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A Review: Parameters Affecting Surface Roughness and Thickness Reduction in Incremental Sheet Forming

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Abstract

Incremental sheet forming (ISF) has demonstrated its great potential to form complex three-dimensional parts without using a matching die. The process locally deforms sheet metal using a moving tool head achieving higher forming limits than those of conventional sheet metal stamping process. The die-less nature in incremental forming provides a competitive alternative for economically and effectively fabricating low-volume functional sheet products. Potential application areas include aerospace industries, customized products in biomedical applications and prototyping in the automotive industry. This paper presents a review on experimental investigation of ISF process parameter like feed rate, speed, tool diameter, sheet thickness, lubrication, step size and tool path affecting surface roughness and thickness reduction.

Keywords: Incremental sheet forming, Surface roughness, Thickness reduction

1. Introduction

Traditional forming processes (like deep drawing, stamping) which are already being used in small scale production need high investment cost and long die-preparation time [14]. Therefore, a computer-aided forming process, called Incremental Sheet Forming (ISF) that locally deforms sheet metal using a moving tool is now available for small batch production or prototyping for addressing the issues existing in traditional forming processes. ISF has a great potential to form complex 3-D sheet metal parts without using a matching die. The die-less forming nature of this process provides a competitive alternative for economic and effective fabrication in low-volume functional sheet products. Thus, this process is viable in small scale production to deal with the various needs like customization, low tooling cost and low setup time.

ISF is a forming technique of sheet metal based on layered manufacturing principle. The sheet is locally deformed through horizontal slices. The moving locus of forming spherical tool (tool path) in these slices can created directly from integrated CAD/CAM system and performed by the CNC milling machine.

Potential application areas of ISF include aerospace industries, customized products in biomedical applications and prototyping in the automotive industry, for example: reflexive surfaces for headlights, a heat/vibration shield see and silencer housing for trucks. Non-automotive applications, for example: motor bike seats, motorbike gas tank, solar oven, production dies, mould surfaces [12]. In order to implement ISF for these different application areas, different sets of process parameters are required to optimize for generating the required accuracy, surface finish and formability etc. Therefore in this paper, a review of manufacturing parameters affecting surface roughness and thickness reduction in ISF has been carried out. During ISF, parameters are so optimized that it reduces surface roughness for increasing the surface quality of parts (e.g. reflexive surfaces for headlights). Moreover, reduction in surface roughness decreases friction between mating parts (like production dies, moulds surfaces). Another parameters optimization requirement is uniform thickness reduction that leads to better geometrical accuracy and good strength of forming parts.

2. Background of ISF

ISF process can be classified as Single Point Incremental Forming (SPIF) and Two Point Incremental Forming (TPIF). In SPIF type, the sheet is clamped along its edges and the tool (generally a spherical tool) moves along the sheet surface, as schematized in figure 1. Thus no die is used. This method can be implemented on a conventional CNC milling machine, including a CAD/CAM system to produce the tool path [11]. In TPIF (see figure 2), the blank is clamped in the blank holder which can be adjusted in the Z axis. The forming tool is similar to the tool in SPIF and performs a trajectory of the outer surface of the part, from top to bottom of the geometry. In TPIF a die is used below the blank & die has the same function as the backing plate or supporting plate only and thus enhance the geometry accuracy.

The terminology used in ISF is shown in figure 3 and explained as follows:

- Tool diameter: diameter of hemispherical shaped tool
- Step size: amount of material deformed for each revolution
- Wall angle: angle between horizontal undeformed and deformed sheet metal
- Sheet thickness: thickness of sheet before and after deformation
- Feed rate: progressive movement of the tool towards the work piece
- Spindle speed: number of tool revolutions

