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Parametric Optimization of SPIF Process Using Taguchi Method

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ABSTRACT

The conventional sheet metal forming process need part dependent tooling, which costs in terms of time and money. Due to these factors along with increasing variants, variety in the sheet metal fabrication, highly flexible forming processes are being developed. The incremental sheet forming is one of the emerging flexible forming technologies in the sheet metal engineering, which rather uses universal tooling that is mostly part dependent .Hence the process offer higher flexibility reducing the product development greatly and making it suitable for low volume production. The present work focused on the optimization of the process parameters of the single point incremental forming (SPIF) process on vertical milling machine using Taguchi approach. The main aim of the optimization is to obtain the appropriate surface roughness values in the forming process. Subsequently the mathematical model developed using regression analysis to predict the values of the surface roughness for different products and different values of the predictors.

Keywords: SPIF, Taguchi, Milling Machine, Surface Roughness

I. INTRODUCTION

ISF and spinning are closely related. Both are Incremental Sheet Forming processes with aspects in common, but there are some fundamental differences. As a general rule, in spinning a work piece is clamped onto a rotating mandrel while the spinning tools approach the work piece and deform it into the required shape. In conventional spinning the blank edge is moving inwards, and the material thickness is kept more or less constant. In shear spinning the blank edge is not moving inwards and the sheet thickness are reduced considerably .As in flow forming, the final wall thickness is determined by the distance between the tool and the mandrel. Basically, the mould determines the final shape. Unlike the standard metal forming process, fast production changes are possible to the very simple IF machine configuration. Even if the time required for making one product is much longer than in the traditional press forming, the IF advantages are gained on tool design and production in prototyping phase. IF could be also successfully applied in completion flexible work cells, for example after hydro forming operations for slots or small parts finishing. Furthermore, instead of using general purpose CNC machines, the modern incremental sheet processes can be directly performed on robotised cells. This will enhance the advantages in flexibility and production time reduction since a robotised cell equipped with the proper tools can produce the part and, on the same fixture, realise the completion operations such as flanging, trimming and so on. To form the sheet into the desired shape, mounted on the machine spindle or on a robot gripper, is moved according to the given tool path. Several IF strategies have been developed which mainly differ for equipment and forming procedure. Sheet metals are manufactured by the rolling processes. Sheet metals have various applications starting from a simple sheet metal tray to complicated parts used in aircraft, automotive, construction. The other applications are house hold appliances, food and beverage containers, boilers, kitchen equipment, office equipment etc. A flat sheet metal is formed into complicated shapes by using the die and punch. The sheet metals are ductile in nature. They can be formed only to a certain limit. Beyond this limit failures like necking and fracture occur. The strain at the failure is called forming limit strain. It is a measure of formability of sheet metals. The conventional sheet metal forming uses the punch and die. It results in less limiting strain. It involves various problems like friction between die and sheet metal, difficulty in lubrication, high severity of forming. This is due to complicate shapes of the component produced. Moreover, the cost of the die and punch is also high. The press forming processes for sheet metal forming is limited due to the formation of necking, fracture, wrinkling or earing. The strain values are measured at the onset of these failures under tension-tension region, tension compression region and plane strain regions.

Literature Review

Nimbalkar D.H. et al [1] demonstrated Incremental sheet forming its great potential to form complex three Dimensional parts without using a component specific tooling. The die-less nature in incremental forming provides competitive alternative for economically and effectively fabricating low volume functional sheet products. The process locally deforms sheet metal using a moving tool head achieving higher forming limit than that conventional sheet metal stamping process. Incremental sheet metal forming has the potential to revolutionize sheet metal forming, making it accessible to all level of manufacturing. This paper describes the current state of the art of Incremental sheet metal forming.

