EXPERIMENTAL INVESTIGATION OF MATERIAL BEHAVIOUR IN SINGLE POINT INCREMENTAL FORMING USING STATIC TOOL CONDITION FOR ALUMINIUM ALLOY

Dr. SARAT KUMAR MISHRA
Professor, Dept. of Mechanical Engineering, Aryan Institute of Engineering & Technology, Bhubaneswar
PRASANTA MALLICK
Department of Mechanical Engineering,Raajdhani Engineering college,Bhubaneswar, Odisha
Dr. SINGULURI SRINIVASAN
Department of Mechanical Engineering, NM Institute of Engineering and Technology,Bhubaneswar , Odisha

Abstract - The present work focuses on investigating the influence of step size, tool diameter, and spindle speed on aluminium sheets. In SPIF, forming tool is generally programmed to move along a CNC controlled definite path to form a predetermined shape by local deformation layer by layer. Forming force produces stresses and strain in the sheet depending upon part shape which further determines structural integrity of the final component. Experimentation is performed based on full factorial method. In this experimentation, thickness variation in different rolling directions and micro-hardness are taken as output responses and the effect of various process parameters like tool diameter, step depth and feed rate are studied on these responses. Analysis of variance is carried out to find out the significance of the input process parameters and its percentage contribution. It is concluded that tool diameter and step depth are the most significant process parameters for the output responses.

Keywords - Single Point Incremental Forming, Micro-Hardness, Thickness, ANOVA.

I. INTRODUCTION

New sheet metal fabrication techniques have advanced to the point that they can be used to make customize parts or small batches of small batch production with short turnaround times from concept to completion. SPIF (single point incremental forming) is a unique and innovative method for rapid prototyping and small-batch sheet part production. SPIF is a die less technique that may produce parts with symmetrical and non-symmetrical geometries and a wide variety of thicknesses without the use of costly dies. It enables the production of complex sheet metal components at a reasonable cost. SPIF has numerous applications in the medical, aerospace, and automotive industries.

Erika et al. [1] focused on the impact of the tool strain path on AA7075-O sheet formability and localized thinning in single point incremental forming. They came to a conclusion that thickness fluctuation along the truncated cone's wall comprises three separate regions: bending, thinning, and steady state. D.S Malwad et al. [2] experiments were conducted with varied forming angles to analyze the deformation mechanism of commercial aluminum alloy and demonstrated thickness reduction as a function of wall angles. They came to the conclusion that, for wall angles less than 75 degrees, more formability and forming depth can be reached. As the incremental step size lowers, the required forming force lowers, allowing for a larger forming depth and a better surface. In one of papers on SPIF, M. Durante et al. [3] concluded that forming force requirement was reduced when tool was set in any of the direction.

The surface roughness changes slightly but neglected, whether tool is rotating or not as well as its change in direction didn‟t affect the surface roughness. R Lingam et al. [4] studied the anisotropic behaviour of the material with respect to different rolling direction i.e., along rolling, diagonally and in transvers rolling direction that causes large change in thickness variation and in spring-back as comparative to isotropic material during 2018.Meftah Hrairi et al. [5] proposed the variation in the surface roughness and concluded that combination of larger tool size and smaller step depth resulting smooth surface of the formed component whereas, small tool size with larger step depth gives rough surface finish causing surface waviness. Vikas sisodia et al. [6] in 2019 investigated minimum thickness of the formed part with dummy sheet. And it is observed that the variation in wall thickness is small and overall wall thickness distribution along the depth of formed parts is almost uniform. Also, wall thickness distribution obtained is close to the value predicted by sine law. The maximum micro-hardness values are observed in the areas of the higher deformation of the sheet material studied by C. Giardini et al [7] to understand the physical limits of the material when subjected to this deformation process.

II. PROCESS METHODOLOGY

Experimental setup consists of VMC machine (as shown in the below fig.1) having Fanuc controller. The design of the fixture for desired shape as well as tool are prepared in CAD software and then it is fabricated.

