EXPERIMENTAL INVESTIGATION OF TOOL WEAR DURING NOVEL SINGLE POINT INCREMENTAL SHEET FORMING (SPIF) PROCESS FOR AA6061

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Abstract - The Automobile and Aviation industries are trying to replace the current low-strength steel sheets with relatively lower thickness high-strength steel. This leads to a reduction in the weight of the equipment without compromising the stiffness of the structure. Single point incremental forming (SPIF) allows deforming of high-strength steel and other hard-to-deform materials like Titanium at relatively lower stress values. This is done by deforming the material locally with the help of the single-point numerically controlled (NC) tool. However, the process is not yet fully industrialized due to high spring back values and lower geometric accuracy. One of the important aspects of the process is Forming tools, as it is directly related to the economics of the process and the production rate, which is directly affected by tool wear. This paper investigated the tool wear behavior of the SPIF tool at room temperature for High-Speed Steel (HSS) tools of different shapes.

Keywords - Tool Wear, Metal Forming, SPIF, Surface Roughness

I. INTRODUCTION

The incremental sheet forming (ISF) was created due to a partial hybridization of stretch forming and metal spinning techniques combining the benefits of both processes. The process is capable of manufacturing 3D complex forms with various characteristics. Stamping, stretch forming, and other classical sheet metal forming methods necessitate specialized tooling specific to the sheet metal component being formed and are thus only suitable for mass production. For single-piece or small-batch manufacturing, these procedures are prohibitively expensive to adopt. The ISF approach, which may be used for single or batch manufacturing, solves this issue.
The incremental Sheet Forming (ISF) process is from a group of processes where localized deformation is produced onto the blank. These deformations are applied step by step with the help of a tool that follows a particular predefined tool path. To form the sheet metal blanks, different types of tools can be used, viz. spherical, hemispherical, elliptical end type, rolling ball type,and flat end type. These tools are attached to a CNC milling machine, robotic manipulator, or special purpose ISF machine. These machines are fed with tool paths in the form of G - codes & M – codes.

Aschauer et al.[1] studied the effect of adhesive wear formation on PDV-coated tools for hot forming. The researchers have characterized the amount of build-up volume and coating to build-up material interface using TEM. The highest adhesive wear formation was found for Al-Cr-O coated material, and the lowest for $Ti_{0.57}Al_{0.43}N$ / Mo-Si-B coated material. It was evident that the amount of adhesive wear depends upon the amount of interface formation. Narrower the interface, the smallest the adhesive wear. Nilsson et al. [2]compared the wear behavior of carbide steel with other frequently used tool materials like white cast iron, tool steel, and powder steel in the automobile industry. The wear pattern was analyzed using a reduction in weight, galling tendency, and temperature variation during experiments. Results showed that the carbide steel tool shows a significant reduction in galling and significant improvement in wear resistance.

Groche et al.[3] proposed a new method to characterize tool wear in sheet metal forming. They developed a new method using input parameters like the infeed of new sheet metal, the effect of lubricants, and local contact stresses. Results show that the specific wear force also depends on the composition of the sheet metal apart from its strength. Bang et al.[4] quantitatively evaluated the wear behavior of the CrN-Coated tool for the sheet metal forming process using progressive punch and die sets. A newly developed numerical simulation model was used to identify wear characteristics determining to concoct surface of the tool during forming. Using tool wear sensitivity, a correlation between tool surface wear and part quality was developed to predict the tool life.

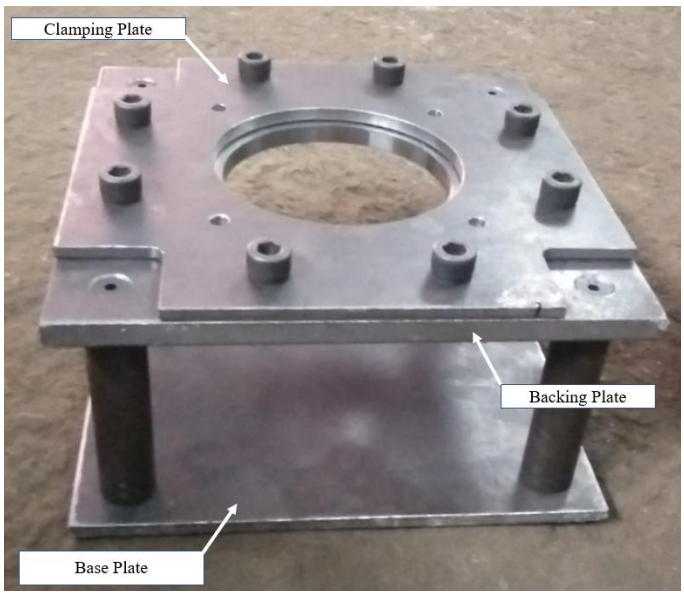
Nurnberg et al.[5] developed a modified Archard model with varying wear coefficients. In the original Archard model, the coefficient of the wear is assumed to be constantly leading to linear wear development.

