Presenting a New Method for High Speed Incremental Forming

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Abstract: Recently, incremental sheet metal forming (ISMF) process as one of the new methods in rapid prototyping collection has been considered by researchers. This process is based on a defined path in CNC controller and applies a spherical-head tool that supplies the required pressure for sheet metal forming. Despite affirmation of process ability in forming symmetric geometries, some of its aspects such as: high cost in die design and its manufacturing, high cost in using NC machine tools and time consuming forming processare its constraints. Hereupon, a new method for incremental sheet metal forming on turning machine has been presented. This process uses a spherical-head tool in tool-holder turret, forming sheet metal in symmetric geometries in shortest possible time without requiring a die. With a view to increasing sheet formability, two types of forming strategies were designed and implemented. Finally, the best forming strategy based on final forming depth and effective strain calculations is introduced.

Keywords: Incremental Sheet Metal Forming, Rapid Prototyping, Sheet Formability

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1 INTRODUCTION

Incremental forming process is a technology for sheet metal forming that has been the focus of research in recent years [1-4]. This method is an economic process for low production volume and especially suitable for single production. Ability of this process in different applications such as: manufacturing of automotive pieces [5], medic productions [6] and aviation industrial pieces has been confirmed. On the other hand, the natural process slowness, due to its characteristic of point-to-point forming process, is one of the main drawbacks which limit the industrial application, if large batches have to be manufactured [7]. Nevertheless, the production of small lots or unique parts requires particular attention. Also a finite element approach, due to elongated computation time is not suitable [8]. Forming speed, in this process in comparison with other forming processes, is slow. Because imposing deformation by tool is local and hence increases sheet formability [9-12]. So, to increase forming speed, high speed incremental forming process (HSIF) is proposed for investigation. In the present research, incremental sheet metal forming process on turning machine has been investigated. This new process has considerable efficiency with respect to time and cost. The presented method, hereby described, uses a spherical-head tool without die, which forms the clamped sheet on the fixture in symmetric geometry.

2 COMPARISON BETWEEN SPINNING PROCESS AND THE NEW METHOD

Table 1 Comparison between spinning process and the new method

Title	Spinning	New method
Tool geometry	Disk tool	Spherical or hemispherical tool
Die geometry	Manufactured according to final desired shape	No need for a die
Condition of sheet clamping	Situated outside the sheet floor	Situated in the perimeter of the sheet
Distribution of sheet thickness after it has undergone the process	Sheet thickness is approximately constant throughout the sheet. Sheet thickness varies throughout the sheet wall.	Sheet thickness is approximately constant throughout the sheet floor and the sheet wall.
Process speed	Very high	Incremental, high
Product's final shape	According to the applied die	Symmetric shapes: Cylindrical, conic

Spinning is a cold-forming operation where a rotating disk of sheet metal is progressively shaped over a mandrel to produce rotationally symmetrical shapes. Localized pressure is applied through small roller, which traverses the entire surface of the part to produce the progressive deformation. Although the spinning process is a traditional manufacturing technique, it is still a popular and common topic to study. There are many basic differences between the spinning process and the new defined method. Some of these differences have been shown in table 1.

3 PRINCIPLES OF PROCESS EXECUTION

In this new method, the sheet metal will be formed incrementally using a turning machine, a fixture, a tool and an adequate lubricant. This process uses pre-manufactured pattern or dies placed under the sheet. The task of fixture is avouching and conducting the sheet metal throughout the forming area while sheet boundary is clamped completely on the fixture. The tool on the turret of the turning machine and the sheet is clamped on a fixture attached on chuck tightly. The fixture together with the sheet has rotational motion and the forming tool has both vertical and radial motions. At the beginning of the process, the forming tool moves towards the inner side of the sheet vertically, its progress, equal to the vertical step size and then travels linearly along the radius. The produced sample has symmetric geometry with closed end. With a view of accrediting successful execution, the forming process was tested on an annealed aluminum sheet. The fixture consisting of the main base and ring piece (Fig. 1) and the forming tool consisting of the main shank and ball (Fig. 2) were manufactured according to the designed sketch. The ring piece applies equal pressure on the sheet for safe clamping and to prevent sheet motion. On the other hand, the ball at the end of the tool has free rotational movement. A sheet with 1(mm) thickness was cut to determined dimensions (150 mm×150 mm) and drilled on the allocated positions (Fig. 3) to be clamped on top of the fixture. Next, the fixture together with the clamped sheetwas tied on the chuck of the turning machine (Fig. 4). After concentric adjustment between ball and sheet centre, the forming tool was avouched on the tool-holder turret. To check the sheet behavior and its deformation in this process, variable parameters were used. These parameters were: vertical feeding step size of the tool at the inner side of the sheet (v_f), rotational speed of the chuck (s), automatic radial feeding of the tool (f) and diameter of the forming zone (d_f). When the first tearing appeared at the end of the sheet, the process was stopped (Fig. 5).

