International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 04 Issue: 07 | July -2017 www.irjet.net p-ISSN: 2395-0072

A REVIEW ON COMPUTER AIDED MANUFACTURING FACTORS AFFECTING REDUCTION OF SURFACE ROUGHNESS AND THICKNESS IN INCREMENTAL SHEET FORMING PROCESS

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Abstract - *Incremental sheet forming (ISF) has established 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 attaining higher forming limits than those of conventional sheet metal stamping process. The die-less nature in incremental forming provides a viable substitute for economical and effective fabricating low-volume functional sheet products. Various application areas include aerospace engineering, customized products in biomedical engineering and prototyping in the automotive engineering. This paper presents a review on experimental investigation of ISF process factors or parameters like feed rate, speed, tool diameter, sheet thickness, lubrication, step size and tool path affecting surface roughness and thickness reduction.*

***Key Words*: Incremental sheet forming (ISF), single point incremental sheet forming, roughness, thickness reduction, tool path.**

1. INTRODUCTION

Incremental Sheet Forming (ISF) process is sustainable in small scale production to deal with the various needs like customization, low tooling cost and setup time. The conventional forming processes already used in the industry (like deep drawing, stamping) need high investment cost and long die-preparation times for small scale production [14]. Therefore, ISF is a process which is, now a days, available for small batch production or prototyping as it deals with the issues in the conventional forming process.

ISF is a forming technique of sheet metal process based on layered manufacturing principle. The sheet part is locally deformed through horizontal slices. The moving locus of forming tool (tool path) in these slices is performed by the CNC milling machine. The tool path is generated directly from CAD model of final product by using CAM system.

Surface roughness is reduced to increase the surface quality of parts (e.g. reflexive surfaces for headlights) and to reduce friction between mating parts like production dies and mould surfaces etc. Thickness reduction defines both geometrical accuracy as well as the strength of the forming parts. Uniform thickness distribution leads to better geometrical accuracy and better strength.

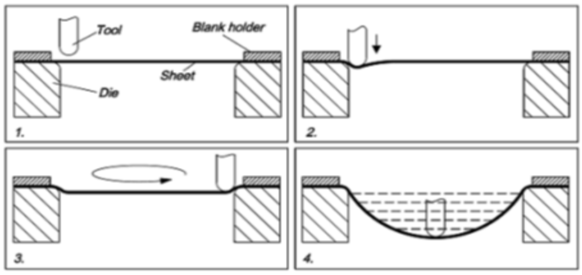

Fig -1: Principle of Incremental Sheet Forming [14]

1.1 Classification of Incremental Sheet Forming

The ISF can be classified as

- Single Point Incremental Forming (SPIF)
- Two Point Incremental Forming (TPIF)

1.1.1 Single Point Incremental Forming (SPIF)

In SPIF type of incremental forming, the blank is clamped along its edges and the tool (generally a spherical tool) moves along the sheet surface, as shown in figure 2. Hence no die is used and even asymmetrical parts can be easily formed. This method can be executed using a conventional CNC milling machine, including a CAD/CAM system to produce the tool path [11].

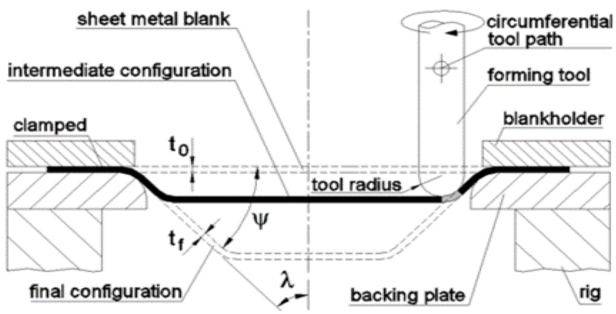

Fig -2: Single Point Incremental Sheet Forming [11]

1.1.2 Two Points Incremental Forming:

In Two Point Incremental Forming (TPIF) 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 supporting plate only and increase the geometry accuracy.