However, experimentally, it is confirmed that the wear development is non-linear over time. The modified Archard model also accommodates the energy dissipation approach to calculate the wear development. Wear calculated using the modified Archard model share good agreement with the experimental wear. Diabb et al.[6] investigated the effect of sunflower and corn oils with different weight % of SiO2 nano-particle as lubricants for single-point incremental sheet forming. The investigation on sample surface quality was investigated using varying friction through different tribological conditions. Results show significant wear reduction while using 0.25 wt % of SiO2 nano-particles in vegetable oils.

Oraon[7] developed a model using an Artificial Neural Network (ANN) to predict and compare the tool wear in the novel Single Point Incremental Sheet Forming process. The tool used is made of 440C steel and a workpiece of AA3003 – Annealed aluminum alloy. The developed tool predicts the tool wear accurately upto 2 decimal points. Kondratiuk et al.[8] evaluated the wear behavior of hot dipped Aluminum – Silicium and electroplated Zinc alloy coatings for the hot forming process. They observed that Zinc alloy coating results in more mass reduction of the workpiece but results in a low friction coefficient. Whereas, Al-Si coated blank shows less mass reduction but with aggressive wear behavior by means of adhesive wear, which leads to metallic build–up on the die periphery. Yilkiran et al.[9] carried out a wear investigation of oxide layer on high strength DP600 + Z formed using selectively oxidized $\alpha - Fe_2O_3$ tool steel. The investigation was carried out by varying pressure on the surface of the specimen, varying pulling force, and reaction force. The results show that the oxide layer acts as a friction reducer and protects the tooltip from wear.It is evident from the above literature review that although many attempts have been made to improve the surface quality of the formed sheet by reducing the tool wear, very little attention has been given to the quantification of tool wear in the novel Incremental Sheet (ISF) Forming process. The present study aims to quantify the amount of tool wear in the form of mass loss, the surface roughness of the tool, and the tool profile for the S400 tool steel material used to form the composition of the AA6061 – T6 sheet.

II. EXPERIMENTAL INVESTIGATION

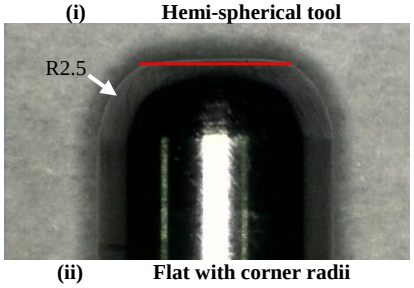
The ISF set-up is shown in Fig. 1(a), containing the backing plate and clamping plate, between which the 1 mm thick sheet of AA6061 – T6 was held. The tool used for the forming process is shown in Fig. 1(b), which is made up of High-Speed Steel T42. Fig. 1(b)(ii) clearly shows that the end of the tool is not perfectly straight, the right end corner is slightly above the left end corner. The chemical composition of the sheet and tool is shown in Table 1 and Table 2, respectively.



