Effect of Process Parameters on Incremental Sheet Forming: A Review

[1]Madan Boruah, [2]Snehal Trivedi, [3]Prashant Khanna
[1]M. Tech student, [2]Assistant Professor, [3]Assistant Professor
[1,2,3] Mechanical Engineering Dept
[1,2,3] Parul Institute of Technology, Parul University, Vadodara, India.

Abstract : Incremental sheet forming is a process to produce sheet metal components that are well suitable for small batch prototypes. The process ISF is classified under sheet metal forming processes, more specifically in the asymmetric incremental deformation process. Some studies have been carried out to analyze the influence of different parameters (Speed feed, depth of cut, tool dia, tool path, Sheet thickness, etc,) in the process. Selection of appropriate process parameters such as tool path, feed, step depth, wall angle, tool diameter etc. with respect to selected sheet metal structure plays an important role for the reduction in processing time. Moreover, it provides a better understanding of the process, which will help for further improvement of ISF process, compare to other metal forming processes. Stretching in the plane normal to the tool movement direction and with shear in the plane parallel to the tool movement direction are the deformation mechanisms of Incremental sheet forming. Process parameters such as Tool dia and Depth of cut have a major influence over the surface roughness of the component, which has been discussed under.

Index Terms **- Incremental Sheet forming, Process Parameters, Deformation mechanism, SPIF, TPIF.**

I. INTRODUCTION

Incremental sheet forming (ISF) is a versatile sheet forming process used for small batch manufacturing and rapid prototyping of nearly arbitrary 3D shapes. In ISF, a clamped sheet metal is formed progressively by a moving forming tool. The path of the tool covers the surface of the desired product, similar to the finishing step in z-level processing. In every instant of the forming process in which the tool is moved over the material, localized plastic deformation is generated, and the final part shape is the result of all localized plastic deformations.

Single Point Incremental Forming (SPIF) is a flexible process which uses very simple tooling to make sheet metal prototypes and custom specific parts. In this, the sheet is clamped along its edges and a hemispherical headed tool is moved along required path so that it presses the sheet locally along the path. Better conformability, simple tools without special dies and low training forces are some of the advantage of this process. The tool diameter, the pitch depth, the feed speed, the spindle rotation speed, the blade thickness, the lubrication and the tool trajectory are some of the important process parameters that affect the process mechanics in incremental training.

In Two-Point Incremental Forming (TPIF) process the sheet metal moves vertically on bearings, which move on sheet holder posts, along the z-axis, as the forming tool pushes into the metal sheet. This process is called TPIF because it has two contacting points between forming tool and partial die. The first point where forming tool presses down on the sheet metal to cause local plastic deformation. The second point is a point of contact between a static post and the sheet that is created when the instrument (tool) is pressed on the sheet. Although TPIF process used a partial die as support, it is often called as dieless forming.

Tool path plays a vital role in the geometric accuracy of the part and homogeneous thickness distribution. Thus selecting the right tool path is very important for the successful manufacturing of parts in incremental sheet forming. Incremental forming is a potential process which has the formability above the forming limit curve in comparison with conventional sheet forming process. The experimental evidence and analysis are concluded that the formability of ISF process is mainly influenced by four major parameters: depth of step, tool RPM, tool diameter and sheet thickness.

The deformation mechanism of incremental sheet forming (ISF) of both SPIF and TPIF are stretching and shear in the plane normal to the tool direction, with shear in the plane parallel to the tool direction. Rate of deformation increase on successive laps, and the most influencing component of strain is shearing parallel to the tool direction Increasing stretching and shear normal to the tool direction account for differences between the sine law prediction for wall thickness and wall thickness of incremental deformed sheet.

