

A BRIEF STUDY OF LUBRICATION AND ROTATION INFLUENCE ON THE FORMABILITY IN SINGLE-POINT INCREMENTAL FORMING OF ASTM A653 CS-A STEEL

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Abstract. *Single Point Incremental forming (SPIF) is a free forming process of sheet parts in a specific equipment like CNC machining centers or special hexapod robots. It stands out for its high formability and low production cost, being ideal for prototypes and small batches. The main design parameters are the wall angle, material and sheet thickness and, most of the cases, they cannot be modified or even adjusted to improve the manufacturing performance. On the other hand, the main process parameters that impact the product total quality are tool rotation, vertical step size, lubrication and all of them can be continuously optimized. Thus, these last three process parameters are widely investigated in several kinds of research. This study investigates the influence of the lubrication on incremental forming applying different tool rotation when shaping a truncated cone of ASTM A653 CS-A steel sheets - 0.43mm thick - with different types of lubrication and vertical step size. It was chosen three level for each factor: 600, 1200 and 1800rpm for tool rotation n ; 0.6, 0.8 and 1.0mm for vertical step size Δz and dry, mineral oil and molybdenum disulfide grease for lubrication condition. The statistic Taguchi method was applied to evaluate the maximum depth of forming and better surface quality (roughness R_a). The results confirmed the use of mineral oil as the most predominant factor in the process for minimum roughness, maximum forming height. The rotation found that contributed for best forming results was 600 rpm.*

Keywords: SPIF, ASTM A653 CS-A, lubrication, rotation, step size

1. INTRODUCTION

Incremental sheet forming (ISF) is a free-form stamping process, where the sheets are fixed at their peripheries and formed by the tool, generally a semi-spherical punch, which moves through a predefined path (Ambrogio et al., 2005 and Buffa et al., 2013). Although its application seems current, the process had already been patented by Edward Leszak in 1967, long before it became feasible (Governale et al., 2017; Hirt et al, 2003; Hirt et al. 2005; Jeswiet et al., 2005). Compared to conventional stamping processes, the ISF has advantages because of its simplicity, it doesn't need the traditional and expensive dies (Keeler, 2002; Kim and Park, 2002; Kobayashi et al., 1989). Besides that, it is possible to perform in CNC machining centers, with three or more axes, programmed by CAM direct from CAD projects (McAnulty et al., 2017; Micari and Filice, 2007). So that, the deformations are imposed incrementally by the tool through path strategies, until obtaining the desired geometry (Otsu et al., 2010). Due to its advantages, incremental forming is shown to be satisfactory and feasible even with longer production time, being ideal for prototypes and small batches in the automotive, aerospace and biomedical markets (Valle, 2016; Wang et al., 2016).

Since the process has become attractive in recent decades, many articles have been written to evaluate the parameters involved in it and to improve incremental forming techniques (Xu et al., 2013). Jeswiet et al. 2005 performed one of the main studies related to this subject, evaluating a large part of the parameters and they concluded that the significant variables in the process are: the sheet thickness t ; the maximum wall angle α ; the vertical step size on the z-axis, Δz ; the tool diameter d ; and the tool feed f . Other parameters are also considered important in the process, such as the tool rotation n , and the lubrication condition.

Moreover, Micari et al. 2007 found that, thanks to the tool-induced deformation, the formability at ISF is greater than the conventional stamping, so the rotation parameter becomes very interesting for evaluation.

This expanded abstract shows the lubricant and rotation impact on the incremental forming process of ASTM A653 CS-A commercial steel. To evaluate the results, the maximum forming height h_{max} was measured as well as the surface quality roughness R_a .

Thus, for the accomplishment of the experiment it was chosen to follow the Taguchi method L9 orthogonal arrays with three factors and three levels. So that, it was possible to evaluate the signal/noise ratio results and to estimate the higher h_{max} and better roughness for the set designed, as well the influence of each variable in the process. The tool rotation range was 600, 1200 and 1800rpm, the vertical step size Δz was 0.6, 0.8 and 1.0mm and two types of lubricants, solid and oil, were used in addition to dry experiments. In the experiment, circular meshes were also recorded in the specimens in order to evaluate the deformations imposed by the process.

2. METHODS AND MATERIALS

Single point incremental forming tests were carried out on ASTM A653 CS-A rounded tablets sheets of 68mm diameter and 0.43mm tick to investigate the influence of the lubrication and rotation on the formability in SPIF. The maximum forming depth h_{max} and quality surface R_a were the outputs to be observed.

Thus, Design of Experiments was applied, DOE aims to determine the influence of different variables on a given process.