(a) Experimental fixture set-up for ISF process

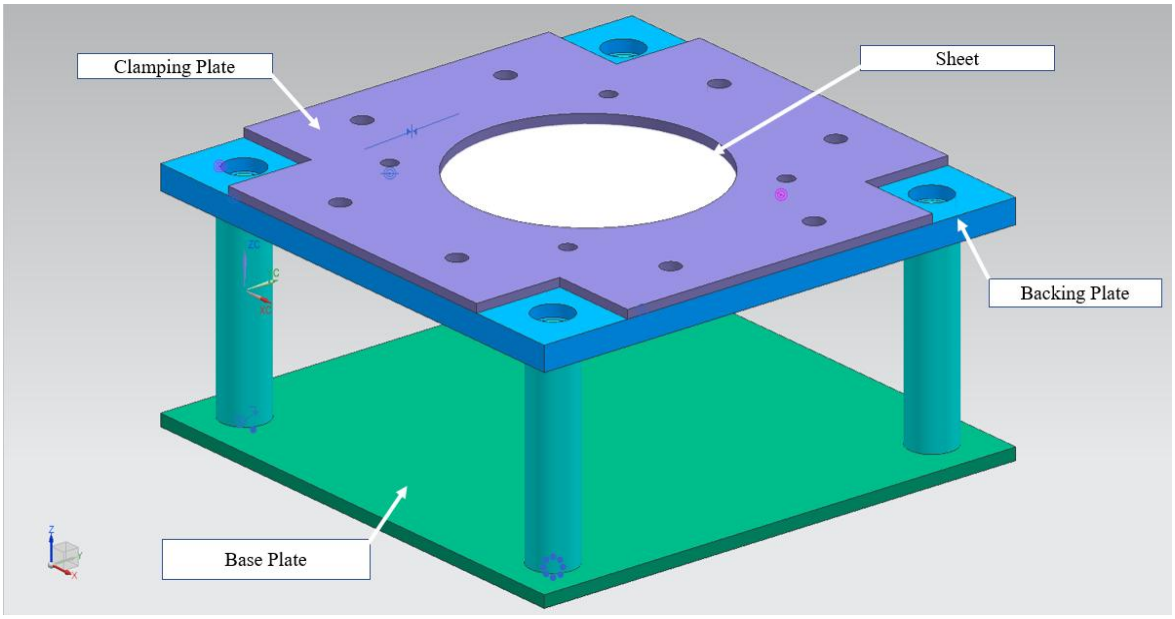


(i) Hemi-spherical tool



(ii) Flat with corner radii

(b) HSS T42ISF tool profiles



(c) Model of ISF set-up holding AA6061 – T6 sheet

Figure1: ISF set-up and tool

Chemical composition of AA6061 – T6				
Al	Mg	Si	Cu	Cr
97.9	1	0.60	0.28	0.20

Table 1

Chemical composition of HSS T42					
C	Cr	Mo	W	Co	V
1.26	4.0	3.6	9.3	10.0	3.2

Table 2

The experiments were performed at a very high speed and feed to simulate the extreme condition wear quantification. The pilot experiments were performed at the spindle speed of 2000 RPM and feed of 840 mm/min; however, heavy chipping of the base material was observed. To reduce the chipping of the base material, several combinations of speed and feed were analyzed. The final experiments were performed at the spindle speed of 350 PRM and feed of 560 mm/min. The depth of increment was 0.6 mm for the constant Z – Level tool path. No lubrication was used for the formation of the conical frustum ata 60° wall angle. Two types of tools (Hemi-spherical and Flat with corner radii) having a diameter of 8 mm were utilized to investigate the effect of tool wear. Each experiment was repeated five times for both tools. The forming depth of the frustum was 8 mm. It was revealed in the pilot experiments that AA6061 fails after the depth of 8.5 mm at room temperature.

III. RESULTS AND DISCUSSION

The loss of mass, surface roughness, and geometry of the tool were analyzed to characterize the tool wear for the ISF process. Fig. 2 shows the loss of mass for the HSS T42 tool for both; the hemispherical and flat tools,while Table 3 shows the before and after mass of the tools. The measurements were taken in the vacuumed chamber with an accuracy of 5 decimal points. The results show that mass loss in the case of the flat tool is much higher compared to the spherical tool. This is due to the contact area of the flat tool is much higher compared to the hemispherical tool.

Also, while forming using the flat tool, microchipping was observed; these chips continuously rub with the right end corner of the tooldue to geometric error (End is not perfectly flat – see Fig. 1(b)(ii)) and resulting in abrasion wear.

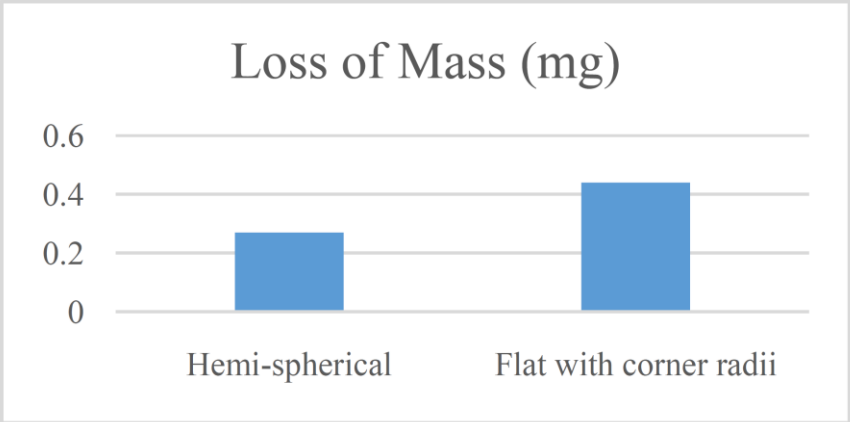


Figure 2: Mass loss after the experiments

Tool Profiles	Before experiments (mg)	After experiments (mg)	Loss of Mass (mg)
Hemi-spherical	28365.29	28365.02	0.27
Flat with corner radii	30966.41	30965.97	0.44