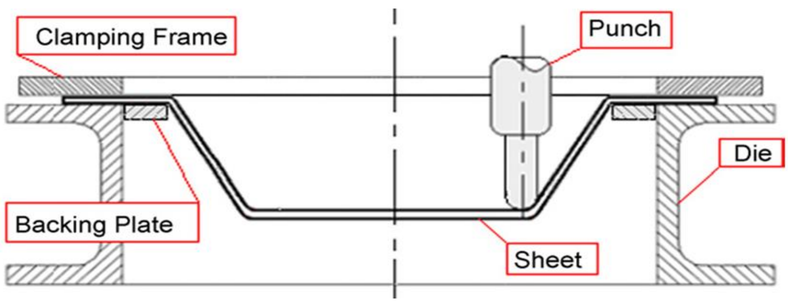

Figure 1: Incremental Sheet forming [14]

II. TYPE STYLE AND FONTS

Jeswiet et al. [1] reported asymmetric incremental sheet forming, with a single point doing the forming, is a viable process for making complicated shapes from sheet metal. It makes the forming of sheet metal a flexible operation and is an easy operation for all facilities having access to a three axis CNC mill. There are two variations to the process, one with a single point doing the forming and the other with two points where one point is either a partial or full die. The process has tremendous potential and there are many future possibilities where it can be used.

Skjoedt et al. [2] proposed a methodology to convert the profile tool path in to helical tool path. This program will generate the helical tool path for any geometry provided with its profile tool path. But one dis advantage of helical tool path is that is the step size exceeds optimal limit then there is chances of twist and dent may occur which will affect the dimensional accuracy of the component.

Jadhav et al. [3] observed twist and dent in parts formed using helical tool path. To overcome this drawback a bifacial profile tool path has been recommended. This tool path is similar to profile tool path except that in each subsequent cycle tool changes the direction of motion. This toolpath minimizes the twist and enhances then geometric accuracy of the formed component. However it's going to not be attainable to divert the scar mark to unimportant space all told cases. He also proposed Bi-directional profile tool path with distributed increment, which is not in commercial CAM packages. In the bi-directional tool path, the tool completes a cycle and a quarter of tool path cycle is added before it moves to next cycle. By doing this the position of tool amendment from one cycle to a different cycle can amendment and scar mark isn't be visible on the half pure mathematics. Moreover by doing this forming force distributes uniformly on the edge of the component and enhances the geometric accuracy.

Rauch et al. [4] depicted that tool path generation is a key topic in incremental sheet forming. It is important to introduce a dedicated tool path to improve the efficiency of this process. The implementation of intelligent CAM programmed tool paths for incremental sheet forming is proposed. This new approach adapts the trajectories of the instrument during the production of a part based on the evaluations of the process data. Tool trajectory adaptive is by using CNC data. This ensures a high flexibility.

Kurra Suresh et al. [5] proposed methodology that can generate the required helical tool path for numerical simulations directly from the NC part program generated using CAM package. They proposed to input the tool path trajectories generated using CAM packages in to numerical simulation softwares such as ABAQUS and Ls-Dyna. In all cases, the planned methodology is ready to get the desired tool path definition with smart geometric and dimensional accuracy.

Attanasio et al. [6] suggested that in order to reach good results in terms of surface quality, geometric accuracy and thickness distribution of the final part, it is important to correctly set the value of two parameters: step depth and scallop height. If we can maintain the scallop height as per requirement we can reduce the working time and improve the surface quality.

Carrion et al. [7] concluded that the punch radius should be chosen large as possible. However, two main factors represent a limitation in using a very large amount of radius (r). In fact, as the punch radius increases, manufacturing parts with geometrical complexity (small values of horizontal radius r) becomes very difficult and the forces required for completing the forming operations become larger.

Leon et al. [8] determined that the greater the sheet thickness, the greater the strain value. It additionally affects, in a lesser extent, the radius of the instrument (tool) and the turns of the spiral. The deformation will increase once the instrument radius is reduced and with the amount of turns. In the analysis of the most force undergoes by the tool, It is obtained that the foremost important issue is that the sheet thickness. Therefore, if the thickness also the radius of the instrument (tool) reduce and also the turns of the spiral multiply, the deforming force reaches a lover worth.