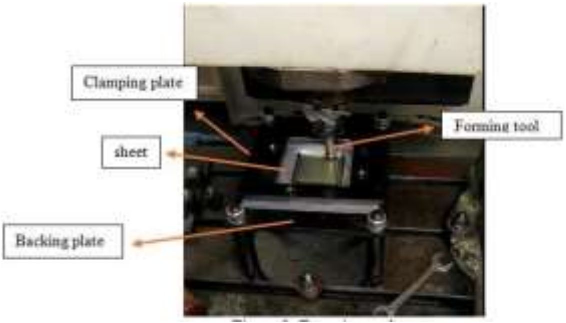

Figure 1: Experimental setup

Aluminium alloy (AA5052) sheet is cut into pieces of required dimensions with drilled holes on it for clamping rigidly onto the fixture. Truncated Square pyramid geometry of 600 and 90x90 mm2 was decided for the experimental work. Tool path for getting desired shape was generated in FUSION 360 Cam software. Afterwards the generated tool path was post process to get G and M codes for Fanuq controller.

For the study, experiments are designed as per Full Factorial design of experiment and total 8 experiments are performed without spindle rotation. The set of parameters with their levels are listed in Table 1. The level of wall angle, step size, tool size and feed rate are selected on the basis of literature review.

Sr no	Parameters	Units	Level1	Level2
1	Tool Diameter	Mm	10	14
2	Step Depth	Mm	0.5	1
3	Feed rate	mm/min	1000	1500

Table 1. Factors and their levels

Figure 2: Formed parts of aluminium alloy as per DOE

Thickness distribution is measured at 11 different locations i.e., 5mm from each other from the start point of the tool to the end point of the tool along the wall depth of the formed parts and also minimum thickness reduction was noted for each formed part. Each formed parts are wire cut in such a way that allowing to measure thickness in longitudinal and diagonal rolling direction. Micro-meter screw gauge is used to measure the thickness at marked locations along the wall length. Micro-Hardness of the formed parts is measured along the wall depth at the same location where thickness of each sample is measured to know the hardness variation as a function of strain hardening with respect to the thickness distribution. Vickers micro-hardness testing machine equipped with software is used for hardness measurement. In order to place, the wire cut samples rigidly on the platform of the tester so the indentation can be achieved properly, cold mounting is done. Dwell time of the indentation for an applied load must be adequate to give little or no error in the D1 and D2 values of the diagonal to obtain accurate reading of Micro-hardness.

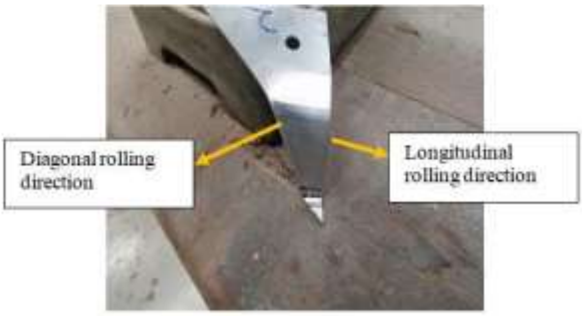

Figure 3: Sample for thickness calculation

Figure 4: Cold mount for micro-hardness test

III. RESULT AND DISCUSSIONS

Thickness distribution in longitudinal and diagonal rolling direction is calculated for each formed part. At the same time hardness of the formed parts is calculated with respect to thickness distribution. Hardness is the function of plastic deformation i.e., strain hardening. Hardness variation is observed as thickness change at different locations. Noted average hardness varies from 67HV to 105HV for the formed parts. Maximum micro-hardness value is observed where maximum thickness reduction is noted.

