

Effect of Lubricants: Experimental Investigation in SPIF Process

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Abstract— Few studies have focused on the incremental forming of copper sheets. Moreover, the pyramid shape containing circular generatrix has not been investigated yet. Considering the friction produced during the incremental sheet forming process, between the sheet and the forming tool, a lubricant is used during the experiments in order to get a better surface finish quality. In this work, the influence of lubrication on surface roughness and forming forces in single point incremental forming (SPIF) of copper sheets is studied. This is considered keeping the same parameters such as the feed rate, the step increment and the sheet thickness.

Keywords— SPIF, Lubricant, Surface Quality, Experiment, Forces.

I. INTRODUCTION

Single point incremental sheet forming (SPIF) is a fairly recent forming process. It is used to locally deform a thin sheet gradually. This process is performed using a hemispherical tool with small diameter compared to the stamping process. The used tool is controlled by a CNC machine. The interest of this method is to guarantee the sheet shape by managing the tool-path. Despite the complexity of the existing forms in the biomedical, aeronautical and mechanical fields [1], the SPIF process is able to produce shapes by dint of the development of CNC machine following the development of computer-aided and design manufacturing software (CAD/CAM).

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This SPIF process has been investigated in several works [2, 3]. In the literature, the majority of authors have studied the influence of parameters such as step increment, feed rate, rotation speed, thickness of the sheet and material types on forming forces, formability, surface roughness of produced parts quality and dimensional accuracy. However, little regard has been given to the influence of lubricant. Using lubrication at the contact area tool/sheet seems necessary to reduce the friction and consequently the wear. In addition, it improves the heat distribution over the entire part and excludes shavings [4, 5]. Ben messaoud et al [6] have shown that the use of lubricant during the forming process of Al-3003-H12 sheet helps to obtain an optimized surface roughness quality.

Azevedo et al [7] have evaluated the effect of the lubricant type used for the incremental forming of aluminium and steel sheets. They have shown that the use of lubricant improves the quality of surface roughness and reduces the forming forces values. Jawale et al [8] have found that the use of lubricant has no effect on formability and reduces the surface roughness of copper sheets. Else, the diversity in the lubrication has not influenced by the grain shapes of the formed parts. Few studies have evinced that the use of lubrication during the SPIF process improves the obtained surface part' quality.

In this paper, the effect of lubricant is evaluated on the forming forces and the surface quality roughness.

II. EXPERIMENTAL PROCEDURE

A. The geometry of studied part and the process parameters

In this study, three tests were carried out using copper sheets with the thickness of 10/10 mm. Two experiments (N1, N2) are realized using parameters such as the feed rate ($V=600\text{mm/min}$) and the same step increment ($Z=0.25\text{mm}$). The third experiment was accomplished with a smaller feed rate ($V=300\text{mm/min}$) and a larger increment ($Z=0.75\text{mm}$). A truncated pyramid shape having a sides equal to 100mm and 20 mm of depth. This contain a circular generatrix. To deform the truncated pyramid a continuous tool-path has been used as presented in Figure 1.

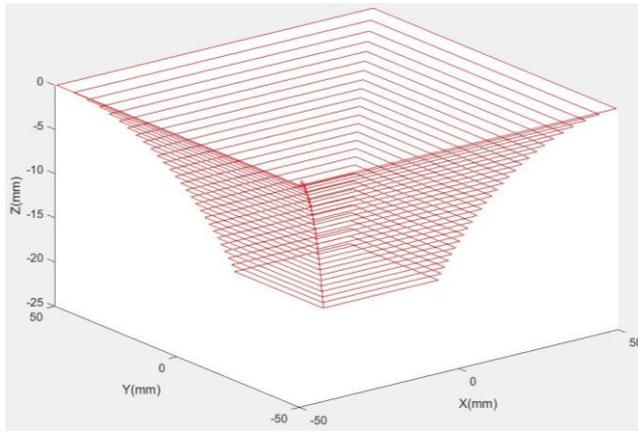


Fig. 1 Tool path

For the conducted experiments, three lubricants were used characterized by the properties summarized in Table I.