J.R. Duflou et al. [9] extended process window achievable by means of multiple SPIF can be explained by the straining of horizontal workpiece area under that remain unaffected in conventional toolpath strategies. This allows producing vertical walls without leading to part failure. While a major decrease in radial strain are often determine in steep wall compared to single-step forming, the multi-step toolpath strategy results in substantial tangential strains. The ensuring thinning of the sheet throughout multi-step forming will exceed the maximum thickness reduction determined in single-step process, implying a formidability shift.

Hirt et al. [10] motivated by the drawbacks of typical ISF, two different forming methods have been recommended to assist enlarge the range of potential method applications, specifically a multistage sheet forming strategy to provide steep flange and a correction algorithm to enhance the geometric accuracy. Process modelling using a definite problem solver has been applied to predict the sheet thickness distribution for the forming of tailor rolled blanks.

Ham et al. [11] discussed that feed rate, spindle rotation speed, step depth and forming angle affect whether a part can be successfully formed or not. This experiment also shows step depth and diameter have no effect on the likelihood of forming a part. Thus smaller and shallower parts can be utilized for future experimentation, reducing machine time requirements. A significant finding in the DOE is faster spindle rotation speeds improve formability.

Kopac et al. [12] stated that execution of the technological process of incremental sheet metal forming is intended for justification of small batch production. The time necessary for prototype making can be reduced. Another important strategy is the trajectory of the forming tool along surface of sheet metal. The movement of the tool beginning within the centre of sheet then restarting from the initial depth from inside to outside direction has a priority. As the inclination of wall increases more than 450, it may cause errors, cracks, and product failure.

D. S. Malwad et al. [13] discussed that for higher wall angle stretching plays a vital role in deformation than shearing. When the draw angle decreases deformation is mainly takes place due to shearing. With smaller vertical step depth forming forces decreases and better surface finish can be achieved. Size of the tool affects both the formability and the surface finish of the component. Higher amount of forming forces generated, when go with large tool size. Large tool size have a bigger contact area and it tends to support the sheet better during forming two directional stretching at the corners and plain strain stretching at the sides produced. This has been the reason for occurring of cracks at the corner.

G. Ambrogio et al. [14] proposed an industrially oriented methodology for detecting the approach of failure in incremental forming. The approach relies on the analysis of the trend of the forming force so as to assess whether or not the method can be run safely. If not, a correct strategy, to avoid material failure, is proposed and valid through an experiment. By reducing tool diameter more localised forming effect can be generate, wear reduces and formability can be increase.

F. Capece Minutolo et al. [15] considered FE simulations of the method have been carried out with the help of LS DYNA code. On the basis of the numerical analysis, it has been possible to give some relevant conclusion for different strain conditions, including the most stressed zone that explains the position of the fractures, which can be experimentally, validate for a value of the angles beginning, respectively, from 640 and 670.

Kathryn Jackson et al. [16] observed that the deformation mechanisms of both SPIF and TPIF are stretching and shear in the plane normal to the tool moving direction, with shear in the plane parallel to the tool moving direction. Rate of deformation increase on successive laps, and the most influencing component of strain is shearing parallel to the tool direction. Increasing stretching and shear normal to the tool direction account for differences between the sine law prediction for wall thickness and wall thickness of incremental deformed sheet.

G. Hussain et al. [17] concluded that the regular conventional stretch ability indicator called as hardening exponent does not have any meaningful relationship with formability. The same applies to the other parameters such as percent elongation and strength co-efficient on formability. The tensile reduction percentage of area appeared as the sole major property influencing the formability. It has an important relationship with formability and therefore, can be used as a formability indicator of the SPIF process.