Exp. No.	Tool diameter (mm)	Step depth (mm)	Feed rate (mm/min)	T_{min} in longitudinal rolling direction (mm)	T_{min} in Diagonal rolling direction(mm)	Max. micro – hardness (HV)
1	14	1	1000	0.631	0.645	104.38
2	10	0.5	1500	0763	0.755	91.5
3	14	1	1500	0.602	0.610	104.93
4	14	0.5	1500	0.681	0.675	99.75
5	10	1	1500	0.728	0.729	97.68
6	10	0.5	1000	0.801	0.810	91.135
7	14	0.5	1000	0.695	0.714	100.695
8	10	1	1000	0.755	0.785	90.815

Table 2. Experimental result considering static tool condition

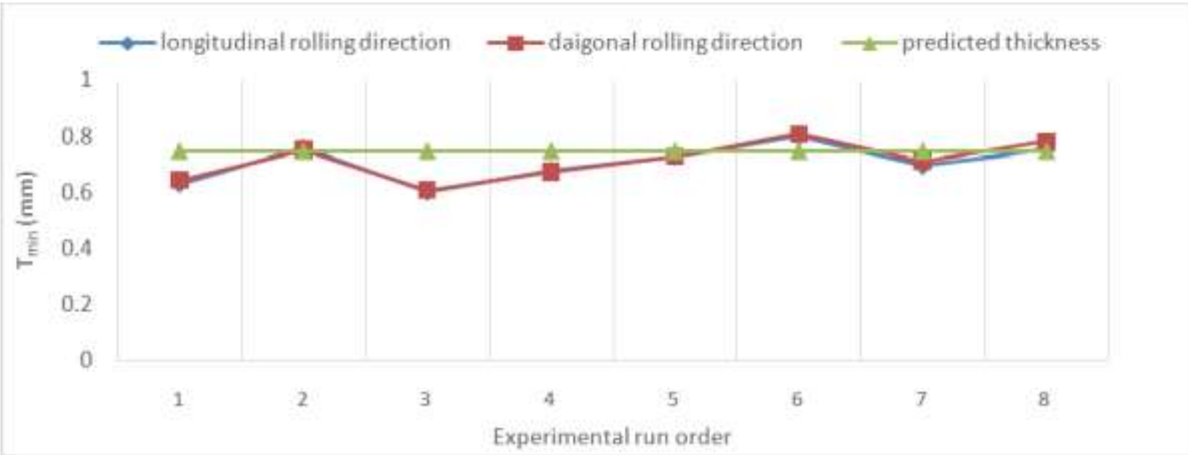

Figure 5: Comparison of wall thickness distribution between predicted thickness and measured minimum wall thickness in different rolling directions.

In SPIF, wall thickness variation is observed contrary to the stated sine law for wall thickness distribution. The occurrence of the thinning band in SPIF mainly due to local necking and stretching which is similar to the necking noted in uniaxial tensile test. Predicted thickness is calculated using sine law and compared with calculated minimum thickness in longitudinal and diagonal rolling direction along the wall of formed parts. There is no significant change observed in minimum thickness distribution along the wall of the formed parts in different rolling directions.

Source	DF	SS	MS	F-value	P-value
Model	3	0.031711	0.010570	67.38	0.001
Linear	3	0.031711	0.010570	67.38	0.001
Tool Diameter	1	0.023980	0.023980	152.86	0.000
Step depth	1	0.006272	0.006272	39.98	0.003
Feed rate	1	0.001458	0.001458	9.29	0.038
Error	4	0.000627	0.000157		
Total	7	0.032338			

Table 3. ANOVA for Minimum Thickness Distribution in Longitudinal Rolling Direction

Analysis of variance (ANOVA) is carried out at 95% confidence level to know the significant process parameters and to their percentage contribution on response. From the ANOVA table it can be observed that tool size has major contribution in thickness reduction followed with step depth in this experimental analysis and feed rate has no significant effect on the response.