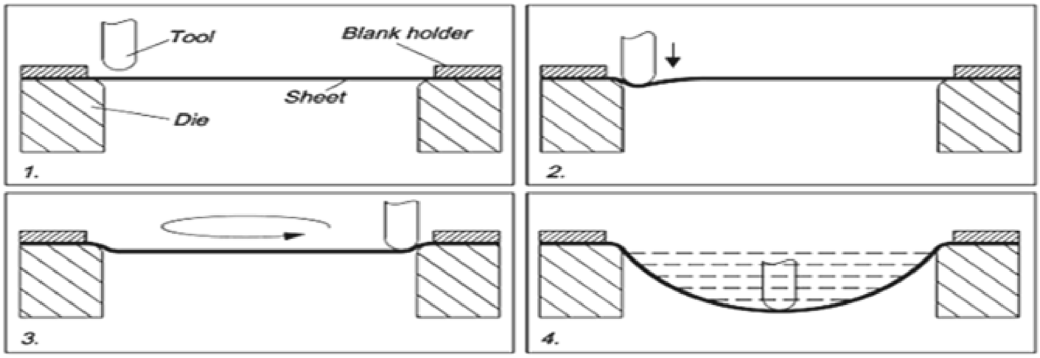

Fig. 1: Single Point Incremental Sheet Forming [14]

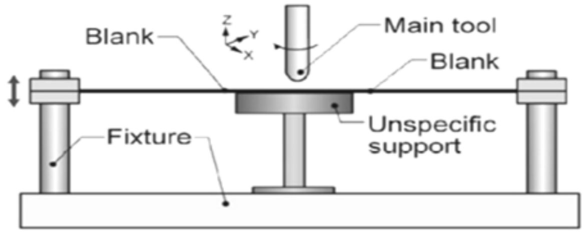

Fig. 2: Two Point Incremental Sheet Forming [12]

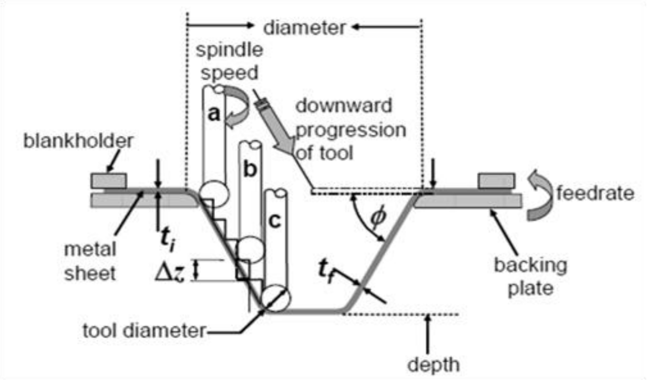

Fig. 3: ISF Terminology [14]

3. Manufacturing Parameters in ISF Process

Today Different parameters are used by different researchers in ISF. A review of these parameters affecting particularly surface roughness and formability is carried out and shown in table 1. The possible range of these parameters and their effects on surface quality and formability are as follows:

1. Tool diameter: It can be taken in range 2-30 mm, but in most of papers it has been taken in range 10-20 mm. As the tool diameter increases, the surface roughness decreases. But, formability increases at smaller diameters. The best formability has been obtained with the 10 mm tool [1].
2. Step size: It is taken by most of researchers in between 0.2 to 1mm. As the step size increases, the surface roughness increases. When step size decreases, it increases the production time. The optimum surface quality has been obtained at 0.39 mm step size [24].
3. Feed rate: It can be used above 1000 mm/min and up to 6000 mm/min. Increase in feed rate increases the surface finish, but decreases the formability.
4. Speed: It is used by most of researchers in range 100-1000 rpm. With the increase in speed, there is directly increase in productivity and but increase in roughness too. Increase in speed also decreases the formability. Highest effective speed has caused lowest formability [13].
5. Sheet Thickness: This parameter in ISF process can be ranges from 0.5 to 2mm. Increase in sheet thickness decreases surface quality but increases formability. It has been revealed that 0.6 mm sheet have good surface finishing than 0.8 mm thick sheet [22].
6. Lubrication: Most of researchers used grease as lubrication in ISF. Lubrication added the cost in manufacturing but it increase surface finishing as well as formability. The ball tool with lubrication left no scratches while hemispherical head tool without lubrication left most scratches [2], [3]. Houghton TD-52 and Tellus oil 68 also have been used for lubrication in ISF [23] [24].
7. Tool path: There are two type of tool paths used in ISF: spiral and helical. Spiral tool path is mainly used but it causes scare on surface while helical tool path increases surface finish. Helical tool path at high speed causes vibration in machine therefore, it would be used less than 1000 rpm. Other tool paths depend on tool trajectory; it may be angular step, vertical step, circular motion and loxodrome [19].