G. Ambrogio et al. [18] discussed the shape errors in incremental forming process characterized by a single point tool, are due to the lack of a counter acting die or due to the absence of a guide for the deforming sheet metal. On the other hand probably the most significant characteristic of the considered forming process is the absence of rigid dies; in this way the introduction of a rigid die would make the forming process more expensive and reducing its potential. In this current research, a simple way is proposed to reduce the geometrical errors affecting the accuracy geometry of the investigated component. In particular, two different geometric trajectories were inducted in the numerical simulation with the purpose to obtain a final deformed mesh closer to the desired geometry. The first the traditional trajectory in which the tool advances tangentially to the desired surface and in the second path the tool trajectory is reconstruct by introducing an increased initial slope which is calibrated to the former one. In this way, the shape error, due to the bending, near clamping zone, can be minimized to improve the geometrical accuracy of the product.

S. Dejardin et al. [19] demonstrates the potential of single purpose progressive sheet forming to produce sheet metal components with geometrical accuracy. It also depict the accuracy and the reliability of 3D finite elements simulation of the forming method, by accounting the tool path strategy. The paper also focuses on the Springback effect on SPIF. It has been depicted through experiments and finite elements analyses that Springback, characterized through the cut rings method, can be accurately predicted from numerical simulations based on shell elements associated with a suitable forming tool path. In the case of Springback associated with in plane shear, it is necessary to perform simulation based on 3D elements accounting shear, to visualize the effect on the part accuracy.

Rahul Jagtap et al. [20] concluded that the profile tool path results in higher surface roughness and thinning of the formed part as compared to the helical tool path. Tool diameter has a maximum effect on the surface quality of the formed part as compared to other parameters. Higher tool diameter gives a better surface finish. The surface quality and thinning are inversely proportional to each other, i.e. if one characteristic is improved, other deteriorates. Therefore, required surface quality should be decided in advance based on the application of the formed part so that thinning can be optimized. As the pitch increases, the surface roughness also increases considerably. Thus to obtain a good surface finish of the formed part, the low value of pitch should be used.

D. Young et al. [21] proposed a twin pass technique as a new method to improve the final wall thickness profile of sharp geometry. Wall thickness of test cones have been analyzed and have revealed that the development of the characteristic thinning band available in single-pass forming can be a hold-up. The twin-pass forming method can permit the production of parts that thin to failure with the single-pass process.

Luigino Filice et al. [22] discussed improving the thickness distribution along the wall, improving the final geometrical accuracy of the product and the energy consumption. The approach based on the “sine law used to estimate the thickness of the formed part is not correct in exercise since material thinning accompany a more complex behavior (polynomial trend). Experimental work is done with the help of two different tool path with an optimized model slope (Single slope and Decremental slope). In both the cases significant reduction in localized thinning was observed and with higher wall angle the part accuracy penalizes and leads to greater chances of failure.

Mingshun Yang et al. [23] discussed the influence of thickness-reducing proportion on the forming limit of the deformation zone in the SPIF method. Moreover, Yang proposed a new formula with high accuracy that can forecast the deformation zone thickness was suited with the simulation results, and the influences of process parameters, such as tool dia, depth of cut, tool RPM, blank thickness, and forming angle, on thinning proportion were analyzed and reliability of the FEM was verified by experiment. The thinning rate can be controlled by changing the forming tool path was introduced and results indicate that the obtained data by using the modified formula is nearer to the experimental results than that acquired by the sine theorem.

III. Summary

Incremental sheet forming, with a single point contact doing the forming, is a useful method for generating complex shapes from sheet metal. It makes the forming of sheet metal a versatile operation and is an easy method for all types of facilities having access to a three axis CNC milling machine.

Influence of wall angle (α): The material parameter, draw angle (α), is important in AISF. The largest design draw angle in the part must be less than the material parameter i.e. the maximum value of the draw angle, which is a material characteristic. As wall angle increases deformation occurs due to stretching and local shearing. Due to stretching there is greater wall reduction.

Influence of vertical step size (Δz): The amount of the step down in z-direction that the tool made after each pass is an important parameter which had an influence on limits of formability. Sheet formability decreases with increasing increment step depth (Δz). Furthermore large increment steps, Δz, give a higher roughness.