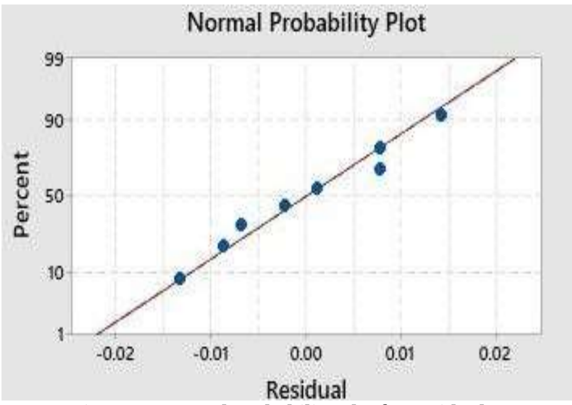

Figure 6: Normal probability plot for residual

The „pred R-squared" of 0.9224 is in good agreement with the „adj R-squared" of 0.966; i.e., the difference is less than 0.5. Figure 6 shows the normal probability plot of residuals and it can be observed that the predicted values by the model are in reasonable agreement with the experimental results.

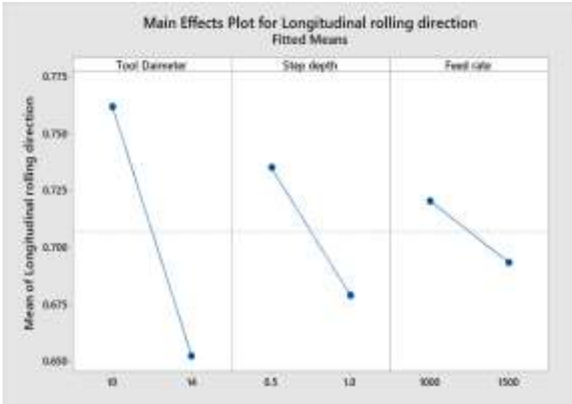

Figure 7: Main Effects Plot for Minimum Thickness in Longitudinal Rolling Direction

The main effect plot for minimum thickness variation shows the effect of each main factors on the output response. It can be observed that Tool diameter has the maximum effect on thickness reduction followed with step depth as the second most contributor whereas feed rate has no significant effect on thickness reduction. It gives the optimum values for all the three factors as Tool diameter = 14 mm, Step Depth = 1 mm and Feed rate = 1500 mm/min.