It was decided to use the Taguchi method, with its orthogonal arrays delineation L9 and, thus, to analyze the answers through the signal noise, being larger is better for h_{max} and smaller is better for the roughness (R_a). For the current experiment there are three factors with three levels each, Table 1.

Table 1. Experiment factors and levels

Factor (units), symbol	Levels		
	Level-1	Level-2	Level-3
Rotation (rpm)	600	1200	1800
Step Size (mm)	0.6	0.8	1.0
Lubricant	Dry	Mineral Oil	Grease

The appropriate orthogonal array L9 could be seen in Table 2. Three replications were made totaling 27 tests.

Table 2. Orthogonal array L9

Test Experiment	Factor (units)		
	Rotation (rpm)	Step Size (mm)	Lubricant
1	600	0.6	Dry
2	600	0.8	Mineral Oil
3	600	1.0	Grease
4	1200	0.6	Mineral Oil
5	1200	0.8	Grease
6	1200	1.0	Dry
7	1800	0.6	Grease
8	1800	0.8	Dry
9	1800	1.0	Mineral Oil

In this work was applied 68.0mm diameter specimens of ASTM A653 CS-A, with a thickness of 0.43mm and supplied by CSN Company in Brazil, Figure 1.

So that, following studies already carried out by Valle et al. [15] with the same material and dimensions, it was suggested the tool feed at 200mm/min and the wall angle at 45° to enhance the expected results. The punch with a diameter of 8.0mm was performed.

In order to measure the deformations imposed by the punch during the SPIF process, a mesh of circles with a diameter of 4.0mm was recorded on the outer surface of the specimens by the photo-corrosion process.

A CNC machine was the ROMI Discovery Model 4022 – MACH 9 command using a carbide hemispheric punch coated with TiAlCN (2600HV) were used to perform the ISF process. The rotation direction of the punch was programmed to discordant once McAnulty et al. 2016 [11] evaluated this parameter and concluded that this direction minimizing friction better than concordant.

In relation to the output parameters the deformations in the mesh were obtained by a Mitutoyo caliper with a resolution of 0.02mm and the roughness was measured with a Taylor-Hobson Surtronic S-128. The R_a and R_z values

were measured in direction of the vertical step size of the inner surface of formed cones. The cut-off was 0.8mm for this level of expected roughness (ABNT NBR ISO 4287, 2002).

3. ANALYSES AND RESULTS

Table 3 brings all the experiment results under different lubricant and rotation conditions following the Taguchi design. The table shows the mean values and the standard deviation for hmax e Ra data.

Table 3. Experiment results

Experimental Tests	Average		Standard Deviation	
	hmax [mm]	Ra	hmax [mm]	Ra
1	17.37	1.376667	0.10	0.607069
2	16.80	0.81	0.09	0.08544
3	17.00	1.69	0.09	0.182483
4	17.77	0.71	0.13	0.017321
5	12.27	1.8	0.41	0.287924
6	5.00	3.436667	0.87	2.272297
7	9.80	1.476667	0.31	0.307463
8	16.63	1.813333	0.26	0.315647
9	17.00	1.033333	0.09	0.065064

Based on the average data of the average hmax and Ra a brief correlation study was made. Analyzing Pearson's linear correlation for hmax and Ra, the value of $r = 0.8117$ shows us that there is a good correlation, showing that in processes that generate rougher surfaces it will directly impact on a better conformability of the parts.

