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Experimental Investigation of Single Point Incremental Sheet Metal Forming of Aluminum 6061.

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دراسة تجريبية لتشكيل الألواح المعدنية بنقطة واحدة تدريجيا للألومنيوم 6061

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KEYWORDS:
Single Point incremental Forming;Dieless formingProcess; Process Parameters;Thinning, SurfaceRoughness; Aluminum 6061.

الملخص العربي:- **يتناول هذا البحث دراسةعملية للعوامل المؤثرة على عملية التشكيل بنقطة واحدة تدريجيا وتهدف إلى وصف تأثيرهذه العوامل على تشكيل الواح الألومنيوم 6061. وقدأجريت التجارب العمليةعند مستويات مختلفة من العمق ومعدلات التغذية، وسرعة عمود الدوران،بهدف دراسة تأثير هذه العوامل علي خشونة الاسطح والتخفيض فى السمك. وأظهرت النتائج أن التغيير في العمق له تأثير كبير على خشونة السطح، حيث تزيد خشونة السطح مع زيادة العمق التدريجي،كذلك اظهرت الدراسة أن معدل التغذية كان له تاثير علي خشونة السطح. كما اوضحت الدراسة أنالتخفيض فى السمك يعتمد اعتمادا كبيرا على سرعة عمود الدوران. وقد كشفت النتائج أنألواح الالومنيوم 6061تمددت بشكل كبير مع زيادة معدل التغذية حتي (1000 مم/ دقيقة)، ثم يقل التمدد مع الزيادة في معدل التغذية**

***Abstract*—This paper presents an experimental assessment of the factors affecting the Single Point Incremental Forming (SPIF) process aiming to characterize their influence when forming Al 6061 sheets. The experimental trials were undertaken at different levels of incremental depths, feed rates, and spindle speeds and the process responses were the obtainable surface roughness and thinning. The results showed that the incremental depth has a significant effect on the surface roughness and feed rate found to be the second effective parameter. Also, thinning was highly dependent on the applied spindle speed. However, the results revealed that the stretching of the material prominently increased with the increase of feed rate up to a certain limit (1000 mm/min), then the stretching slightly decreased with the further increase in the feed rate.**

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I. INTRODUCTION

SHEET metal forming operations play an important role in producing varieties of products for a wide range of engineering applications [1]. In sheet-metal operations, parts are processed by forming the material either in cold or hot conditions. In particular, when the workpiece material heated, it has a lower-resistance to deformation and thus many sheet metal parts are formed in hot condition [2]. Examples of sheet metal techniques include spinning, stamping, flow forming, hammering and Incremental Sheet Metal Forming (ISMF) [3].

ISMF is an advanced method of metal forming processes recently emerged using computerized numerical control (CNC) potential. In particular, with the aid of CNC technology complex shapes [4] can be produced directly without using dies, by simply deforming tool with step by step incremental feed [1, 5]. ISMF can be classified according to various points of view such as: the forming method, the part geometry, the forming path, tool path strategy, and the applied tools, etc. [6].

The most common classification is based on the forming method and is divided to single-point, two-point and hybrid processes. Single-point incremental forming (SPIF) can also called negative incremental forming, while Two-point incremental forming (TPIF) is also called positive incremental forming.

Incremental Sheet Forming processes (ISFP) has become a reliable alternative to conventional sheet forming techniques when few products have to be produced. However, using ISFP becomes a necessity in those applications in which the product has to be unique. Due to the need of deformation complex parts plastically, in addition to prevalent application of CNC technique in industry there was a lot of important research to develop it [7].

Hagan and Jeswiet [8] gave an excellent overview of this new process; they suggested spinning as the originating process of incremental sheet forming and emphasized the potential of this technology in rapid prototyping applications.

The main definition for incremental sheet forming was adduced by Jeswiet [9]. According to his interpretation Incremental sheet forming is a forming operation takes place using a tool with a certain shape being constantly in contact with a small deformation zone of the processing sheet without any dedicated die determining the shape of the component [9]. It is worth emphasizing that a wide range of material can be processed that evolves aluminum alloys, brass, titanium alloys and steel [10]. However, the governing process parameters are tool diameter, depth of forming, thickness of sheet [11], rotation speed and feed rate [12]. It should be mentioned as well, that the first machine clearly dedicated for incremental forming was developed from the principles created by Matsubara [13].