J. Leona, et al. [2] classified within the field of sheet metal forming processes, more specifically in the asymmetric incremental deformation process. Some studies have been carried out on the influence of different parameters in the process. However, there are few publications that evaluate the influence of these parameters using design of experiments by finite element modelling. This work provided a better understanding of the process, which will enable an optimization of the ISF process and its comparison with other metal forming processes. Furthermore, this study will be the basis for determining the development of the equipment necessary to carry it out. Bagudancha, et al. [3] estimated that incremental sheet forming force is required in order to design dedicated equipment, utilize adapted machinery or develop online process control strategies. In the present work, forces on Single Point Incremental Forming (SPIF) of variable wall angle geometry were studied under different bending conditions. The effect of several process parameters was analyzed. The results demonstrated that the maximum forming force increases with the tool diameter and the step down while for higher spindle speeds the forming force decreases. The last effect is due to the higher friction between the tool and the blank when using a fixed spindle speed, which causes an increase of the forming temperature. The forming force evolution, which varies with the bending conditions, could be used as an indicator to prevent the sheet failure.

J. Lupianez, et al [4] studied the influence of the variation of several process parameters in Single Point Incremental Sheet forming has been carried out. Thus, a campaign of experiments with its corresponding statistical analysis has been done. The calculation of CO_2 emissions for the ISF-formed part, under the Spanish framework, has been also carried out. Spindle speed variation is the most significant parameter, followed by the material and incremental step. From results, an improvement of the combination of process parameters in order to minimize energy consumption will be possible. Massimo Callegari, et al.[5] studied the The standard metal forming process, fast production changes are possible thanks to the very simple IF machine configuration. Even if the time required for making one product is much longer than in the traditional press forming, the IF advantages are gained on tool design and production in prototyping phase. IF could be also successfully applied in completion flexible work cells, for example after hydro forming operations for slots or small parts finishing. Furthermore, instead of using general purpose CNC machines, the modern incremental sheet processes can be directly performed on robotised cells. C. Pandivelan et al. [6] suggested Single Point Incremental Forming (SPIF), a state of art technique, was carried out on Aluminum AA 6061 alloy sheets and its forming limit was determined experimentally. The straight groove and cupping tests were carried using ball ended tool in CNC vertical milling machine. In order to investigate the effects step depth and depth of grove on formability, the straight groove and cupping tests were conducted. Straight groves were performed along the rolling and transverse directions. The sum of major strain and minor strain as a measure of formability was measured. The forming limit diagrams (FLD) for straight groove and cupping tests were plotted. Moreover the effect of anisotropy of SPIF in rolling and transverse directions was confirmed through the straight groove test. It is also found that the formability decreases as the step depth increases during the SPIF.

II. METHODS AND MATERIAL

A Scientific approach to plan the experiments is a necessary for efficient conduct of experiments. By the statistical design of experiments the process of planning the experiment is carried out, so that appropriate data will be collected and analyses by statistical methods resulting in valid and objective conclusion. Using Minitab Design of experiments was designed and S/N ratio's for the concerned experiments was calculated.

TABLE I

ANALYSIS OF S/N RATIO

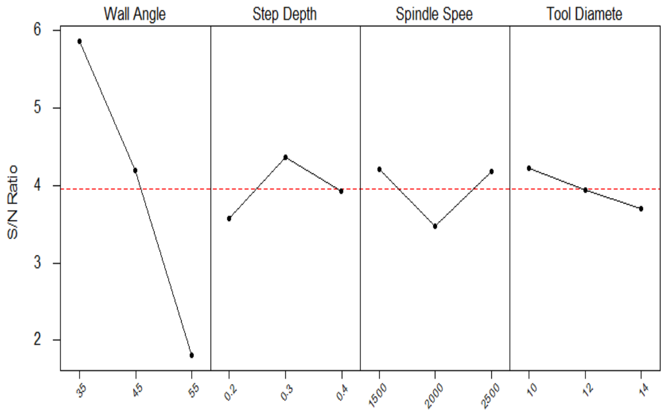
Sr. No.	Wall Angle	Step size	Spindle Speed	Tool Diameter
1	35	0.2	1500	10
2	35	0.3	2000	12
3	35	0.4	2500	14
4	45	0.2	2000	14
5	45	0.3	2500	10
6	45	0.4	1500	12
7	55	0.2	2500	12
8	55	0.3	1500	14
9	55	0.4	2000	10

Analysis of Variance is a statistically based objective decision making tool for detecting any difference in average performance of groups of items tested. The decision rather than pure judgments, take variation in to account. The experimental design and subsequent analysis like ANOVA are intrinsically tied to each other. Analysis of Variance breaks total variation down into accountable source and total variations is decomposed into its appropriate components.