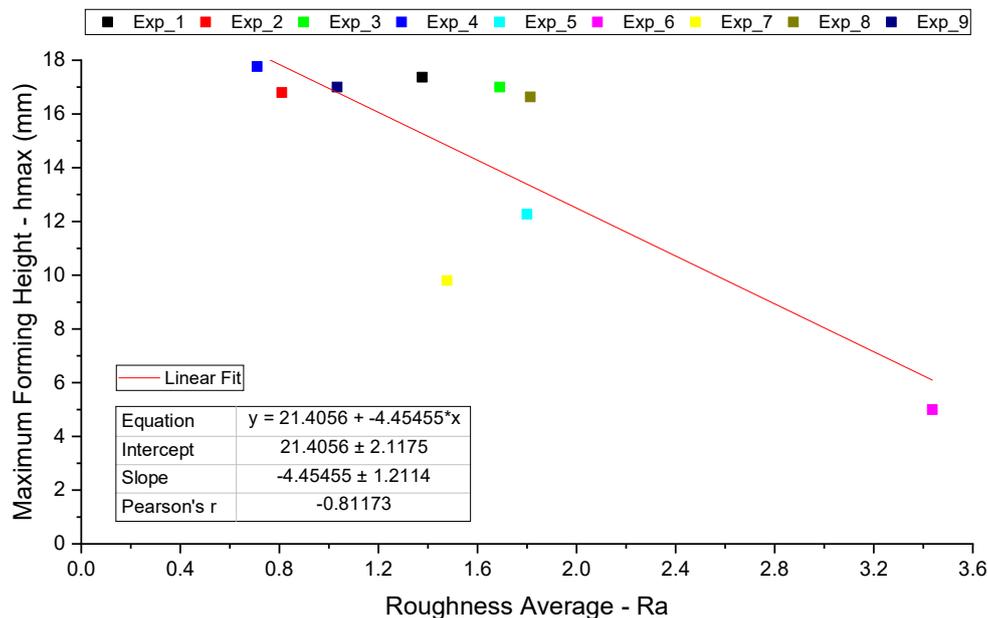


Figure 1. Roughness Average - Ra versus Maximum Forming Height – hmax

When SPIF was done with mineral oil it was not possible to visualize the internal surface because the oil layer became dark as the vertical step size was applied cycle by cycle. Nonetheless, all formed bodies by mineral oil lubrication reached the maximum height without failure for all tests. It means, reaching maximum height ($h_{max}=17.4\text{mm}$) when vertical step size was set to 0.6mm and 29 cycles were performed. Maximum height also was reached ($h_{max}=16.8\text{mm}$) when vertical step size was set to 0.8mm and 21 cycles were performed. Maximum height was ($h_{max}=17.0\text{mm}$) when vertical step size was set to 1.0mm and 17 cycles were performed.

Additionally, there was no material added on the tool nose surface and the visual aspect proved to be much better than the other lubricant conditions too.

The use of molybdenum disulfide grease shows that the behavior of the specimen was standardized, the failures occurred when applying greater rotation, 1200rpm and 1800rpm with h_{max} around 12mm and 10mm respectively. No

one test body failed with 600rpm and grease. It was possible to verify the formation of gases due to the heating of the grease, being harmful to the environment and operator. Figure 2 shows some aspects of these three sets of experiments based on lubricant.

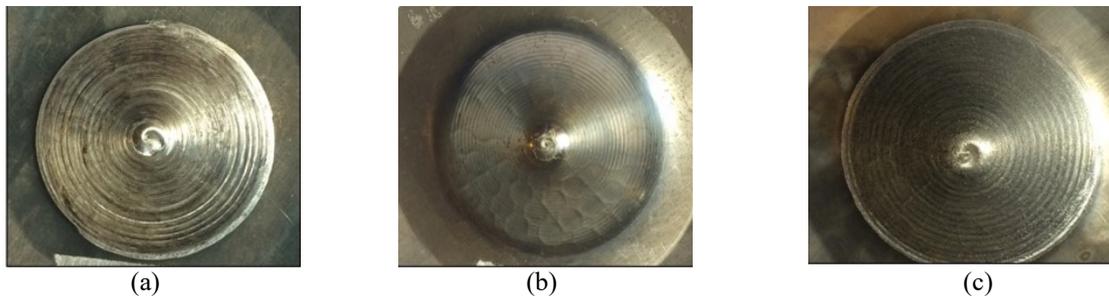


Figure 2. (a) Dry, 1200rpm and $\Delta z=1.0\text{mm}$ (b) Mineral Oil, 1200rpm and $\Delta z=0.6\text{mm}$ (c) Grease, 600rpm and $\Delta z=1.0\text{mm}$

On the other hand, the influence of lubricant and rotation on a quality surface is not completely clear in this research. So that, it must be investigated in further work.

In fact, when spindle speed is increased from 600rpm to 1200rpm, proper lubrication at the contact zone of tool-sheet reduces scratching on the formed surface and results in decreasing average roughness. However, when spindle speed is increased from 1200rpm to 1800rpm the quality surface decrease this may be due to the fact that low viscous forming oils are not able to withstand high forming temperature and squeezed out from tool-sheet contact zone.

4. CONCLUSION

Among the lubricant factors, the one with the greatest impact on the forming depth h_{\max} is the mineral oil that ensures the highest performance to the ISF process. Molybdenum disulfide grease can be applied, however, it does not present as satisfactory results as mineral oil and has a high cost. The solid lubricant has also formed gas during the process that can be harmful to the operator and the environment. At least, the worst case was the dry condition.

In general, increased tool rotation reduced the formability of ASTM A653 CS-A steel sheets and the best rotation found was at 600rpm.

5. ACKNOWLEDGEMENTS

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