RESEARCH AND PROGRESS IN SINGLE POINT INCREMENTAL FORMING

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***Abstract*— *Incremental sheet forming (ISF) is an up-coming metal-forming technology in which the tool movement is controlled numerically. The process is cost-effective to form complex parts in small to medium batch and provides a short and economical method of forming products having a comparatively simple but interesting shape. In this article, a review of the present state-of-the-art technologies and the potential applications of incremental sheet metal forming are presented in short. This article seeks to address the approaches and methods that are usually applied. Furthermore, the article also seeks to point researchers for future work, by identifying inadequacies of the current approaches and potential for valuable contributions in the field of incremental Sheet forming Processes.*

Keywords*— *Single-Point Incremental Forming; Rapid Prototyping; Incremental Sheet Forming

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1. INTRODUCTION

In sheet metal forming manufacturing, the mass production of different parts is usually done by using accurate but expensive punches and dies. In mass production, because of the large quantities of the produced parts, the cost per part becomes significantly small, which makes these processes economically feasible for sheet metal forming industry. However, when small batch sizes or prototypes are required, the cost per part increases drastically. This increased cost makes the conventional methods based on dies and punches not feasible anymore. Therefore, it is necessary to develop and implement new developing techniques to satisfy the requirements imposed by the small batch production industries[1]. Incremental sheet forming (ISF), which originates from hybridization of stretch forming and conventional spinning processes[2], can be considered as a plastic forming process which meets the requirements of individual part or small-batch production, enabling the manufacturing of the desired shape through an incremental localized deformation[3].

In ISF process, the forming of a sheet metal is performed with the arrangements of a CNC controlled hemispherical head tool, which plastically deforms the blank according to a predefined path. The tool path generated with computer aided manufacturing (CAM) software, makes it possible to obtain difficult geometries using a simply formed tool, [4, 5]. In addition to eliminating a need for complicated forming tools, ISF results in an increased forming limit compared to imperative process [4]. Due to its unique advantages such as flexibility, cost usefulness as well as reduced time-to market and increased forming limit, ISF has gained a large attention from academic world and manufacturing as an important research area. According to Jackson et al.[4], and Jeswiet et al.[5], the first industrial appearance of ISF which is also called “dieless forming”, dates back to 1960s in the USA. This process has been patented by Roux6 and Leszak7, while academic research covering behind industrial application began in the early 1990s in Japan.

Today, there are new processes whereby sheet metal is plastically deformed at a local point enabling truly flexible production of complex sheet metal parts. This can be done in either small batch lots with short lead times, or in production of usable rapid prototypes within one day. The new processes are attractive because manufacturing sheet metal can be accomplished by any facility having a three-axis CNC mill. Inspiration for the emerging processes is usually found in traditional forming methods. These conventional processes are typically constrained as far as achievable part geometry is concerned and require dedicated tooling and dies. CNC hardware and software have reached a mature state of development enabling the development of new sheet metal forming processes. The new forming methods give the possibility to create flexible forming facilities, without dies, capable of producing complex shaped surfaces, while applying generic tooling. The ultimate goal is ‘dieless forming’.

This paper comprises a review of literature on single point incremental forming, specifically to present the process parameters that influence the formability of the material during forming. Organizing the results of this investigation will assist in creating straightforward parameter guidelines and instructions useful for future research and manufacturing real components with SPIF.

2. SINGLE POINT INCREMENTAL FORMING

Single point incremental forming (SPIF) is a new sheet metal forming process with a high potential economic payoff for rapid prototyping applications and for small quantity production. Fig. 1 presents the basic components of the process; (i) the sheet metal blank, (ii) the blankholder, (iii) the backing plate and (iv) the rotating single point forming tool. The blankholder is utilized for clamping and holding the sheet in position during SPIF. The backing plate supports the sheet and its opening defines the working area of the single point forming tool. The tool is utilized to progressively shape the sheet into a component and its path is generated by a CNC machining centre. During the forming process there is no backup die supporting the back surface of the sheet.