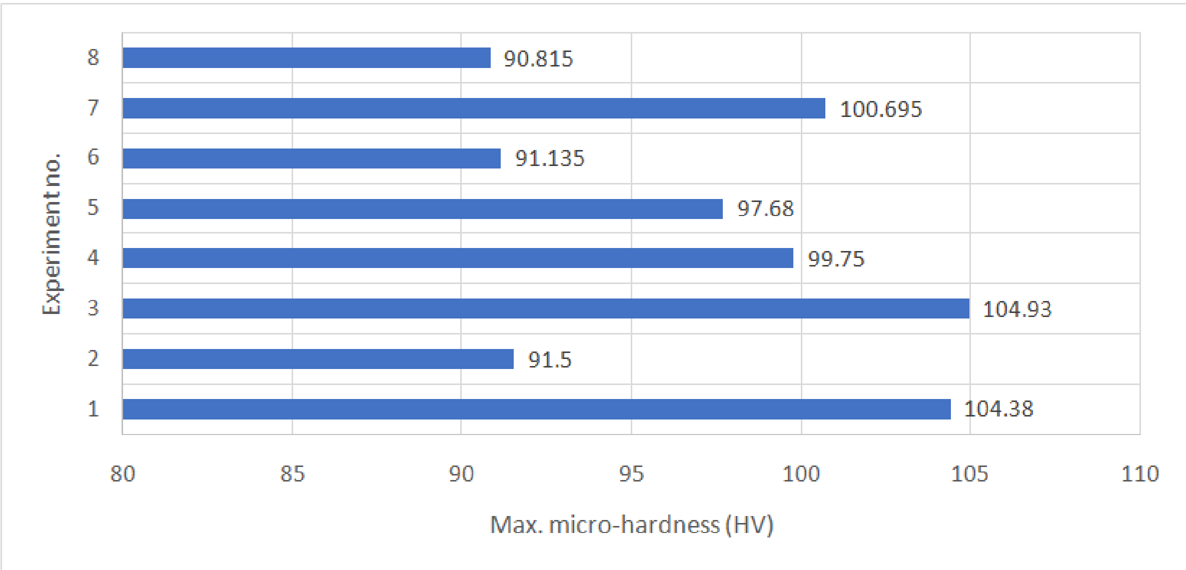

Figure 8: Max. micro-hardness for each formed part

IV. CONCLUSION

The effect of various process parameters in static condition of forming tool on thickness distribution was studied. Tool Diameter and Step Depth are the most influencing parameters for thickness distribution. And, feed rate showed no significant effect on thickness distribution. It is found that wall thickness value reduced continuously and pass through a minimum value i.e., it doesn"t follow sine law of thickness distribution. As Thickness reduction increase hardness increase and reaches to maximum where maximum thickness reduction is observed due to larger plastic deformation and hence large work hardening is observed. For Thickness variation, as Tool diameter increases thickness reduction increases i.e., it shows direct relation between them. Also, Thickness reduction increases as Step Depth increases i.e., it shows direct proportionality between them. However, Feed rate has least significant effect on Thickness reduction. From the graphical representation it can be observed that there is no significant change in thickness reduction along the wall depth of each formed parts in Longitudinal and Diagonal rolling direction. For max. micro-hardness, it is observed that Tool diameter and Step depth are the most significant process parameters whereas Feed rate has no significant effect on micro-hardness of the formed parts. Maximum micro-hardness is noted in case of high-level values of process parameters for tool diameter of 14mm and step depth of 1mm.

REFERENCE

[1] Erika Salem, Jaekwang Shin, Maya Nath, Mihaela Banu, Alan I. Taub, "Investigation of Thickness Variation in Single Point Incremental Forming", 44th Proceedings of the North American Manufacturing Research Institution of SME, vol. 5, pp. 828-837,2016.

[2] D. S. Malwad a, Dr. V. M. Nandedkar, "Deformation mechanism Analysis of Single Point Incremental Sheet Metal Forming", 3rd International Conference on Materials Processing and Characterization, pp. 1501-1510,2014.

[3] M. Durante, A. Formisano, A. Langella, F. Memola Capece Minutolo, "The influence of tool rotation on an incremental forming process", Journal of Materials Processing Technology, pp. 4621-4626,2009.

[4] R Lingam, K G Kalathiya, P Konka, S Shamshoddin and N V Reddy, "Analysis of Anisotropic Effects in Single Point Incremental Forming", IOP Conf. Series: Journal of Physics: Conf. Series, vol. 1063, no. 1,2018.

[5] Salah B. M. Echrif a & Meftah Hrairi, "Significant Parameters for the Surface Roughness in Incremental Forming Process", Materials and Manufacturing Processes, pp. 697-703,2015.

[6] Vikas Sisodia and Shailendra Kumar, "Experimental study of single point incremental forming with dummy sheet", Int. J. Materials Engineering Innovation, vol. 10, No. 1, pp. 60-82,2019.

[7] C. Giardini, E. Ceretti, C. Contri, "Analysis of Material Behaviour in Sheet Incremental Forming Operations", AIP Conference Proceedings, pp. 1016-1021,2004.

[8] Rajiv Malhotra, Liang Xue, Ted Belytschko, Jian Cao, "Mechanics of fracture in single point incremental forming", Journal of Materials Processing Technology, pp. 1573-1590,2012.

[9] Isaac Jiménez, Cecilio López, Oscar Martinez-Romero, Pedro Mares, H. R. Siller, J. Diabb,Jesús A. Sandoval-Robles ,Alex Elías-Zúñiga, "Investigation of residual stress distribution in single point incremental forming of aluminium parts by X-ray diffraction technique" The International Journal of Advanced Manufacturing Technology, vol. 91,no. 5,pp. 2571-2580,2016.

[10] Kishore Jawale, José Ferreira Duarte, Ana Reis and M B Silva, "Lubrication study for Single Point Incremental Forming of Copper", Journal of Physics: Conference Series, vol. 734, no. 3,2016.