Fig. 1 Fixture including main base and ring piece

Fig. 2 Forming tool

Fig. 3 Clamping annealed Al sheet on the fixture

Fig. 4 Attaching the fixture to the chuck

Fig. 5 Sheet forming process

At the end of the process, the sheet was formed into conical geometry (Fig. 6). The initial formed sample was produced successfully and the ability of this new method for forming symmetric geometries was approved. The presented method will open a new path for researchers and industrialists. In the next section, two strategies for forming process will be studied.

Fig. 6 Conically formed sheet

4 EFFECT OF FORMING STRATEGY ON SHEET FORMABILITY

Forming strategy is one of the effective parameters in incremental forming process. In this process, strain-hardening effects will appear. When imposed deformation on the sheet is increased, this effect will also increase. This means once the process begins, sheet behavior differs at different levels of the forming process. Deformation will be created in the weakest zone of the sheet undesirably. This effect can be controlled by varying forming strategies and decreasing deformation at different levels of the forming process.

To study the forming strategy in the defined process and its circumstantial effects on the final sheet deformation, two experimental tests based on two different strategies were designed:

1. In the first test, after applying vertical feeding step size at sheet centre by forming tool (ν_{f1}), the forming tool will move toward the sheet boundary. Automatic radial feeding of the tool in this motion is f, then the forming tool without imposing secondary load on the sheet boundary, will travel towards the sheet centre. The above cycle will continue until the initial tearing appears on the sheet (Fig. 7).

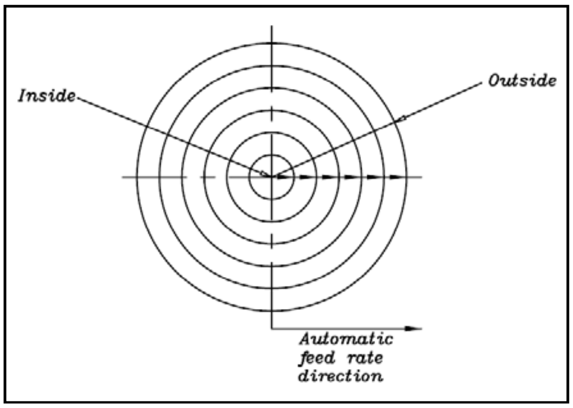

Fig. 7 Schematic of the first strategy forming

2. In the second, after applying vertical feeding step size at sheet boundaries by the forming tool (ν_{f1}), the forming tool will move towards the sheet centre. Automatic radial feeding of the tool in this motion is f, then the forming tool without imposing secondary load on the sheetcentre, will travel towards the sheet boundary. The above cycle will continue until the initial tearing appears on the sheet (Fig. 8).
Adjusted parameters for implementation of tests are:

. Vertical feeding step size of the tool: $\nu_f = 0.5\,\text{mm}$
. Rotational speed of chuck: $s = 26\,\text{rpm}$
. Automatic radial feeding of the tool
$f = 1.984\,\text{mm/rev}$
. Diameter of forming zone: $d_f = 60\,\text{mm}$

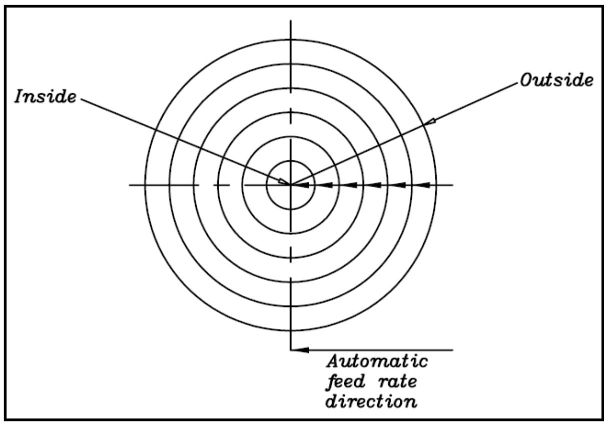

Fig. 8 Schematic of the second strategy forming

Two annealed Al sheets of $1\,\text{mm}$ thickness were cut to $150\,\text{mm} \times 150\,\text{mm}$ dimensions. The study criterion of sheet formability in this process is final forming depth and effective strain ($\bar{\varepsilon}$). In order to determine effective strain (based on von-mises yielding criterion), a circle by diameter: $d_0 = 25\,\text{mm}$ was drawn on the back and centre of the sheet by beam compass (Fig. 9). The tests were performed in accordance with the designed process. Sheet surface should be lubricated. Lubrication will decrease the friction between the tool and the sheet surfaceand will absorb deformation heat.