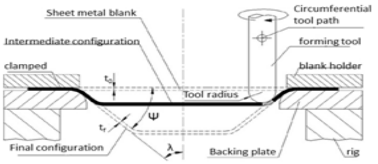


Figure 1 Schematic Diagram of SPIF. (P.A.F. Martins et. al[6])

3. LITERATURE REVIEW

Erika Salem et.ac.[7]worked on investigating the influence of the tool strain path on formability , local thinning of AA7075-O sheets in single point incremental forming. Through numerical models and experiments, the influence of the tool path on the cumulative strain along the wall of the formed sheet was established with consequences on dimensional accuracy. a grid composed of 2 mm diameter circles with center marks was electrochemically etched onto the back side of the sheet. ABAQUS dynamic explicit scheme was used with a mass scaling factor 107 to calculate the evolution of the stress and strain in the metal sheet during forming along the wall of the formed part. Dynamic explicit scheme was used in order to improve the convergence of the problem. Five models were simulated in order to obtain truncated cones with 20 mm, 30 mm, 35 mm, 45 mm and 55 mm depth. For 55 mm depth, the total computation time of the simulation was 636 seconds using a standard time increment in ABAQUS. Modeling the evolution of the thickness reduction indicates that the majority of the thinning occurs under the tool.

Subramanian Chezhian Babu[8] investigation, stainless steel AISI 304 sheets (size 240×240×0.6 mm) were incrementally formed using a hemispherical tool of SiC tool with dimensions 6 mm diameter and 100mm length under varying step depths, spindle speeds and horizontal feeds. The limit of formability and thickness distribution of the formed sheet were characterized. The microstructure of the formed specimens was studied using an optical microscope. For a constant step depth both feed and speed influence the formability and thinning limit of the formed component. A maximum reduction in sheet thickness is around 50%. The highest forming limit was achieved for a sheet thickness of 0.6 mm at a feed of 1600 mm/min and at a speed of 1000 RPM.

Sa'id Golabi [9] studied, finite element technique experimentally , was employed for developing applicable curves for determining the depth of frustums made from 304 stainless steel (SS304) sheet with various cone angles, thicknesses from 0.3 to 1 mm and major diameters from 50 to 200 mm using incremental forming. The simulation process was planned using ABAQUS finite element software. Both explicit and implicit method can be used for solution, however; implicit solution has shown better conformance with experimental results. On the other hand, much more solution time is required even for forming a simple shape and short tool path in implicit mode. Explicit solution needs less analysis time; and since it produces acceptable results and for generation of the applicable curves hundreds of solutions were required. Feed rate did not have considerable effect on deformability of blank; increasing tool diameter increases the depth of the formed frustum. Increasing vertical pitch will not only reduce the depth but will also worsen the surface finish of the part.

KurraSuresh [10] presented some of the experimental studies in multi stage incremental forming of steel sheets to get steep wall angles. Feed rate was fixed at 1500 mm/min and the spindle speed at 300 rpm. EDD quality steel sheets of 250 mm X 250 mm and 1-1.5 mm thick were used as the blank material and High Speed Steel with 8mm, 10mm, 14mm diameter hemispherical headed tools were used. The effect of process parameters in forming cylindrical, square and spherical cups in MSIF process also discussed. For the formation of square cups, corners had to be avoided. Fracture occurred at the corners due to the springback effect, which makes it necessary for the tool to deform larger amount of material in the subsequent stages. A radius of 180% of the tool diameter when applied to the geometry gave successful results.

M. Skjoedt [11] presented new version of single point incremental forming (SPIF) by using a dummy plate on top of the plate which was to be formed into a geometry. The use of dummy plates offers a lot of new variables for improving the process. The three most obvious variables for the dummy plate are thickness, material and position (top or bottom). It has been shown that wear can be removed and that bulging of planar sides is reduced. Further work needs to be done to look into the influence from thickness and different material combinations. It is believed that the right combinations will also allow for improving formability with the dummy as the bottom plate.