Influence of tool diameter (d): Smaller tool dia improves formability of the sheet. Higher formability seen with small dia tools is thought be a consequence of the concentration of force and strain as the area of contact is less at the tool tip. If considerable small tool diameter (less than 6 mm) used, formability will be decreases as the tool will penetrates inside the sheet instead of causing uniform deformation.

Influence of lubrication: Lubrication plays an important role in single point incremental forming in order to reduce the friction between tool and sheet at the point of contact and thus to improve the surface quality.

Influence of sheet thickness (t): The magnitude of the forces increases considerably with increasing sheet thickness. The sheet thickness is a dominant factor determining the amount of force required for deforming the sheet.

Formability: Anisotropy has an influence upon formability, greater formability can be achieved with the small tool size, in the transverse direction up to certain limit, because as the tool dia decreases the vibration forces comes in to play and it has adverse effect on the dimensional accuracy of the manufactured component. Higher rate of formability is achievable with thick metal sheets as more material is available to flow during deformation.

REFERENCES

[1] Jeswiet, J., Micari, F., Hirt, G., Bramley, A., Duflou, J., &Allwood, J. 2005. Asymmetric single point incremental forming of sheet metal. CIRP Annals-Manufacturing Technology.

[2] Skjoedt, M., Hancock, M. H., and Bay, N., 2007. Creating 3D Spiral Tool Paths for Single Point Incremental Forming, Key Eng. Mater.

[3] Jadhav, S, 2004. Basic Investigations of the Incremental Sheet metal Forming Process on a CNC Milling Machine. Doctorate Thesis, University of Dortmund, Germany.

[4] Rauch, M., Hascoet, J. Y., Hamann, J. C., &Plenel, Y. 2009. Tool path programming optimization for incremental sheet forming applications. Computer-Aided Design.

[5] Kurra Suresh, Arman Khan, Srinivasa Prakash Regalla. Y. 2013. "Tool path definition for numerical simulation of single point incremental forming". Dept. of Mechanical Engineering, Birla Institute of Technology and Science pilani-Hyderabad Campus Hyderabad.

[6] Attanasioa, E. Cerettia, C. Giardinib, L. Mazzoniaa. Y. 2007. "Asymmetric two points incremental forming: Improving surface quality and geometricaccuracy by tool path optimization" Universita` di Brescia, Dipartimento di Ingegneria Meccanica,via Branze 38, 25123 Brescia, Italyb Universita` di Bergamo, Dipartimento di Progettazione e Tecnologie,viale Marconi 5, Italy.

[7] L. Carrino, G. Giuliani and M. Strano. Y. 2006. "The Effect of the Punch Radius in Dieless Incremental Forming". Intelligent Production Machines and SystemsD.T. Pham, E.E. Eldukhri and A.J. Soroka (eds) @ 2006 Cardiff University, Manufacturing Engineering Centre, Cardiff, UK. Published by Elsevier Ltd.

[8] J. Leóna, D. Salcedoa, C. Ciáurriza, C.J. Luisa, J.P. Fuertesa, I. Puertasa, R. Luria. Y. 2013. "Analysis of the influence of geometrical parameters on the mechanical properties of incremental sheet forming parts". The Manufacturing Engineering Society International Conference, MESIC 2013.

[9] J.R. Duflou (2), J. Verbert a, B. Belkassem, J. Gub, H. Sol, C. Henrard, A.M. Habraken. Y. 2008. "Process window enhancement for single point incremental forming through multi-step toolpaths". CIRP Annals - Manufacturing Technology @ 2008

[10] G. Hirtl, J. Ames, M. Bambachl/ R. Kopp. Y. 2004. "Forming strategies and Process Modelling for CNC Incremental Sheet Forming". Materials Technology/Precision Forming, Saarland University, Saarbrucken, Germany.

[11] M. Ham & J. Jeswiet. Y. 2006. "Single Point Incremental Forming and the Forming Criteria for AA3003". Mechanical & Materials Engineering, Queen's University, Kingston, ON, Canada.

