INVESTIGATION OF SINGLE POINT INCREMENTAL FORMING PROCESS APPLIED ON THIN SHEET METAL

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Abstract. Single incremental metal forming SPIF and deep drawing process are similar technologies and SPIF can be used to build a prototype for additional analysis and later construction. In this paper the selection of parameters needed for SPIF process production with software Solidcam are shown. A consideration to strain hardening has been given. Experiment on a thin sheet metal TH435 CA ST E2.8/2.8 of 0.19 mm thickness has been conducted in order to understand basics of the technology.

Introduction

The Single Point Incremental Forming (SPIF) process is a flexible sheet metal forming method adapted to form various complex shapes using a milling machine, a multi-axis robot or a dedicated machine without the need of specific and costly tools, such as a punch and die, as described by [1]. To increase the quality of the final geometry, it is still possible to use a die that can be manufactured in a cheap material because the applied forces are low. Depending on the length of the tool path and speed of the tool, the forming process can take up to a few hours for large parts. It is, in consequence, adapted to small batch production and rapid prototyping. Furthermore, the SPIF process, is known to shift Forming Limit Diagrams (FLD) to higher formability [2] compared to conventional forming processes. Because SPIF has a high industrial interest, the applicability of this technique on the new material studied must be experimen-tally verified. The problem of shape inaccuracy which is usually an important limiting factor for SPIF applications, must be solved [3]. The SPIF process can be optimized by experimental trials and errors and/or by a numerical analysis. The numerical approach predicts the forming forces and the final shape according to the tool path. However such information is accurate only if the simulation has been validated by experiments. During the working process the position of the tool is defined by the process kinematics and the force of deformation depends on the tool path. The forming force is controlled by the operator during the whole process. As it can be seen from Fig. 1 a sheet of metal is tightly clamped in a working device and then the spherical tool executes the working process. The tool moves along a predetermined contour in the horizontal plane, after which the tool incrementally descends and starts a new contour in the next horizontal plane, building up the workpiece layer by layer.

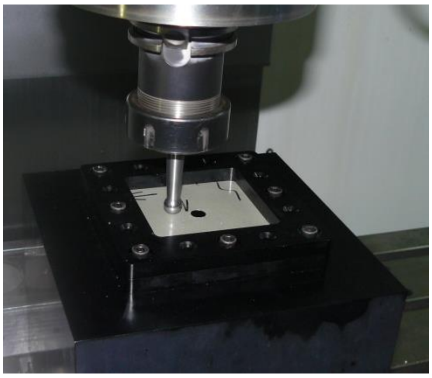

Fig. 1 The experiment in this investigation was conducted on a Hurco VMX 30m milling machine

Thinning of the workpiece is the dominant failure mode in SPIF and is related to the workpiece drawing angle. For a given material and initial thickness, the maximum drawing angle represents the limits of the conventional incremental forming process. In this investigation thin sheet metal TH435 thickness 19 mm was used, the material is used in packaging industry for cans that are made for meat products. The used specimens were coated from both sides with Alupigmented Lacquer homogeneous opaque film of silver-grey color.

Solidcam

Solidcam software 2009 was used to simulate milling parameters needed for deformation process of incremental sheet metal forming. The model was done in Solidworks software and in Solidcam the target, stock, tools and a strategy for tool path was selected.