B. NAVYA SRI [12] determined the formability of 304 stainless steel alloy to fabricate elliptical cups using single point incremental forming (SPIF) process. The FEA has been complete to model the single point incremental forming process by ABAQUS-CAE software code. The process variables of SPIF were sheet thickness, step depth, tool radius and coefficient of friction. The process parameters have been optimized using Taguchi techniques. The main process parameters affecting the SPIF of elliptical cups were sheet thickness, step depth and tool diameter. Optimal process variables were sheet thickness of 1.0 mm, step depth of 0.5 mm, tool radius of 5.0 mm and coefficient of friction of 0.20

Y.H. Kim [13] worked with, the outcome of process parameters - tool diameter, tool type, feed, friction at the interface between tool and sheet on the formability was investigate through experimentation and FEM analyses. Two types of tools, such as ball tool and hemispherical head tool, were tested with and without lubrication. The ball attached to the end of the ball tool rotates freely. The result of the test is as follows. When the ball tool was used, the value of (Ɛmajor + Ɛminor) was 0.72 with lubrication and 0.73 without lubrication. On the other hand, when the hemispherical head tool was used, the value was 0.67 with lubrication and 0.69 without lubrication. Therefore, using the ball tool without lubrication is the majority best combination of increased formability. The formability increases as the feed rate decreases. With the configurations of the sheet used in the experiment, the best formability was obtained with the 10 mm tool. The ball tools are more effective than the semispherical head tool in terms of formability.

Oscar Martínez-Romero [14] focused on studying the dynamics interaction between the tool, the experimental set up and the sheet blank throughout the forming process. To quantify these effects, they have dynamically characterized the process response behavior and used finite element simulations to identify the resonance vibrational frequencies as well as the magnitude of the maximum stresses. They observed from the computer simulations that the experimental set up remains fixed when the deformed part oscillates close to the modal frequency value of 4.88 kHz. The experimental set up is rigid enough to avoid vibrations that could produce geometrical inaccuracies in the final part.

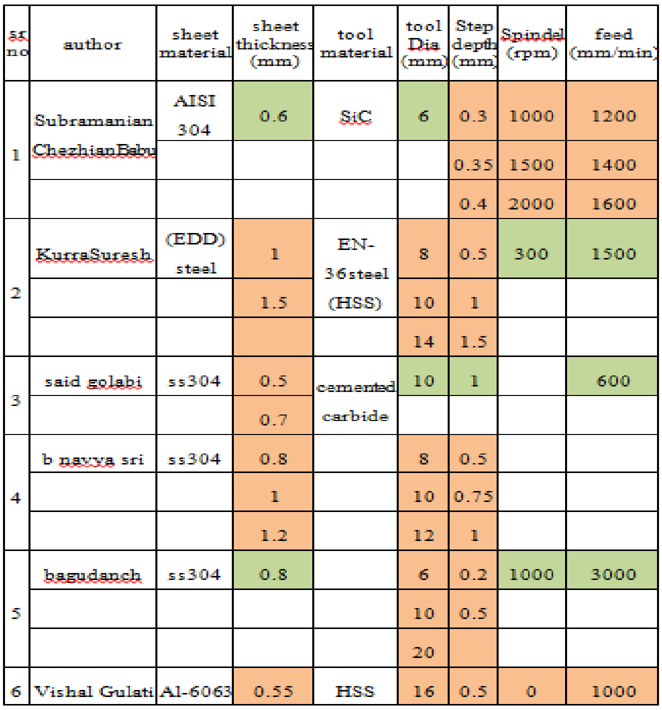
Fahrettin Ozturk [15] In his study, grid marking and measurement methods were discussed in detail and evaluated in terms of measurement accuracy. Methods for marking line patterns on sheet specimens are screen printing, also referred to as serigraph or silk-screen printing, electrochemical etching, photochemical etching, and laser etching. All of these have particular advantages and disadvantages. The useful grid pattern with a chosen process must not influence the forming process and must also be able to oppose the effects of forming process conditions, such as friction or lubricants. Moreover, it should be possible to apply the marking with as little effort as possible. These methods vary from each other in terms of a pattern's accuracy, resolution and contrast, durability, quality and cost.