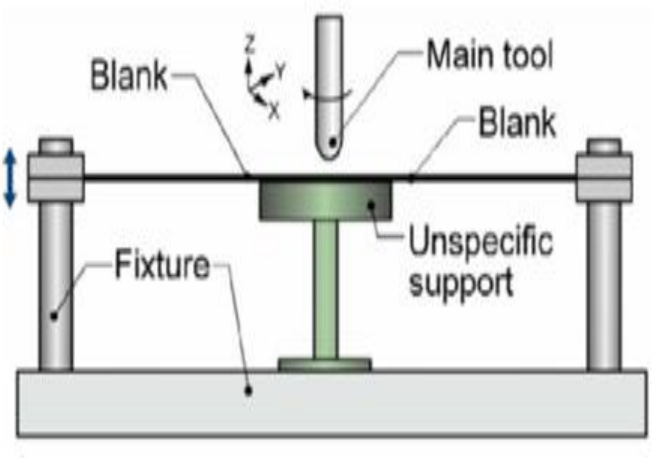

Fig -3: Two Point Incremental Sheet Forming [12]

1.1.3 Computer Aided Manufacturing factors in SPIF

In SPIF Vertical step size is the amount of material deformed for each revolution of forming tool. Tool diameter is the diameter of hemispherical shape tool used in SPIF process. Wall angle is the angle between horizontal undeformed sheet metal and deformed sheet metal, sheet thickness is the thickness of undeformed sheet used before processes and the Lubricant used in SPIF process is either solid lubricant or semi-solid or highly viscous lubricant. Feed rate is the progressive movement of the tool towards the work piece. Tool Path is the path followed by tool in ISF process.

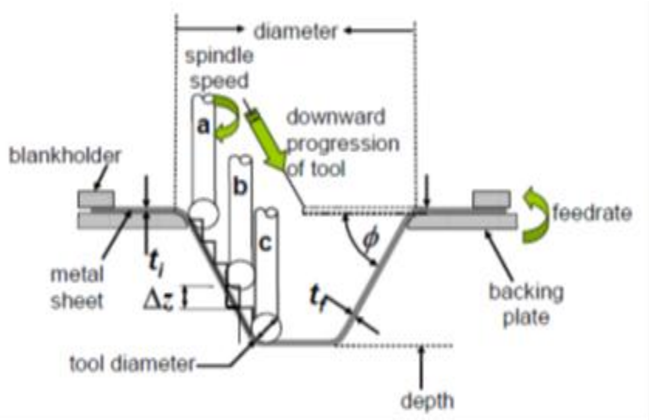

Fig -4: SPIF Terminologies as seen in deformed parts [14]

1.2 Computer Aided Manufacturing factors for Incremental Sheet Forming

Following factors or parameters are used for ISF:

(i) Tool diameter: Tool diameter in ISF can be taken 2 to 30mm, but most of researchers took it from 10 to 20mm.The surface roughness decreases as the tool diameter increases, but formability increases at smaller diameter. The optimum formability was attained using the 10mm tool [1].
(ii) Step size: Step size taken by most of researchers is 0.2 to 1mm. The surface roughness increase as the step size increase but also enhance production time.
The optimum surface quality was attained at 0.39mm step size [24]
(iii) Feed rate: Feed rate in ISF process can be use above 1000mm/min and up to 6000mm/min. the surface finishing increases as increase in feed rate but it leads to decrease the formability.
(iv) Speed: Speed used by most of researcher was 100 to 1000rpm. Productivity increases with increase in speed. Roughness increase with increase in speed but increase in speed decreases the formability. Highest effective speed caused lowest formability [13].
(v) Sheet Thickness: Sheet thickness used in ISF process can be ranges from 0.5 to 2mm. surface quality decreases with increase in sheet thickness but increases the formability.0.6 mm sheet have good surface finishing than 0.8 mm thick sheet [22].
(vi) Lubrication: Most of researchers used grease as lubrication in ISF. Lubrication increases the cost in manufacturing but it also increase surface finishing and 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 used for lubrication in ISF [23] [24].
(vii) Tool path: Mainly two type of tool path are used in ISF; spiral and helical. Spiral tool path mainly used but it causes scars on surface while helical tool path increases surface finishing. But helical tool path at high speed cause vibration in machine so it must be used less than 1000 rpm. Another tool paths depend on tool trajectory that may be angular step, vertical step, circular motion and loxodrome [19].

2. A REVIEW OF LITERATURE RELATED TO SINGLE POINT INCREMENTAL FORMING:

In ISF the process parameters (like speed, feed rate, incremental step size, lubrication, tool diameter, sheet thickness, material, and tool path) are affecting the surface roughness, and thickness reduction.
Table 1 is formed to show the variation of Computer Aided Manufacturing factors used different researchers in Incremental Sheet Forming Process either for surface roughness or for thickness reduction testing experiments.