II. Related Work

Masuku et al., [14] has introduced the ISF process that used CAD/CAM technology to manufacture sheet metal products without the use of die and punches similar to those in traditional processes. Different process parameters have been identified such as: tool speeds, feed rates, and tool path strategies. The results showed that the trajectory was the most effective factor to be considered for successful implantation of the process. Many researchers have studied the theoretical and practical impact of the ISF parameters. They found that decreasing the incremental depth better surface quality obtained and higher tool rotation speed gives better surface quality and lesser geometrical error [15, 16].

Mugendiran et al., [17] examined the effect of forming parameters (spindle speed, tool feed, and step size) on the generated roughness and sheet thickness. The results showed that the interaction between the forming parameters identified to produce minimum surface roughness and maximum wall thickness. A minimum Ra of 2.45 μm and maximum thickness of 0.753 mm were obtained at a spindle speed of 1931 rpm with feed 654 mm/rev and step size of 0.65 mm.

Desai et al., [18] performed an experimental study of the effect of various process parameters such as feed rate, rotational speed of the tool and incremental depth on die -less rapid prototyping (DLRP). Frustum of cone with 800 cone angle was formed. The material used was aluminum alloy Al1200-H14. The forming tool was having hemispherical end. Effects of these process parameters on feasibility of forming, forming time, geometrical accuracy, and surface quality of formed surfaces were investigated. The others found that the feed rate in the DLRP process played a vital role in achieving higher cone angle. Tool rotation speed had no influence on the forming time in DLRP process. Decreasing the incremental depth improve the quality of surface obtained. Higher tool rotation speed gave better surface quality and lesser geometrical error. For decreasing forming time it was required to increase the feed rate and the incremental depth.

Al-Obaidi and Hamdan [19] studied the effect of factors related to the incremental deformation process such as (feed rate, incremental depth and forming angle) on surface roughness, working time and thickness distribution by using Taguchi method. The result showed that the incremental depth had the main effect and is followed by feed rate and angle respectively on the surface roughness and showed that angle played a significant role in controlling thickness distributions of wall part with percentage contribution of (92.74%). Moreover, the step over and feed rate are non-significant parameters.

Looking at the literature, it can be noted that there have been significant research activities in incremental sheet forming. However, there has been no comprehensive study to investigate the influence of the process parameter on matter such as the obtainable dimensional accuracy, resulting thinning, achievable surface roughness. the aim of this paper is to presents a detailed experimental investigation conducted to examine the effects of feed rate, spindle speed and incremental depth on the resultant surface roughness, and thinning when processing Al6061 sheet of 0.8 mm thickness using ISFP method

Experimental Work

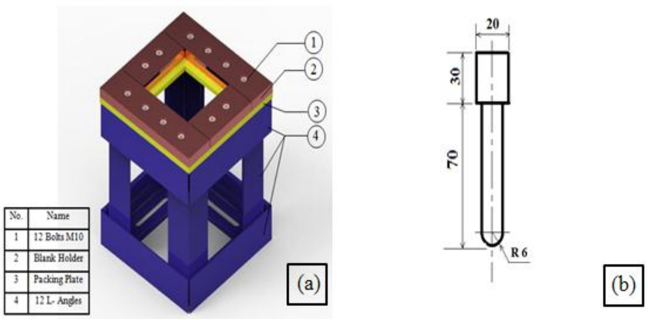
A. *Work piece material*

The material used in the present study is aluminum sheet (6061). The test samples were prepared and cut in dimension of 200 x200 mm.

B. *SPIF Set up*

A fixture was utilized to fix the sheet metal during the forming process, as shown in Fig. 1a. In particular, the fixture design considered the following parameters; shape and size of the deformed sheet, machine limits and complexity of the part to be produced.