[12] J. Kopac, Z. Kampus. Y. 2005. "Incremental sheet metal forming on CNC milling machine-tool". Journal of Materials Processing Technology 162–163 (2005) 622–628. University of Ljubljana, Faculty of Mechanical Engineering, Aˇskerˇceva 6, 1000 Ljubljana, Slovenia.

[13] D. S. Malwada, Dr. V. M. Nandedkarb. Y. 2014. "Deformation Mechanism Analysis of Single Point Incremental Sheet Metal Forming". 3rd International Conference on Materials Processing and Characterization (ICMPC 2014).

[14] G. Ambrogioa, L. Filice , F. Micari. Y 2006. "A force measuring based strategy for failure prevention in incremental forming". Department of Mechanical Engineering, University of Calabria, 87036 Rende, CS, Italy. Journal of Materials Processing Technology 177 (2006) 413–416.

[15] F. Capece Minutolo, M. Durante, A. Formisano, A. Langella. Y 2007. "Evaluation of the maximum slope angle of simple geometries carried out by incremental forming process". Department of Materials and Production Engineering, University of Naples "Federico II", Piazzale Tecchio 80, 80125 Naples, Italy.

[16] Kathryn Jackson∗ , Julian Allwood. Y 2008. "The mechanics of incremental sheet forming". Department of Engineering, University of Cambridge, 16 Mill Lane, Cambridge CB2 1RX, UK.

[17] G. Hussain, L. Gao, N. Hayat, Xu. Zirana. Y 2008. "A new formability indicator in single point incremental forming". College of Mechanical & Electrical Engineering, Nanjing University of Aeronautics & Astronautics, PR China.

[18] G. Ambrogioa, I. Costantino , L. De Napoli, L. Filice, L. Fratini b, M. Muzzupappa. Y 2004. "Influence of some relevant process parameters on the dimensional accuracy in incremental forming: a numerical and experimental investigation". Department of Technology, Mechanical Production and Management Engineering, University of Palermo, Italy. Journal of Materials Processing Technology 153–154 (2004) 501–507.

[19] S. Dejardina, S. Thibaud, J.C. Gelin, G. Michel. Y 2009. "Experimental investigations and numerical analysis for improving knowledge of incremental sheet forming process for sheet metal parts". ENSMM – National Engineering Institute in Mechanics and Micro-technologies, 26 rue de l'Epitaphe, 25000 Besanc¸ on, France.

[20] Rahul Jagtap, Sachin Kashid, Shaiendra Kumar & H. M. A. Hussein. Y. 2016. "An experimental study on the influence of tool path, tool diameter and pitch in single point incremental forming (SPIF)." Advances in Materials and Processing Technologies. Department of Mechanical Engineering, S.V. National Institute of Technology, Surat, India; Advanced Manufacturing Institute, King Saud University, Riyadh, KSA; Faculty of Engineering, Mechanical Engineering Department, Helwan University, Cairo, Egypt.

[21] D Young and J Jeswiet. Y. 2004. "Wall thickness variations in single-point incremental forming", Proc. Instn Mech. Engg. Vol. 218 Part B: J. Engineering Manufacture. Department of Mechanical Engineering, Queen's University, Kingston, Ontario.

[22] Luigino Filice & Giusy Ambrogio &Manlio Gaudioso. Y. 2011. "Optimised tool-path design to reduce thinning in incremental sheet forming process", Springer-Verlag France 2011.Department of Mechanical Engineering, University of Calabria, Cosenza.

[23] Mingshun Yang, Zimeng Yao, YanLi, Pengyang Li, Fengkui Cui, and Lang Bai. Y. 2018. "Study on Thickness Thinning Ratio of the Forming Parts in Single Point Incremental Forming Process". Faculty of Mechanical and Precision Instrument Engineering, Xi'an University of Technology, Xi'an 710048, China, Zimeng Yao.