Table 1: Different CAM factors used by different researchers

S.no.	Researcher	Year	Diameter(mm)	Speed(rpm)	Feed rate(mm/min)	Step size (Δz)	Lubrication	Material	Sheet thickness(mm)	Tool path
1	Matteo, Macro	2004	2.2,3	n/a	150-1700	n/a	n/a	AA 1050	0.6	Spiral
2	G. Ambrogio	2005	11	500	1000	n/a	Emulsion	Al	n/a	n/a
3	A. Attanasio	2006	20	100	1500	0.2,0.5,1.0	Grease	Fe P04 St.	0.7	Contour tool path
4	M. Skjoedt	2007	12	35	1000	0.5	D. C. fluid	n/a	n/a	helical
5	M. Rauch	2008	20	n/a	n/a	0.5,1.5	n/a	Al 5086	0.6	Contour parallel
6	M. Hrairi	2010	n/a	n/a	n/a	n/a	n/a	Al 3003-o, Al 1050-o	n/a	Unidirectional, Bidirectional and helical
8	Adrian Blaga	2011	8	n/a	n/a	n/a	Forming lubricant	DC04 steel	0.7	Constant vertical, angular, spiral& loxodrome
9	Adrian Blaga	2012	6,10	n/a	240	n/a	n/a	DC04 St.	0.5,0.9	spiral
10	I. Bagudanch	2013	6,10,20	1000	3000	0.2,0.5	H. TD-52	AISI304	0.8	n/a
11	Rajiv Malhotra	2013	9.5	n/a	n/a	1, 0.5	PTFE	AL5052	1	Spiral
12	A Mohammadi	2013	10	n/a	2000	0.75	n/a	AA5182	1.25	Spiral
13	CRINA RADU	2013	6,10	500,700	1500,3000	0.1,0.5	n/a	A1050	0.8,1	n/a
14	Zhaobing Liu,	2014	15,20,25	n/a	4000, 5000, 6000	0.2,0.5,0.8	Tellus Oil 68	AA7075-O	1.02, 1.6, 2.5	n/a

Surface roughness:

Factors have greatly influenced the surface quality in incremental sheet forming. J. Kopac, Z. Kampus (2005) [5] presented the processes controlled by CNC milling machine tool with CAD/CAM. Surface roughness of aluminum sheet is lower that steel because steel is highly deformable and subjected at minimum hardening. I. Cerro, E. Maidagan (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.

A. 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 (S0) and surface quality is poor when constant step size ((Δz) and varying scallop height (S0).

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 given by

Rz = 117p2/r1.43,

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

Rzexp/Rzmod = 0.93r-0.43,

Where Rzexp for experimental value of Rz and Rzmod for analytical value of Rz. 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.

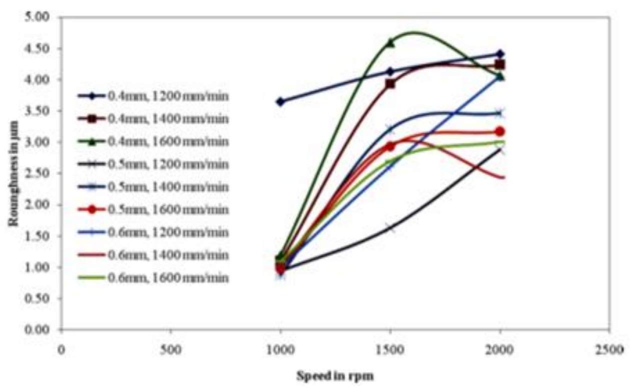

Fig -5: Roughness Vs Spindle Speed for Step Depths and Feed rates Increase. [19]

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.

Thickness reduction:

Factors mainly affecting thickness reduction are sheet thickness, step size and feed rate. Ambrogio et al. (2005) [4] and Young and Jeswiet (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.

Hussain and Gao (2007) [9] worked on aluminum alloy using HSS tool without coating. Process parameters used are tool dia, feed rate, step size and lubrication. This paper stated that for a particular step depth and feed the thick ness reduces. The slope of forming is fixed causing higher thinning limits.

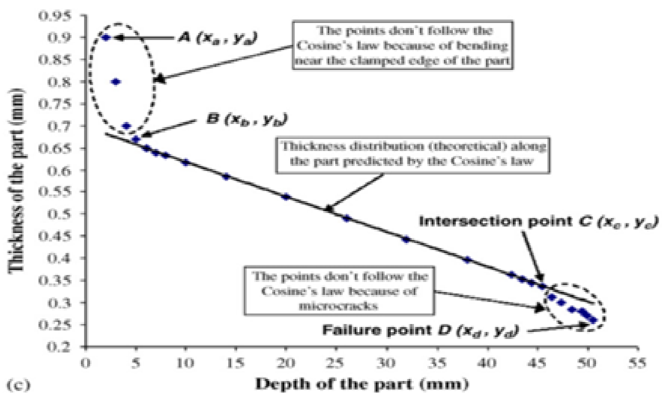

Fig -6: Thickness distribution along cracked part [9]

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.