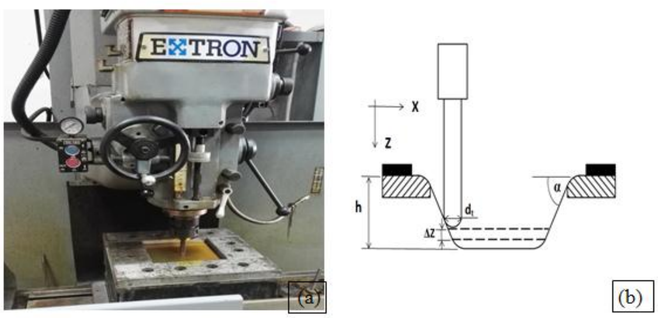
The Forming tool is the part which converts the cutting action in CNC milling machine into the forming process. Forming tool needs a special tolerance and accurate manufacture. A tool steel bar (K100) of high carbon and high chromium 12% contents of 250 mm length and 15mm diameter was machined to the desired length 100 mm and turned to hemispherical shape with 12 mm diameter.as shown in Fig. 1b.



(a) Fixture component (b) Forming tool

Fig. 1. Setup design.

A simple cone shape has been selected to carry out the experimental work. An Extron CNC milling machine was used as shown in Fig. 2a, while Fig. 2b illustrates the forming process to generate the conical shape of the final part.



(a) Extron CNC milling machine & set up (b) CNC forming process criteria

Fig. 2. milling machine.

Single point incremental forming process (SPIF) was performed the experimental investigation to study the process behavior and monitor the effect of process parameters on the process outcomes. In particular, five different feed rates were selected to perform the experiments, the feed rate varied between 700 and 6300 mm/min with a step of 1400 mm/min, and the vertical tool increment was ranged between 0.2 and 1.0 mm with a step of 0.2 mm. Also, four different spindle speeds of500, 1500, 2500 and 3500 rpm were tested. Each deformed part was previously coded by (α, Δz, N), where α is a constant shear angle of 63̊, Δz is the incremental depth, and N represent the tool spin rpm. The performed parts parameters for cone shape are shown in Table 1.

The process performance was characterized using two parameters; the change in thickness and the obtainable surface roughness of the final product. Dial gauge indicator was used to measure the change in thickness with accuracy of 1 μm, which consists of two combination sets, two rulers, dial gauge and two surface plates as shown in fig. 3.

TABLE 1
SPECIMEN DESIGNATIONS

Feed Rate (mm/min)	700,1000, 2100, 3500, 4900, 6300
Incremental Depth (mm)	0.2,0.4,0.6,0.8,1.0
Spindle Speed (rpm)	500,1500,2500,3500
Shear Angle (α^o)	63

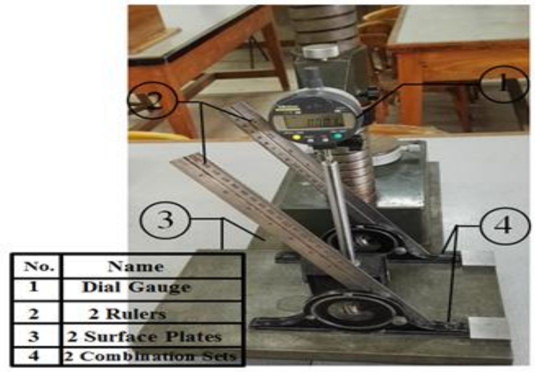


Fig. 3. Dial Gauge Indicator Parts.

The surface quality is an important parameter to evaluate the efficiency of machine tools as well as produced components. Surface Roughness Testers (PCE-RT 1200) was used to measure surface roughness with cut off =0.8 mm with accuracy 0.01 μm. The mean value of the surface roughness for each parameter was calculated for four values.

III. RESULTS AND DISCUSSIONS

The effects of (SPIF) applied parameters; particularly spindle speed (rpm), feed rate (mm/min), and incremental depth (mm) on the obtainable surface roughness and final sheet thickness have been evaluated.

A. *Effect of spindle speed on sheet thinning*

The effect of spindle speed on the sheet thinning was examined at spindle speeds of 500, 1500, 2500, and 3500 rpm and at a constant incremental depth (Δz) of 0.6 mm and a feed rate (Fr) of 1000 mm/min. The thickness was measured at three different heights (h) of the deformed parts, namely at h1 = 10 mm, h2 = 20 mm and h3 of 30 mm. The relationship between spindle speed and thinning is shown in Fig.4. It can be noticed that the maximum thinning was obtained at the minimum applied spindle speed. However, as the spindle speed increased the thinning decreased. Given that the thinning was occurred due to the deformation of the material by stretching mechanism, it is not surprising that the minimum thinning was found at the maximum height, where the material was subject to the minimum stress. However, the maximum thinning was achieved at the minimum height of 10 mm, where higher stress was applied and for longer time than those applied at the minimum height.