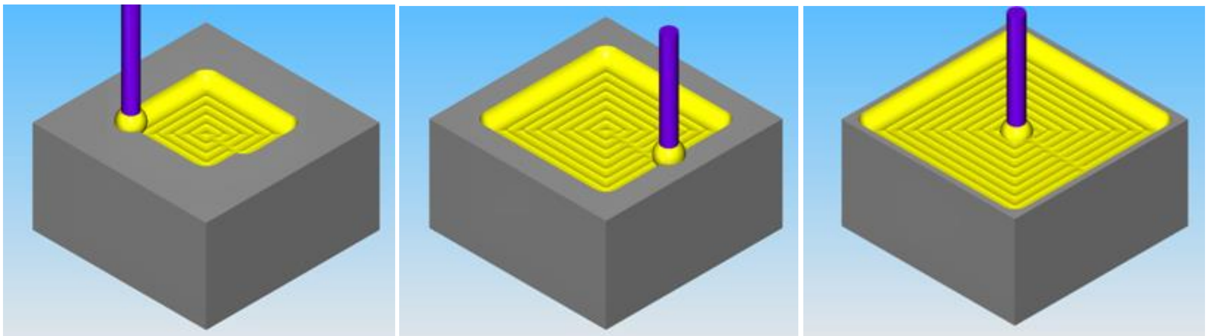

Fig. 2 The programing of layer by layer cutting-deformation

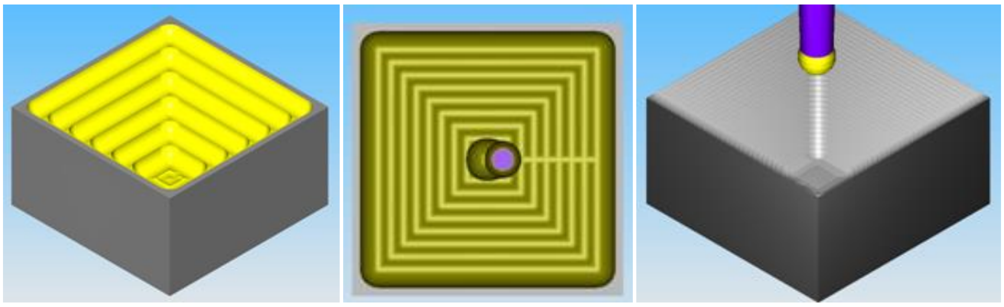

Fig. 3 Final look of solidcam modeling

The programming was done by creating milling condition that would remove layer by layer (Fig. 2 and 3) but instead of cutting deformation is introduced. This manner of programming allows for corrections of the deformation process, however material hardening takes place. Low carbon steel generally exhibits a very linear stress–strain relationship up to a well defined yield point (Fig. 4), [4]. The linear portion of the curve is the elastic region and the slope is the modulus of elasticity or Young's Modulus. After the yield point, the curve typically decreases slightly because of dislocations escaping from Cottrell atmospheres. As deformation continues, the stress increases on account of strain hardening until it reaches the ultimate strength. Therefore it can be said that the work done is conducted on a strain hardening and close to necking area (4 and 5 on the Fig. 34 which makes material brittle and prone to crack occurrence. It is because plastic deformation is accomplished by substantial movement of atomic planes, dislocations which may encounter various obstacles. This movement becomes more complex as number slip systems may get activated during the deformation.

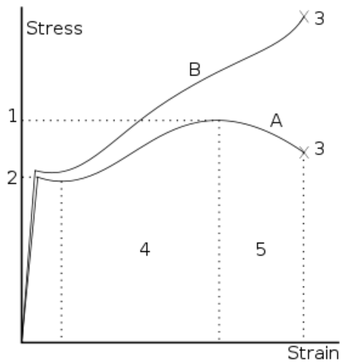

Fig. 4 Strain hardening and the stress strain curve

The most common equations used to describe the hardening behavior of the material flow is (1):

$$\sigma = C\varepsilon^n, \tag{1}$$

where σ – is strength coefficient and n – is strain hardening exponent. The strain-hardening exponent may have values from n=0 (perfectly plastic solid) to n=1 (elastic solid). For most metals n has values between 0.10 and 0.50. The Power law equation described above is also known as Holloman-Ludwig equation.

Tools

Experimental work has been executed on a CNC milling machine Hurco 30 using specially adapted tooling connected accordingly to tool holder CAT 20. Rod shaped tool (Fig. 5) was used in order to create necessary deformations. This tool has a smooth hemispherical head of diameter Ø12 mm and it is clamped into a spindle of the milling machine. Tool used in process was Ø12 mm carbide tool of total tool length 120 mm, the tool was selected as lollipop milling tool as it is the most similar to the actual tool used in process. Adequate length of outside holder is necessary for reduction of possible vibrations the primary impact of workholding on surface finish is vibration. In the worst case vibration will turn into chatter, which is a harmonic effect that will be very visible on the surface finish. Cutting conditions were selected feed xy =1000 mm/min, spin rate = 3000 rpm feed Z = 33 mm/min, Δz was selected as 1 mm (Fig. 5 and 6). The feed z was used in combination with helical path in order to avoid direct pressure on single point while lowering for the assigned Δz.

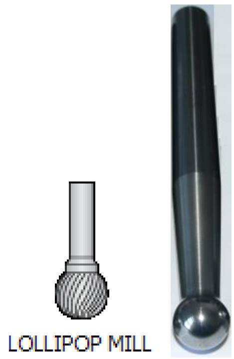

Fig. 5 Tool used in the proces is similar to lollipop mill and was made of carbide steel