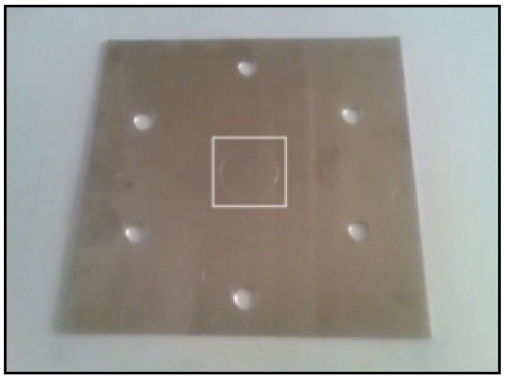

Fig. 9 Drawing of circle on the back and centre of the sheet

The amount of lubricant depends on thematerial type and thickness of the sheet. In this process HLP46 was usedas lubricant. Appearance of initial crack or tearing in the formed sheets is a sign for the end of the process. Figs. 10, 11 show the formed sheets obtained from the first and the second forming strategies respectively. Depicted zones show the appeared crack on the sheet boundary.

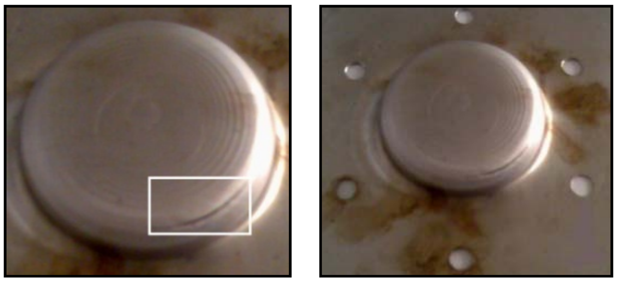

Fig. 10 Failure zone in the formed sheet by first strategy

Fig. 11 Failure zone in the formed sheet by second strategy

Applying the tool's vertical feeding step size of $v_f = 0.5\,\text{mm}$, on the sheet's inner side the samples were torn at the below mentioned depths:

1. The sample based on the first strategy, in depth:

$h_{total} = 18\text{mm}$ (step no. = 36)

2. The sample based on the second strategy, in depth:

$h_{total} = 14.5\text{mm}$ (step no. = 29)

Therefore, for sheets having similar conditions such as composition, thickness, lubricant, parameter adjustments, and process sequence, the maximum forming depth was reached at by implementing the first strategy. On the other hand, after checking samples, the circles by diameter d_0 on the sheets were deformed to circles by different diameters d_1, d_2 (elliptical). Hence, by measuring diameters d_1, d_2 with a calliper, three principal strains $\varepsilon_1, \varepsilon_2, \varepsilon_3$ were calculated from below mentioned relations:

$$\varepsilon_1 = \ln\left(\frac{d_1}{d_0}\right) \quad (1)$$

$$\varepsilon_2 = \ln\left(\frac{d_2}{d_0}\right) \quad (2)$$

$$\varepsilon_3 = -(\varepsilon_1 + \varepsilon_2) \quad (3)$$

After calculating principal strains, the effective strain based on Von-Mises criterion will be calculated as:

$$\bar{\varepsilon} = \left[\frac{2}{3}(\varepsilon_1^2 + \varepsilon_2^2 + \varepsilon_3^2)\right]^{\frac{1}{2}} \quad (4)$$

Table 2 shows measured diameters d_1, d_2 and the resultant principal and effective strains.

Table 2 Resultant strains

Test no.	1	2
d_1(mm)	28.3	26.12
d_2(mm)	28.16	26.05
ε_1	0.124	0.0438
ε_2	0.119	0.0411
ε_3	-0.243	-0.0849
$\bar{\varepsilon}$	0.243	0.0849

Based on the above results, the ratio of effective strain in the first test to the second test is calculated. $\bar{\varepsilon}_1/\bar{\varepsilon}_2 = 0.243/0.0849 = 2.86$, predominance of the first strategy in this process has been confirmed again.

5 DISCUSSIONS

This phenomenon is justifiable as follows: Since the metal sheet's boundary has been fixed, using a ring piece and only the center of the sheet is free, stiffness and rigidity on the sheet boundaries is high where as the sheet center is neither very stiff nor very rigid. so to achieve enhanced formability and forming depth, every incremental step in the forming process should be applied considering the sequence priority of low stiffness to higher stiffness sectors; in this way the center of the sheet with lower stiffness, undergoes plastic deformation first and the boundaries of the sheet with higher stiffness, experience a certain amount of deformation and working hardness simultaneously.

Thus, the plastic deformation of the centre should be increased and the plastic deformation of the boundary should be decreased, which improves the uniformity of deformation.

6 CONCLUSION

In this paper, a new method for incremental sheet metal forming on the turning machine was presented. This process is a subset of high speed incremental forming (HSIF) processes. Forming principles of these processes are based on incremental forming but the forming process takes place in a very short time interval. Following performed experiments, ability of this process to form symmetric geometries was approved. Also, the best strategy to achieve enhanced sheet formability and forming depth was acquired. Finally, the first strategy (loading the center of the sheet and then going towards boundaries of the sheet) was selected as the best strategy.

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