1.2 mm).

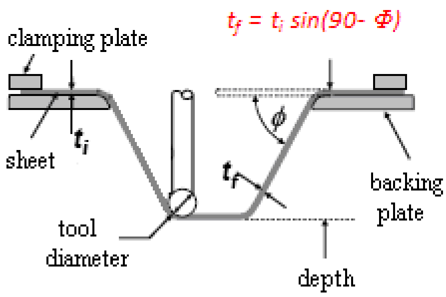

Fig. 2. The forming angle as a spifability criterion.

2. METHODOLOGY OF RESEARCH

2.1 Experimental setup and process parameters

The experimental equipment used to perform the tests consisted in a SUPERMini MILL CNC machine and the rig presented in Figure 1, mounted on the machine worktable for clamping the sheet metal blank. The tool had a hemispherical head of 10 mm diameter. It was used a single tool in order to increase the process flexibility.

The used process parameters were: feed rate – 1000 mm/min, spindle speed – 1500 rot/min, vertical step of tool – 0.2 mm, lubricant – industrial oil, tool trajectory – spiral.

Two geometries of the part were considered: if no fracture occurred in the case of the first geometry (Figure 3), then the second geometry (Figure 4) had to be tested in order to determine the maximum forming angle.

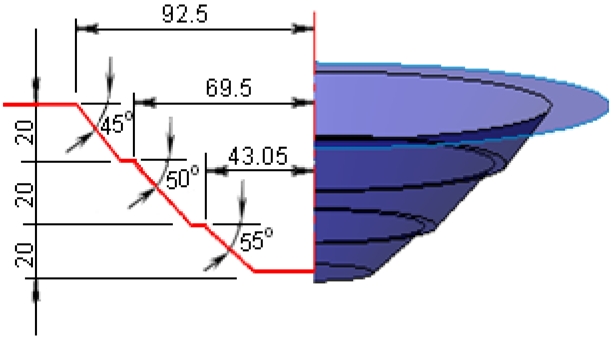

Fig. 3. The first geometry of part.

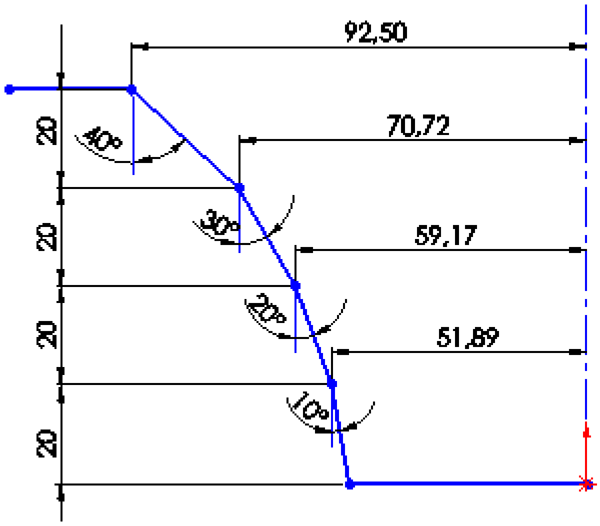

Fig. 4 The second geometry of part.

2.2 Experimental results

In the case of processing sheet metal blanks according to the first geometry of part, no fracture occurred for none of the three thicknesses of sheet and thus, each of them allowed obtaining the desired part (Figure 5). This was good for the process feasibility but not for the intended purpose – determination of the maximum forming angle. Consequently, the second geometry was tested, by using the same process parameters as in the case of the first geometry. This time, failure occurred prior to obtain the entire configuration of part (Figure 6).

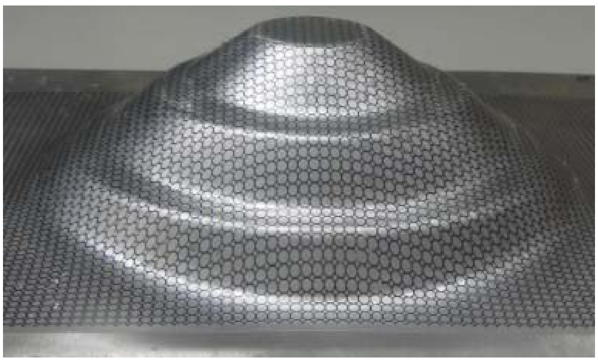

Fig. 5. Part formed according to the first geometry, t_0 = 1mm.

Fig. 6 Part formed according to the second geometry, t_0 = 1mm.

As result, the maximum forming angle could be determined for each of the three thicknesses of the sheet metal blank (Table 1).

Table 1. The maximum forming angle for DC01 carbon steel.

Sheet metal blank thickness, t_0 [mm]	Maximum forming angle, Φ_{max} [deg.]	Depth of the part [mm]
0.8	80	69,92
1	80	70,15
1.2	80	65,4

4. CONCLUSIONS

The aim of this paper was to determine the formability limit, expressed as the maximum forming angle, of the SPIFed DC01 carbon steel.

Two geometries of the part and three thicknesses of the sheet metal blank were tested. Determination of the maximum forming angle was possible by processing the sheet metal blanks according to the second geometry of part since in the case of the first geometry no failure occurred.

By using the SPIF process, it was possible to obtain parts with the slope of the wall up to 80^o and depths up to 70 mm from sheet metal blanks no thicker than 1.2 mm, by using just a very simple tool. The two geometries of part used in this study cannot be obtained with conventional forming processes, without dedicated expensive tools.

According to the sine law, thicker sheets allow obtaining steeper walls of the part, because in SPIF the part is formed by thinning the sheet and not by material flowing from a flange. From Table 1 it can be observed that the maximum forming angle is 80^o for the three thicknesses of metal sheet but the difference is given by the depth of the part where failure occurred. The sheet metal blank of 1 mm thickness resisted longer that the 0.8 mm sheet metal blank. But this rule is not kept anymore in the case of 1.2 mm thick sheet metal blank, which failed earlier compared to the other two metal sheets. This shows that the material behaviour in SPIF obeys to more complex mechanisms during processing than the sine low prescribes, which implies future investigations. Another cause could be the process parameters: in this study, the same process parameters were used for the three different thicknesses but maybe they should be different, especially the values of the vertical step of the tool. Further researches will elucidate this aspect.

Acknowledgments
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