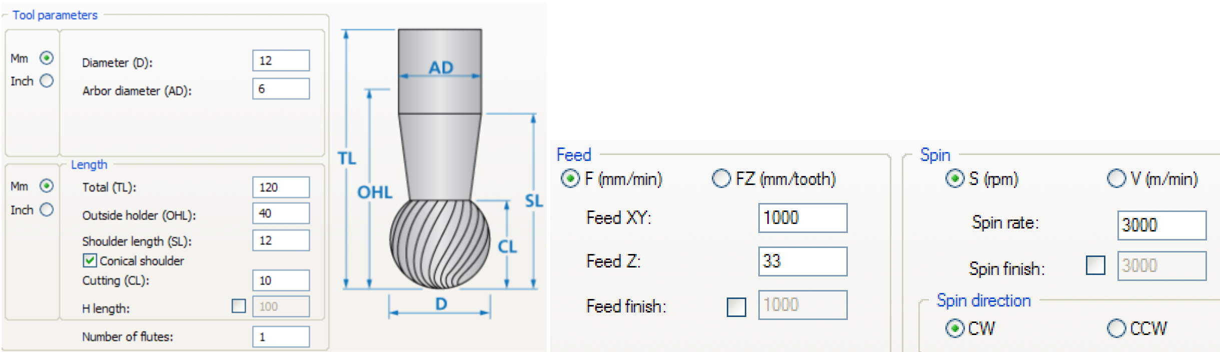

Fig. 6 Cutting conditions

Overlap

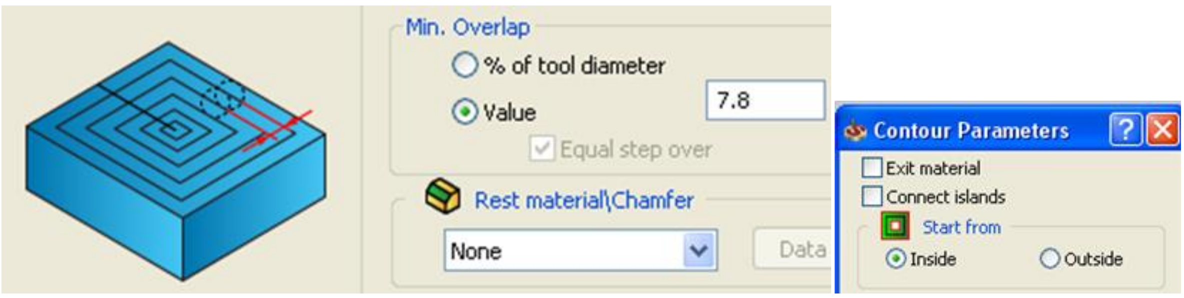

Fig. 7 Scalop or minimum overlap was selected as 0.6 of the tool diametar, center was selected as the starting point

Overlap Fig. 7 determines the distance from the number of passes and distance between each pas in xy direction. Recommendations in literature for minimum milling overlap are 60 % of tool diametar and this distance was used in the investigation. As the tool is in contact with surface with one point and comes to a higher surface contact when it is working edges different strategies can be applied. The thinning can be regulated by careful tool-path generation and modification of overlap by equalizing the stress-strain conditions between each pass.

Experiment

Experiment was conducted with a specimen of 100 x 100 mm and the product dimensions of Ø60 x10 mm. Material that was used was TH 435 CA ST E2.8/E2.8 with 0.19 mm thickness, [8]. The workholder was made of aluminium and carved form one block to increase stiffness of clamping process and remove possible workholder vibrations. For experiment purposes a round path was selected, a depth the contour parameters for the experiment were selected from program and taken from the center toward the outside. A hole was drilled at the center of specimen after it was clamped in order to increase stability of the deformation process [6, 7]. The wall angle was 90 ° and it broke at the 10 mm depth.

Fig. 8 The tested cone

In the Fig. 7 the tested cone is shown. The crack occurred in two places at the opposite direction this indicates dependency on anisotropy properties as the crack first occurred direction of rolling at the 0° of material Fig. 9. Variations of rotational spin speed from 1000 rpm and 3000 rpm were used and they showed no noticeable difference and also the Δz = 2 mm and ΔZ =1 mm, however the material hardened and broke at the steep angle.

Fig. 9 Crack occured in the rolling direction 0°

Conclusion

Incremental sheet forming process is a very promising manufacturing process which still requires further optimizations namely in the speed of the process and optimal tool path strategies. Numerous studies have demonstrated the effect of process parameters like advancing speed, forming force, tool depth step in the characteristics of the formed parts. Future research will include Finite element simulation based on different friction factors and possibilities to add to the formability process, with an elastic springback analysis, but also the evolution of strain and thickness distribution. Slip planes will also be investigated as slip depends on many factors including external load and the corresponding value of shear stress produced by it. For obtaining greater formability the geometry of crystal structure and the orientation of active slip planes with the direction of shearing stresses generated needs to be addressed. Also the speed is very important and it can be achieved by designing faster and multiple clamping systems, and optimizing tool speeds, rotation, feed, feed in the z direction and amount of the lowering Δz.

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