B. *Effect of feed rate and incremental depth on surface roughness*

Roughness average (Ra) is one of the most important parameters which give an indication of the surface roughness. Achievable surface roughness for Aluminum 6061 over the applied range of incremental depth (0.2 mm – 1.0 mm) and feed rate of 700, 2100, 3500, 4900, and 6300 mm/min are presented at two different rotational speeds of 1500 rpm and 3500 rpm in Fig. 5 and Fig. 6, respectively. The experimental results revealed that roughness increased with increase of feed rate because of the increasing of feed rate decreasing the formability of the material, while the larger incremental depth reduced the surface quality because of the marks was lifted by the forming tool on the surface.

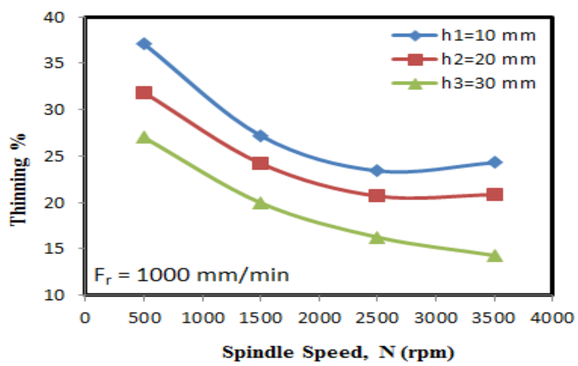


Fig. 4: Effect of spindle speeds on sheet thinning.

Comparing the experimental results obtained for Al. 6061 at different spindle speeds, as shown in Fig. 5 and Fig. 6, it can be seen that lower the surface roughness was achieved at spindle speed of 3500 rpm than those obtained at a spindle speed of 1500 rpm at incremental depth of 0.2 mm. In particular, the surface roughness reduced form 1.20 µm at spindle speed of 1500 rpm to 0.62 µm at spindle speed of 3500 rpm. The reason of increasing the surface roughness when lower spindle speed applied can be attributed to the decreasing of the formability and the rigidity of the machine and process setup. Also, the high amount of strains generated during the process affected on the surface finish. The increasing of the incremental depth increasing the material ridging. As a result, the surface roughness is decreasing.

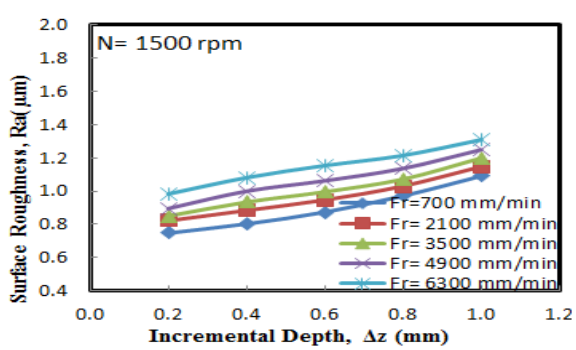


Fig. 5: Effect of feed rate and incremental depth on surface roughness at spindle speed =1500rpm.