Table 3

Fig.3 compares the surface roughness values of the tools before and after the experiments. The hemispherical tool was placed at an angle in such a way that the probe of the surface roughness tester could travel 1.25 mm. Five readings were taken at intervals of 0.25 mm. Multiple readings were taken and averaged out to eliminate the error in the reading, as measuring the surface roughness of the curved surface can be difficult. It is evident from Fig.3 that the surface roughness of the hemispherical tool is much higher in comparison with a flat tool. This can be justified through the profile of the hemispherical tool, as shown in Fig.4. The profile of the hemispherical tool was not completely spherical; the curve was not completely symmetrical about the axis of the tool. This results in variable contact between the tool and the sheet, resulting in a higher surface roughness value.

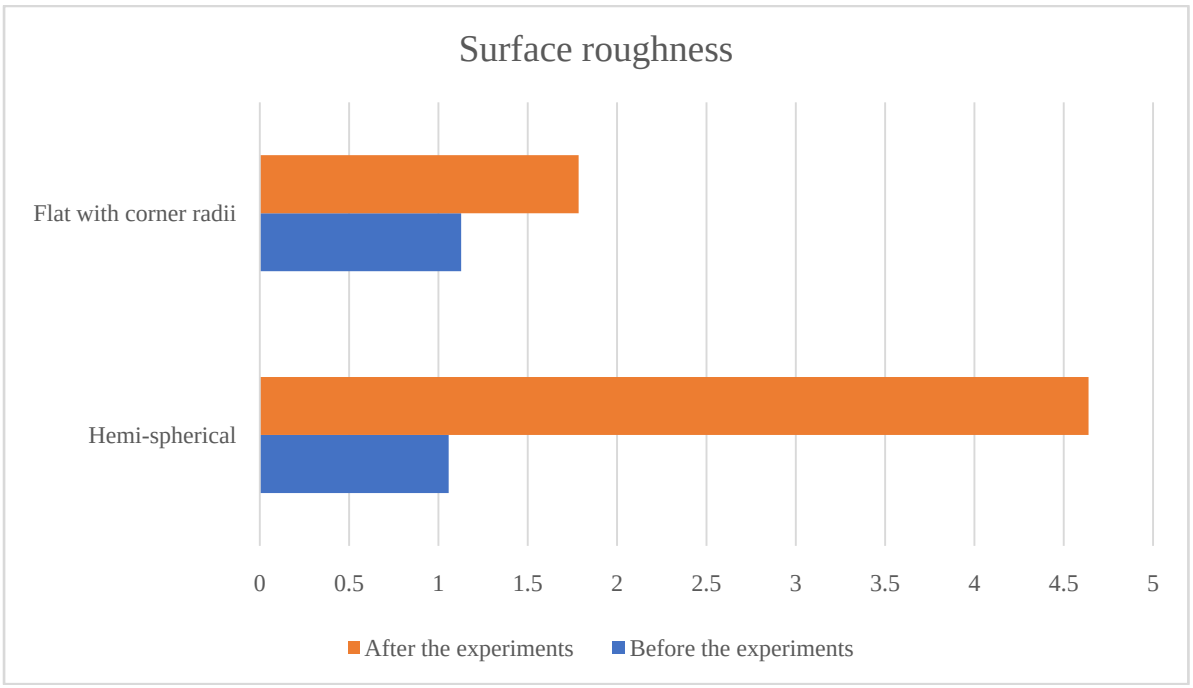
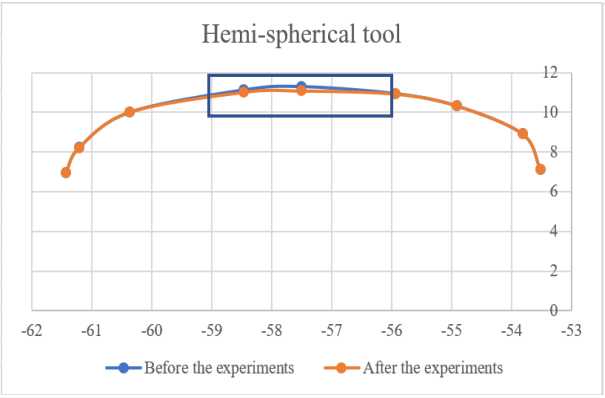