4. Review Of Literature on Manufacturing Parameters Affecting Surface Roughness

Manufacturing parameters have greatly influenced the surface quality in ISF. Kopac et al. (2005) [5] presented the ISF process controlled by CNC milling machine tool. He found that surface roughness of aluminum sheet is lower than steel because steel is highly deformable and subjected at minimum hardening. Cerro et al. (2006) [6] stated that roughness is lower in the tool advancing direction than in perpendicular one. Roughness can be decrease by decreasing axial step size. Although surface quality will be better, processing time will also be higher. Lubrication of the sheet is crucial to obtain a reasonably good surface quality. Attanasio et al. (2006) [7] worked on the optimization of tool path in two point sheet incremental forming, with a full die in a particular sheet incremental forming configuration and studied the experimental evolution of tool path. showed by experimentally that surface quality is better as varying step size (Δz) and constant scallop height (S_0) and surface quality is poor when constant step size ((Δz) and varying scallop height (S_0).

M. Durante et al. (2010) [18] compared the analytical and experimental roughness values on aluminum alloy AA7075 T0 part. The observation of geometries carried out allowed note that the type of roughness is not a shape effect. Value of roughness measured by average surface irregularity is give by

$R_z = 117p^2/r^{1.43}$,

Where p is step size and r is tool radius. So that the

$R_{zexp}/R_{zmod} = 0.93r^{-0.43}$,

Where R_{zexp} for experimental value of R_z and R_{zmod} for analytical value of R_z. L. C. C. Cavaler et al. (2010) [16] worked on AISI 30 stainless steel using cemented carbide tool with a hemispherical tip of 8 and 10mm diameter. This paper verified that for a coating as well as an uncoated tool the roughness reduces with the increase of the vertical depth and it makes possible to state that vertical depth influences strongly the roughness. In case of coating tool TiAIN lower value of roughness obtain as compared to uncoated tool. S. Chehian Babu, V.S. Senthil Kumar (2012) [20] showed by experimental result that roughness increases in the order of 40 to 45% with increase in tool rotational speed. Increase in step depth leads to nearly 30 to 35% increase in surface roughness.

Zhaobing Liu et al. (2014) [24] worked on AMINO DLNC-PC incremental forming machine using AA 7075 O-temper aluminum alloy. The surface roughness measurements are implemented using a portable, self-contained instrument Taylor-Hobson Surtronic 3 + Profilometer. This paper presented the response surface method (RSM) to optimize the surface quality using process parameter like step down, feed rate, sheet thickness and tool diameter. The optimal experimental condition were determined as step down (0.39mm), feed rate (6000mm/min), sheet thickness (1.60mm) and tool diameter (25mm) with a minimum overall surface roughness 0.32 µm.

5. Review of Literature on Manufacturing Parameters Affecting Thickness Reduction

Parameters mainly affecting thickness reduction are sheet thickness, step size and feed rate. Ambrogio et al. (2005) [4] and Young et al. (2004) [3] found that wall thickness initially greater than the sine low thickness then reduces to less than the sine low thickness across the formed region of copper plates. This suggests that thinning beyond the sine low prediction as a result of material being pushed towards the center of geometry. M. Skjoedt, N. bay (2006) [8] experimentally proved that increasing in angle cause decreasing thickness and most of the reduction in thickness occurs in center part where the drawing angle is low. Maximum thickness strain obtains in the corner of cup. So the critical area in not the vertical side themselves but the transition zone between vertical and horizontal.