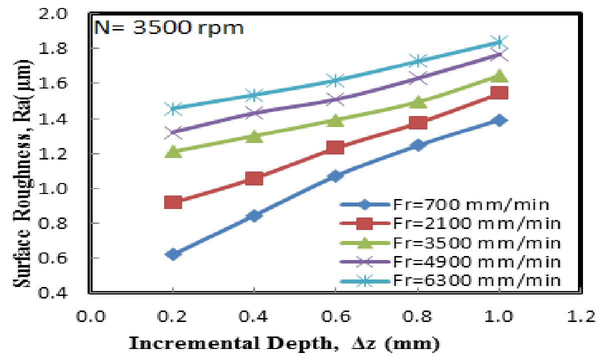


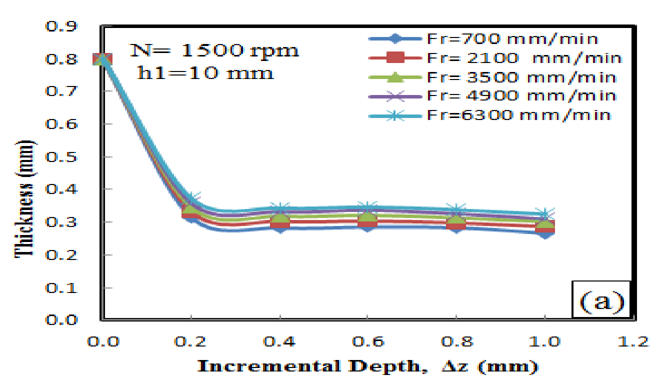
Fig. 6: Effect of feed rate and incremental depth on surface roughness at spindle speed =3500rpm.

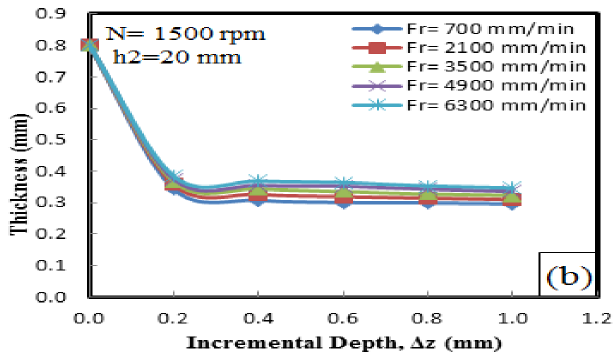
C. *Effect of feed rate and incremental depth on sheet thickness*

An investigation was carried out on the sheet metal thickness at various cross sections at three different heights (10, 20, and 30 mm) respectively. The resultant thickness for Al. 6061 obtained at the considered feed range of 700, 2100, 3500, 4900, and 6300 mm/min and incremental depth of 0.2, 0.4, 0.6, 0.8, and1.0 mm respectively, is presented. Fig. 7 (a, b, and c) at spindle speed of 1500 rpm.

Fig. 7a shows the effect of feed rate and incremental depth on sheet thickness at height of 10mm. It is seen that the change of feed rate and incremental depth influenced the thickness results. This can be observed as all results of thickness found to follow the same tendency. The stretching of the material is increasing significantly until incremental depth of 0.3 mm, and then it decreased slightly with the further increase of the incremental depth. The minimum value of thickness occurred at incremental depth of 1.0 mm and feed rate of 700 mm/min.

Figs. 7 (b and c) present the relationship between the sheet thickness and the incremental depth at height of 20 and 30 mm respectively. It is clearly showed that all the figures have the same tendency. It is shown that from the figures, the sheet thickness increasing with average value of 5% for all the incremental depths.





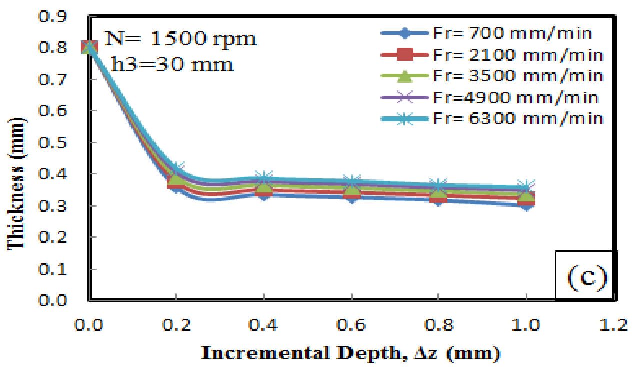
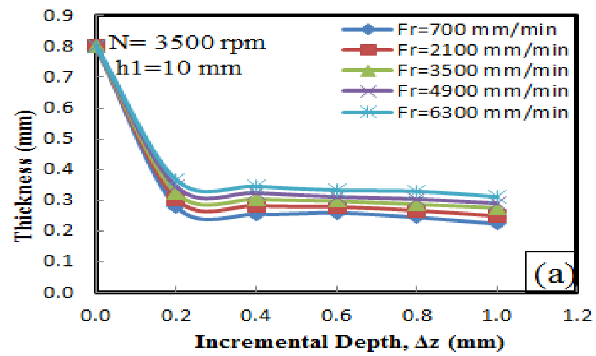