This chapter provides a comprehensive review on different aspects in incremental forming process. The literature study demonstrated that the process is very economical for sheet metal prototyping and low volume production due to its flexibility, simple tooling, die less nature and enhanced formability.

4. SUMMARY

Author	Work	Finding
Erika Salem (2016)	investigating the influence of the tool strain path on formability and localized thinning of AA7075-O sheets	grid composed of 2 mm diameter circles with center marks. ABAQUS dynamic explicit scheme was used.
Subramanian Chezhian Babu (2015)	Investigation on stainless steel AISI 304 sheets (size 240×240×0.6 mm) were incrementally formed using a hemispherical tool of SiC	The highest forming limit was achieved for a sheet thickness of 0.6 mm at a feed of 1600 mm/min and at a speed of 1000 RPM.
Sa'id Golabi (2014)	frustums made from SS304 sheet with various cone angles, thicknesses from 0.3 to 1 mm and major diameters from 50 to 200 mm	Explicit solution needs less analysis time; and since it produces acceptable results and for generation of the applicable curves hundreds of solutions were required.
KurraSuresh (2016)	EDD quality steel sheets of 1-1.5 mm thick and HSS with 8mm, 10mm, 14mm diameter hemispherical headed tools were used.	Fracture occurred at the corners due to the springback effect, which makes it necessary for the tool to deform larger amount of material in the subsequent stages.
M. Skjoedt (2007)	new version of SPIF by using a dummy plate on top of the plate which was to be formed into a geometry	Wear can be removed and that bulging of planar sides is reduced.
B. NAVYA SRI (2016)	Determined the formability of SS 304 alloy to fabricate elliptical cups using SPIF process. The FEA has been carried out to model the SPIF process using ABAQUS.	optimal process variables were sheet thickness of 1.0 mm, step depth of 0.5 mm, tool radius of 5.0 mm and coefficient of friction of 0.20
Y.H. Kim (2002)	the effect of process parameters—tool type, tool size, feed rate, friction at the interface between tool and sheet on the formability was investigated by experiments and FEM analyses	The ball tool is more effective than the hemispherical head tool in terms of formability. The best formability was obtained with the 10 mm tool.
Oscar Martínez-Romero (2014)	The dynamics interaction among the tool, the experimental set up and the sheet blank during the forming process.	The experimental set up is rigid enough to avoid vibrations that could produce geometrical inaccuracies in the final part.
Fahrettin Ozturk (2009)	grid marking and measurement methods were discussed in detail and evaluated in terms of measurement accuracy.	silk-screen printing

Summary of input parameters used by different authors in their experimentation and FEM analysis are shown in table1.



sr no	author	sheet material	sheet thickness (mm)	tool material	tool Dia (mm)	Step depth (mm)	Spindel (rpm)	feed (mm/min)
1	Subramanian ChezhianBabu	AISI 304	0.6	SiC	6	0.3	1000	1200
						0.35	1500	1400
						0.4	2000	1600
2	KurraSuresh	(EDD) steel	1	EN-36steel (HSS)	8	0.5	300	1500
			1.5		10	1		
					14	1.5		
3	said golabi	ss304	0.5	cemented carbide	10	1		600
			0.7					
4	b navya sri	ss304	0.8		8	0.5		
			1		10	0.75		
			1.2		12	1		
5	bagudanch	ss304	0.8		6	0.2	1000	3000
					10	0.5		
					20			
6	Vishal Gulati	Al-6063	0.55	HSS	16	0.5	0	1000

5. CONCLUSION

It is necessary to generate industry interest leading to more challenging applications, which can in turn improve the understanding of the process, drive a trend towards automation and enhance process outcomes.

6. FUTURE SCOPE

In light of extensive research on ISF processes, there are a number of research questions still to be answered; thus, future work is needed in the following areas:

1. It is desirable to extend this work to study effect of variation in other parameters like tool rotation speed, feed rate, different geometry, step depth,.
2. All these parameters can be studied for another material like steel, copper, PVC.
3. Another variation that can be made is variation in sheet thickness
4. There is a considerable scope of looking into using different types of heat treatment to reduce the residual stresses and obtain a part with a lesser degree of spring back

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