TABLE I
CHEMICAL PROPERTIES OF USED LUBRICANT

Test N °	Lubricant	Density (g/l)	Viscosity at 40°C (Cst)
1	Oil Jelt	0.93	136
2	Slide Oil	0.894	100
3	88% water +12% Oil	0.891	--

B. The SPIF machine and the roughness measurements tool

The experiments were performed on a Heidenhain CNC machine equipped with 802 D SIEMENS numerical command. The specifications of the used machine are 560 mm longitudinal travel X, 500 mm transversal travel Y and 400 mm vertical travel Z. The SPIF device is fixed on the CNC machine tray. The forming tool is set on the tool holder which is fixed in rotation into a mandrel. According to the defined path, the tool advances in depth in the blank sheet. Then, it performs the first contour of the forming path. After that, it makes a radial increment until the programmed depth is reached.

In order to study the influence of lubrication on the deformed parts roughness, an altimeter Roughness device is used as it is presented in Figure 2



Fig. 2 Roughness measuring device

III. RESULTS AND DISCUSSIONS

A. Forming force

The forming forces were measured using a load sensor type FN7325-FGB (NI) able to measure the axial and radial forces in real time. The evolution of the axial forces for tests N1, N2 and N3 are shown in Figure 3. In Table II, the maximum for axial and radial forces for each test is summarized.

TABLE II
MAXIMUM FORMING FORCES AND COEFFICIENT OF SHAPE

Test N °	Maximum axial force (N)	Maximum radial force(N)
1	1797.39	2.84
2	1815.9	4.30
3	1704.38	20.10

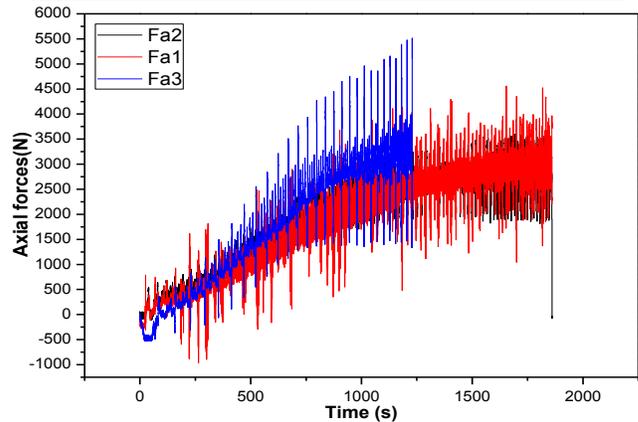


Fig. 3 Axial forces versus time

The examination of the data presented in Figure 3 and Table II show that it is no significant difference between the axial and radial force for experiment 1 and 2 since they present the same maximum for axial forces. The workpieces were formed in about 31 minutes with two different lubricant and two rotation speed. There is no difference between the lubricant 1 and the lubricant 2 despite the difference in the chemical properties of the lubricant. Both led to the same results for the forming forces in the same experimental conditions. By decreasing the feed rate and increasing the step increment of the experiment N3, a large deviation in the evolution of axial and radial forces is observed. This deviation seems due to the lubricant properties such as density and viscosity. Then, the used lubricant with low density seems reducing the axial forces and increases the radial one.as it was observed by Azevedo et al. in forming a AA1050 sheet.

B. Roughness Measurements

To predict the quality of the surface roughness, the arithmetic mean deviation Ra was determined. Fig. 4 presented a comparison between the initial roughness Ra of the sheet and the average roughness of the obtained parts for the three tests.