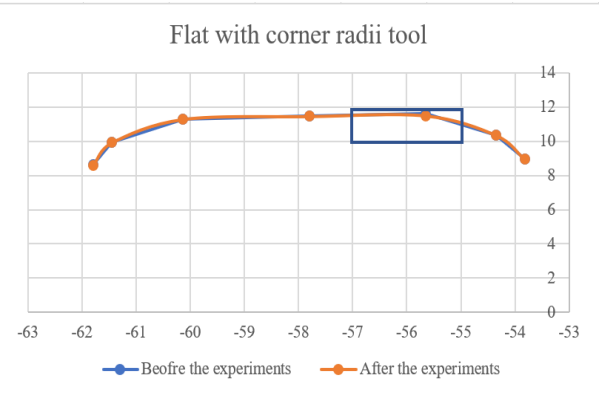
Fig. 3: Surface roughness of the tools before and after the experiments

Fig.4 shows the profile of the tools before and after the experiments. The tools were manufactured using a manual lathe machine and thus did not reflect the perfectly symmetrical shapes of their longitudinal axes. The measurements were taken using Vision Measurement System. It is clear from the results that the deformation of the hemispherical tool is more compared to the flat tool. This is due to better

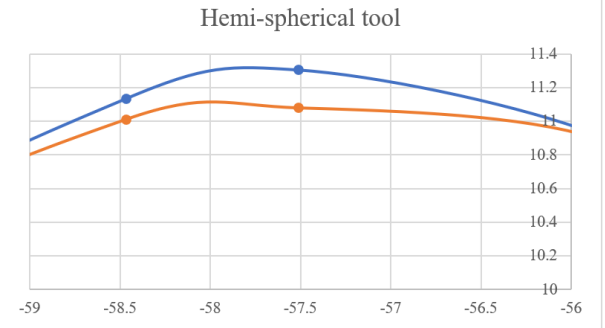
temperature dissipation is possible in the case of the flat tool in the case of dry forming. The hemispherical tooltip has less area, which can dissipate the heat, making the tip softer, resulting in tip deformation. The maximum observed deviation for the hemispherical tool is 0.226 mm. Very little deformation is observed in the case of the flat tool. The end of the flat end is not completely flat (see Fig. 1(b)(ii)), the right end corner is slightly elevated than the left end corner. Due to inaccuracy in the tool profile, the right end corner of the tool partially acts as the tip of the tool, making continuous contact with the sheet. This results in partial thermal softening of the tool. However, the difference between before the experiments and after experiments profiles is much smaller (0.125 mm).



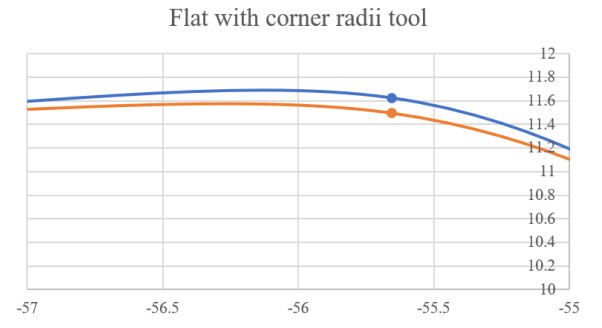
(a) Tool profile of the Hemi-spherical tool before and after the experiments



(b) Tool profile of the Flat with corner radii tool before and after the experiments



(c) Evident tool profile deformation of the hemispherical tool (Enlarged view)



(d) Evident tool profile deformation of the flat with corner radii tool (Enlarged view)

Figure4: Tool profiles of the tools before and after the experiments

IV. CONCLUSIONS

The presented study aimed to quantify the maximum tool wear for the novel ISF process. The experiments were carried out at higher feed and lower spindle speeds to simulate the extreme case of wear. The mass loss, surface roughness of the tools, and tool profiles were analyzed to make the following conclusions:

- The observed mass loss for the flat tool (0.44 mg) is higherthan the hemispherical tool (0.27 mg) profile due to microchipping. The chips of the base material rub the tool resulting in abrasion wear.
- The difference in surface roughness before the experiments and after the experiments of the hemispherical tool (3.582 µm) is much higher than the flat tool (0.658 µm) due to the uneven profile of the tool, resulting in variable contact of the tool.
- The profile of the hemispherical tool shows reasonable deformation (0.266 mm) due to poor heat dissipation in case of dry forming, which leads to thermal softening of the tip.
- The geometrical inaccuracies in the tool profiles play a significant role in the wear characterization, as observed in the case of flat end with corner radii tool (0.125 mm) profile deviation.

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