[11] P.A.F. Martins, N. Bay, M. Skjoedt, M.B. Silva, "Theory of single point incremental forming"", CIRP Annals, pp. 247-252,2008.

[12] J. Jeswiet, F. Micari, G. Hirt, A. Bramley, J. Duflou, J. Allwood, „"Asymmetric Single Point Incremental Forming of Sheet Metal"", Engineering, vol. 54, no. 2, pp. 88-114, 2005.

[13] S. Amini Najafabady & A. Ghaei, "An experimental study on dimensional accuracy, surface quality, and hardness of Ti-6Al-4 V titanium alloy sheet in hot incremental forming", Int Journal in advance manufacturing Technology, vol. 87, no. 9, pp. 3579-3588,2016.

[14] Angshuman Baruah, C. Pandivelan A.K. Jeevanantham and Subhodeep Das, "Optimisation and formability study of AA5052 through incremental sheet forming", Int. Journal of Computer Aided Engineering and Technology, vol. 9, pp. 124-144,2017.

[15] Mariem Dakhli & Atef Boulila & Pierre-Yves Manach & Zoubeir Tourki, "Optimization of processing parameters and surface roughness of metallic sheets plastically deformed by incremental forming process", The International Journal of Advanced Manufacturing Technology, vol. 102, no. 1, pp. 977-990,2019.

[16] M. Honarpisheh & M. Mohammadi Jobedar & Alinaghian, "Multi-response optimization on single-point incremental forming of hyperbolic shape Al-1050/Cu bimetal using response surface methodology", The International Journal of Advanced Manufacturing Technology, vol. 96,2018.

[17] Bagudancha, G. Centenob, C. Vallellanob, M.L. Garcia-Romeua, "Forming force in Single Point Incremental Forming under different bending conditions", The Manufacturing Engineering Society International Conference, vol.63, pp. 354-360,2013.

[18] Ajay Kumara, Vishal Gulatib, Parveen Kumarc, Hari Singhc, Vinay Singhb,Sanjay Kumard, Abid Haleeme,"Parametric Investigation of Forming Forces in Single Point Incremental Forming", Materials Today: Proceedings(Elsevier), vol. 24,pp. 611-617,2020.

[19] K. Hamilton, J. Jeswiet, "Single point incremental forming at high feed rates and rotational speeds: Surface and structural consequences", CIRP Annals, vol. 59, no. 1, pp. 311-314,2010.

[20] Suresh Kurra, Nasih Hifzur Rahman, Srinivasa Prakash Regalla, Amit Kumar Gupta, "Modelling and optimization of surface roughness in single point incremental forming process", Journal of Materials Research and technology, pp. 304-313,2015.

[21] Zhaobing Liu, Yanle Li, and Paul Anthony Meehan, "Experimental Investigation of Mechanical Properties, Formability and Force Measurement for AA7075-O Aluminium Alloy Sheets Formed by Incremental Forming", International journal of precision engineering and manufacturing, vol. 4, pp. 1891-1899,2013.

[22] Fahrettin Ozturk, Murat Dilmec, Mevlut Turkoz, RemzE. Ece, Huseyin S. Halkaci, "Grid Marking and Measurement Methods for Sheet Metal Formability", 5th International Conference and Exhibition on Design and Production of MACHINES and DIES/MOLDS, pp. 41-49,2009

[23] L. C. C. Cavaler, L. Schaeffer, A. S. Rocha and F. Peruch, "Surface Roughness in The Incremental Forming of aisi 304l Stainless Steel Sheets"", Far East Journal of Mechanical Engineering and Physics, vol. 1.pp. 87-98,2010.

[24] Hardik S Beraval, Jigar R Patel, Haresh P Prajapati, Rakesh S Barot, "Setup Development and Feasibility Check of Single Point Incremental Forming (SPIF) Process on VMC for Al-19000 Alloy"", International Journal of Engineering Trends and Technology (IJETT), vol. 20, pp. 197-199,2015.

[25] Douglas c. Montgomery, "Design and analysis of Experiments", vol. 8 (478-480).