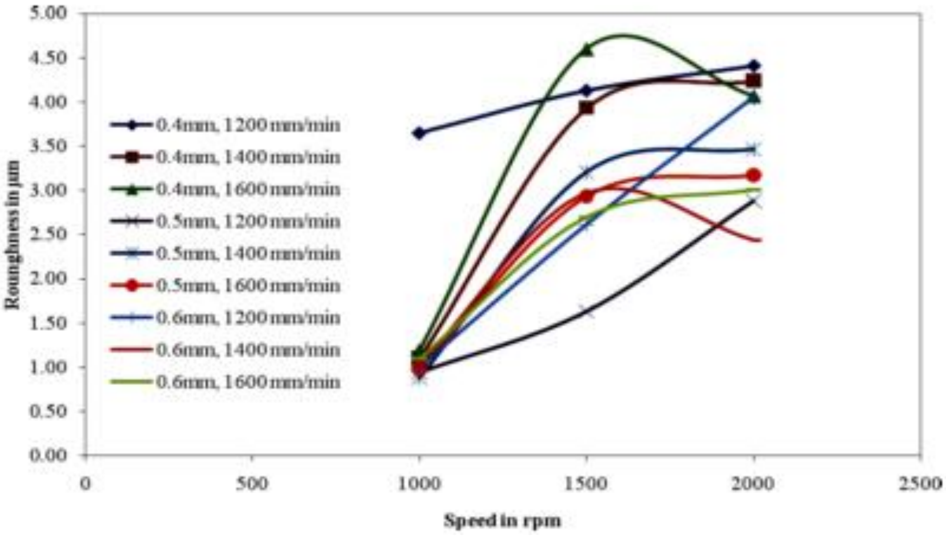

Fig. 4: Roughness Vs Spindle Speed for Step Depths and Feed rates Increase [19]

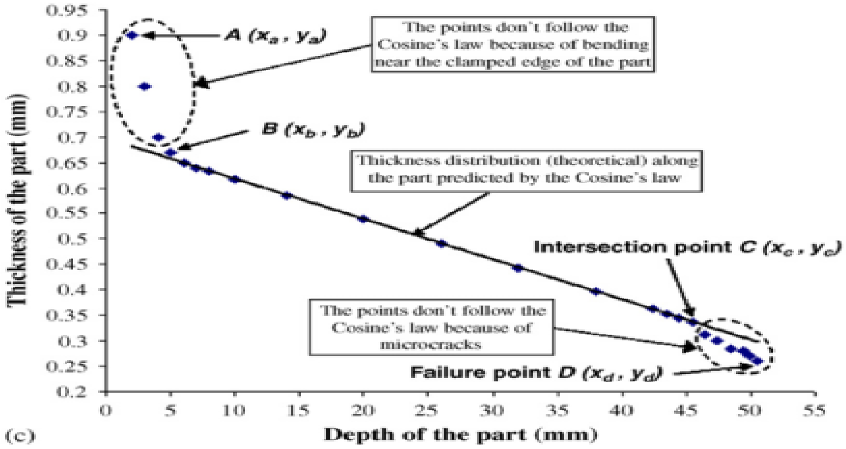

Fig 4: Thickness distribution along cracked part [9]

J. Verbert et al. (2008) [10] analyzed multistep tool path approach to overcome forming limitation. The wall thickness of multi-step cone is significantly longer than the thickness obtained with single step tool path. However the thickness of the bottom of multi-step part is lower than the thickness of the bottom of single-step tool path. Using multi-step approach has clearly led to shift of material from the bottom, which would otherwise have remained unprocessed of the wall part. Chezhian Babu and Senthil Kumar (2010) [17] on the carbon steel study found for lower values of feed the thickness does not very much reduce. Minimum step depth leads to lower value of final thickness.

M. J. Mirnia et al. (2013) [21] worked on Al1050 sheet material to predict the thickness distribution using sequential limit analysis (SLA). The thickness distribution and minimum thickness of the truncated cone can be predicted with reasonable accuracy in less time using SLA than ABAQUS for the equivalent model. The deformation in zone 1, near the backing plate, is affected by bending and in zone 2 is governed by stretching. By increasing the tool diameter, stretching in zone2 increases and decrease in minimum thickness. By increase in step size up to 2mm, the bending I zone1 increases and increase in minimum thickness.

6. Concluding Remarks

Different researchers have carried out experiments varying different parameters like speed, feed rate, incremental step size, lubrication, tool diameter, sheet thickness, material, and tool path etc. Different ranges of parameters have been used and they are varied to find their effects on thickness reduction, surface roughness etc. But from the literature review, it is found that, for AA2024 all the seven parameters (tool diameter, sheet thickness, feed rate, spindle speed, lubrication, tool radius and the tool path) which have the utmost influences on thickness reduction & surface roughness have not been varied altogether and no attempt has been made to optimize the process in this respect.

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