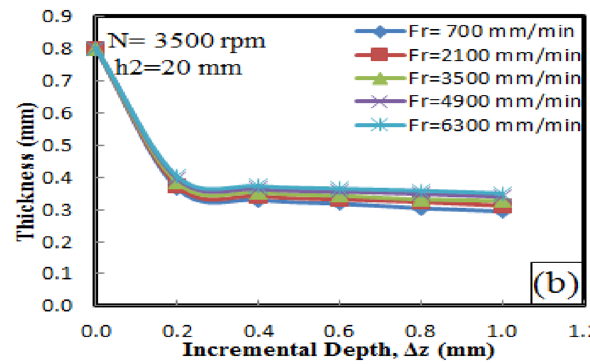
Fig. 7: Effect of feed rate an incremental depth on sheet thickness at Spindle speed=1500rpm (a) at h1=10 mm, (b) at h2=20 mm, (c) at h3=30 mm.

A study was executed on the sheet metal thickness at various cross sections at three different heights (10, 20, and 30 mm) respectively. The resultant thickness for Al. 6061 acquired at the considered feed range of 700, 2100, 3500, 4900, and 6300 mm/min and incremental depth of 0.2, 0.4, 0.6, 0.8, and1.0 mm respectively, is presented. Fig. 8 (a, b, and c) at spindle speed of 3500 rpm.

Fig. 8a shows the effect of feed rate and incremental depth on sheet thickness at height of 10mm. It is seen that the change of feed rate and incremental depth influenced the thickness results. This can be observed as all results of thickness found to follow the same tendency. The stretching of the material is increasing significantly until incremental depth of 0.3 mm, and then it decreased slightly with the further increase of the incremental depth. The minimum value of thickness occurred at incremental depth of 1.0 mm and feed rate of 700 mm/min.

Figs. 8 (b and c) present the relationship between the sheet thickness and the incremental depth at height of 20 and 30 mm respectively. It is clearly showed that all the figures have the same tendency. It is shown that from the figures, the sheet thickness increasing with average value of 10 % for all the incremental depths with increasing the feed rate value.





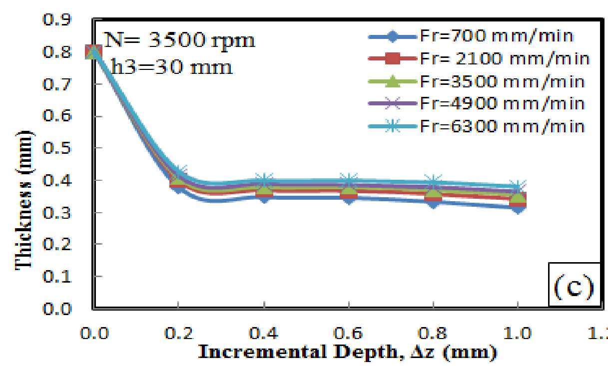


Fig. 8: Effect of feed rate and incremental depth on sheet thickness at Spindle speed=3500rpm (a) at h1=10 mm, (b) at h2=20 mm, (c) at h3=30 mm.

IV. Conclusion

The following conclusions were drawn based on the results by incremental sheet metal forming experiments on Al.6061.

1. The sheet thinning decreases with the increase of the of spindle speeds.
2. The surface roughness increases as the feed rate increases because of the high amount of the generated strain during the process.
3. The stretching of the material is increasing significantly until incremental depth = 0.2 mm, then is decreasing slightly, and is being stable at incremental depth =0.4 mm and what above this value.
4. The increasing of incremental depth increases surface roughness.

5. The quality of the final product was influenced largely by the roughness of the forming tool and the interaction between the forming tool and sheet surface.
6. Increasing feed rate, spindle speed and sheet thickness and reducing vertical step size can lead to a reduction in spring back

REFERENCES

[1] Y. Kumar, S. Kumar, 2015, "Incremental Sheet Forming (ISF)", Metallurgy and Materials Engineering, pp. 978-81.

[2] V. BOLJANOVIC, 2005 "Sheet Metal Forming Processes and Die Design", PhD thesis, New York.