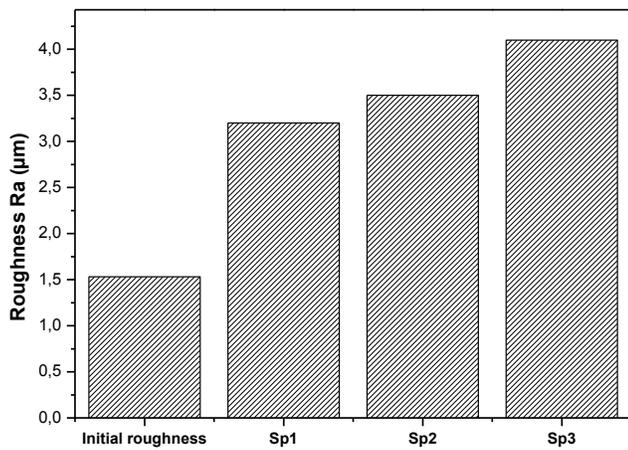


Fig. 4 Arithmetic roughness values

Regarding the formed copper sheets surfaces, it is observed that the surface sheet is smooth. There are no metal fragment at the deformed surfaces compared to the steel and the aluminum in some previous studies [1,2]. The initial roughness Ra for all specimens in the undeformed area is 1.53 µm. The percentage of the arithmetic mean profile deviations was determined with respect to the initial roughness of the workpiece before the forming process. The calculated percentage for the three specimens SP1, SP2 and SP3 are respectively 52.13%, 52.38% and 62.68%.

By analyzing the percentage gaps, it seems that the roughness of obtained copper sheets using a lubricant 3 which contains 88% of water and 12% of Oil leads to poor surface state. On the other hand, the lubricant that has the largest density had the better surface quality.

IV. CONCLUSION

At the contact area between the forming tool and the sheet metal, a friction will occur during the SPIF process which induces a local heating. To reduce the temperature level, it is necessary to use a lubricant. In our investigation, three lubricants are used to detect their influence on the forming forces and the surface roughness, for SPIF process of copper sheet. From this work, some conclusions are drawn:

- The type of lubricant does not affect the forming time despite the increasing in the step time increment.
- The use of lubrication prevents the appearance of metal fragments. Otherwise, the type of lubricant has a significantly impact in the maximum values of axial and radial forces. The lubricant with lower density reduces the axial force.
- The use of lubrication improves the quality of manufactured surfaces. Moreover, the lubricant with lower density has the highest value of surface roughness.

REFERENCES

- [1] A. Boulila, "Contribution to biomedical component production by incremental sheet forming," in *The International Journal of Advanced Manufacturing Technology*, 2017.
- [2] M. Dakhli, "Effect of generatrix profile on single-point incremental forming parameters," in *The International Journal of Advanced Manufacturing Technology*, vol 93, Issue 5–8, pp. 2505–2516, 2017.

- [3] B. Saidi, "Experimental force measurements in single point incremental sheet forming SPIF," in *Mechanics & Industry* 16, 410 (2015), pp: 1-5.
- [4] Fülöp and M. T. T, "A General Overview of Tribology of Sheet Metal Forming," in *Journal for Technology of Plasticity*, vol 26, No. 2, pp. 11-25, 2001. 13.
- [5] Lee .B. H, "Modeling of the Friction Caused by Lubrication and Surface Roughness in Sheet Metal Forming," in *Journal of Materials Processing Technology*, vol. 130-131, pp. 60-63, 2002.
- [6] R.BENMESSAOUD, "Tool, lubricant and process parameters investigation to form an AA 3003-H12 sheet by single point incremental sheet forming process," vol 7, Issue 11, pp.950-960, 2016.
- [7] N. Gil Azevedo, "Lubrication Aspects during Single Point Incremental Forming for Steel and Aluminum Materials," in *INTERNATIONAL JOURNAL OF PRECISION ENGINEERING AND MANUFACTURING*, vol. 16, No. 3, pp. 589-595, 2015.
- [8] Kishore. Jawalea, "Microstructural investigation and lubrication study for single point incremental forming of copper," in *International Journal of Solids and Structures*, pp.1–7,2017

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