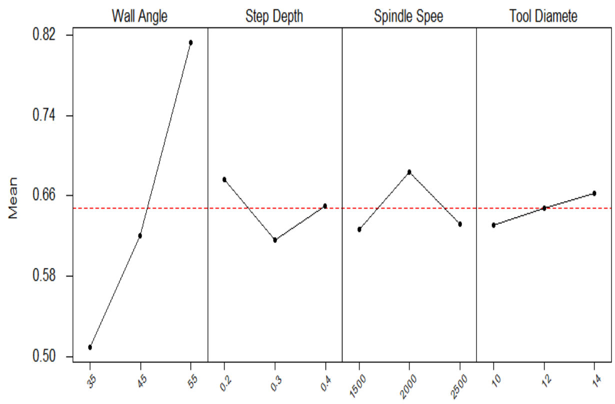
TABLE III

ANALYSIS OF S/N RATIO

Sr. No.	Wall Angle	Step size	Spindle Speed	Tool Diameter	Surface Roughness	S/N Ratio
1	35	0.2	1500	10	0.501	6.00325
2	35	0.3	2000	12	0.515	5.76386
3	35	0.4	2500	14	0.512	5.81460
4	45	0.2	2000	14	0.701	3.08564
5	45	0.3	2500	10	0.556	5.09850
6	45	0.4	1500	12	0.602	4.40807
7	55	0.2	2500	12	0.827	1.64989
8	55	0.3	1500	14	0.775	2.21397
9	55	0.4	2000	10	0.835	1.56627



Graph 1. Main Effects Plot for S/N Ratio



Graph 2. Main effects plot for Means

TABLE IIIII

RESPONSE TABLE FOR MEANS

Level	Wall Angle	Step Depth	Spindle Speed	Tool Diameter
1	0.509333	0.67633	0.62600	0.63066
2	0.619667	0.61533	0.68360	0.64800
3	0.812333	0.64966	0.63166	0.66266

Delta	0.303000	0.06100	0.05766	0.03200
Rank	1	2	3	4

Table III Shows Wall angle proves to be most significant for surface roughness followed by step depth, spindle speed, tool diameter.

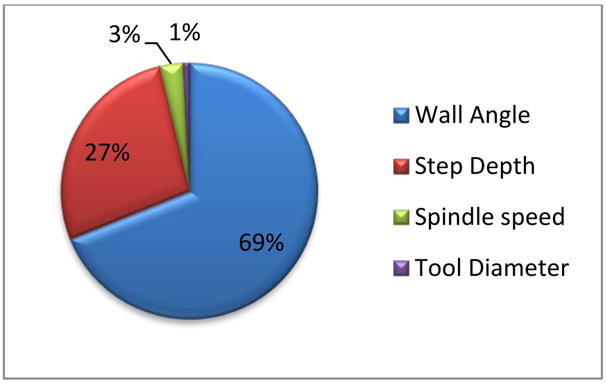
TABLE IVV

ANALYSIS OF VARIANCE

Source	DF	SS	MS	F	P	% Contribution
Wall Angle	2	0.14110	0.0705	32.04	0.001	68.93
Step Depth	2	0.0056	0.0028	0.11	0.003	27.35
Spindle Speed	2	0.0061	0.0030	0.12	0.008	2.97
Tool Diameter	2	0.0015	0.0008	0.03	0.097	0.7327
Error	8	0.4630	0.0772			
Total	16	0.2092	0.0771			

III. RESULT AND DISCUSSION

In order to statistically analyze the result, ANOVA was performed. Process variables having p-value<0.05 are considered significant terms for the requisite response characteristics. The insignificant parameters were having p value larger than 0.05. The percentage contribution is calculated as below.



Graph 3. Percentage Contribution

Wall angle contributes 69%, step depth 27% which are the most significant and contributing parameters in the process. The Spindle speed and tool diameter are relatively insignificant parameters in the forming process with their contribution of 3% and 1% respectively.

IV. CONCLUSION

Percentage contribution to the total sum of square can be used to evaluate the importance of a change in the process parameter on these quality characteristics. From graph 3 it is clear that among three process parameters wall angle has the highest contribution followed by step depth, spindle speed, tool diameter. So, wall angle is most influencing factor on surface roughness.

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