[3] H. ARFA, R. BALLOU, H. BelHadjSalah, 2013, "Finite Element Modelling and Experimental Investigation of Single Point Incremental Forming Process of Aluminum Sheets: Influence of Process Parameters on Punch Force Monitoring and on Mechanical and Geometrical Quality of Parts", International Journal of Mater Form, pp.6:483–510

[4] H. Müller, H. Enzmann, 1998, "Potentials of Rapid Prototyping Techniques for the Manufacture of Prototype Sheet Metal Forming Tools", the European Conference on Rapid Prototyping and Manufacturing, Aachen, pp.337-350.

[5] P.B.Uttarwar 1, S.K.Raini 2, D.S.Malwad3, 2015, "Optimization of Process Parameter on Surface Roughness (Ra) and Wall Thickness on SPIF using Taguchi method", International Research Journal of Engineering and Technology (IRJET), Volume: 02 Issue: 09, pp. 781-784

[6] M.Tisza, 2012, "General Overview of Sheet Incremental Forming", Journal of Achievements in Materials and Manufacturing Engineering,Volume 55 Issue 1, pp. 113-120 .

[7] W.C. Emmens, G. SEBASTIANI, A.H. van den Boogaard, 2010, "The Technology of Incremental Sheet Forming", Journal of Materials Processing Technology 210, pp. 981-997.

[8] E. Hagan, J. Jeswiet, 2003, "A review of Conventional and Modern Single Point Sheet Metal Forming Methods", Journal of Engineering Manufacture 217/B2, pp.213-225.

[9] J. Jeswiet, F. MICARI, G. Hirt, A. Bramley, J. Duflou, J. Allwood , 2005, "Asymmetric Single Point Incremental Forming of Sheet Metal", CIRP Annals - Manufacturing Technology 54 , pp. 623-650.

[10] D. Leach, A.J. Green, A.N. Bramley, 2001, "A New Incremental Sheet Forming Process for SMALL BATCH and Prototype Parts", the 9th International Conference on Sheet Metal, Leuven, pp.211-218.

[11] J. Jeswiet, E. Hagan, 2001, "Rapid Proto-typing of a headlight with Sheet Metal", Proceedings of ShemMet, pp.165-170.

[12] K. Kitazawa, 1997, "Limit Strains for CNC Incremental Stretch-expanding of Aluminum Sheets", Journal of Japan Institute of Light Metals 47, pp. 145-150.

[13] L. Filice, L. Fratini, F. Micari, 2002, "Analysis of Material Formability in Incremental Forming", Annals of the CIRP 51/1, pp. 199-202.

[14] E.Masuku, A.Bramley, A. Mileham, G.Owen, 2005, "Incremental Sheet Metal Forming: A dieless Rapid Prototyping Process for Sheet Metal", Advances in Integrated Design and Manufacturing in Mechanical Engineering, pp.305-314.

[15] I. CERRO, E. MAIDAGAN, J. ARANA, A. RIVERO, P.P. Rodr´ıguez ,2006, "Theoretical and Experimental Analysis of The Dieless Incremental Sheet Forming Process", Journal of Materials Processing Technology 177, PP. 404–408.

[16] Y. Kumar, S. Kumar, 2014, "Design and Development of Single Point Incremental Sheet Forming Machine", 5th International & 26th All India Manufacturing Technology, Design and Research CONFERENCE, DECEMBER 12th –14th.

[17] V.MUGENDIRANA, A.Gnanavelbabub, R.Ramadossc, 2014, "Parameter Optimization for Surface Roughness and Wall Thickness on AA5052 Aluminium Alloy by Incremental Forming using Response Surface Methodology", 12 th Global congress on manufacturing and management.

[18] B. Desaia, K. Desaib, H. Ravalb, 2014, "Die-Less Rapid Prototyping Process: Parametric Investigations", 3rd International Conference on Materials Processing and Characterisation .

[19] B. Al-Obaidi, W.Hamdan, 2016, "The Effect Study of Parameters in (ISMF) on (Surface Roughness, Time Work and Thickness Distribution) for (AL-1060) Sheet Metal", International Journal of Current Engineering and Technology, E-ISSN 2277 – 4106, P-ISSN 2347 – 5161.