Investigation of Process Variables on Forming Forces in Incremental Sheet Forming

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Abstract—**Manufacturing of small batch size products and prototypes are not economical using conventional forming processes as these processes require dedicated and highly specialized equipments such as forming presses, dies, and punches. Incremental Sheet Forming (ISF) process has been confirmed as quiet economical process for rapid prototyping and batch type production. In this work, process variables are investigated on axial peak forces on AA2024-O sheets. A strain gauge based dynamometer has been used to record axial peak forces during incremental process. Combination of higher wall angle and higher tool diameter leads to larger axial forces which can be limitation of the capacity of the machine tool and forming tools used in the process. Higher sheet thickness not only requires larger forming forces to form the components but also increases formability of the material.**

Keyword - AA-2024, Aerospace, SPIF, Forming Force, Process Parameters.

I. INTRODUCTION

The Sheet metal forming is an important aspect of manufacturing industries. In manufacturing sectors, conventional sheet forming processes like deep drawing, shearing, stretch forming, bending, and blanking etc. are being used to facilitate production of components. These conventional processes need dedicated and expensive dies and tools which make the process uneconomical for batch type and rapid prototyping production. In aerospace sector, approximately 200 stamping dies are utilized every year for manufacturing a lot size of about 5000 parts. Manufacturing and inventory of theses dies make the process time consuming and costly. Multi-variety components in small batches can be manufactured at low cost with Single Point Incremental Forming (SPIF) technology which prevents limitations of traditional sheet metal forming processes [1-3]. SPIF is a truly die-less process and beautified with economical tooling cost, shorter lead time and ability to form non-symmetrical geometries without using expensive dies. These advantages permit manufacturing of complex components of sheet metal for rapid prototyping at economical level. SPIF mainly finds its application in medical sector, aerospace and automotive industry. A simple spherical tool can be employed to produce different complex shape in SPIF process. Forming tool deforms the sheet metal layer by layer according to numerically designed tool path. Forming path of the traveling tool is most crucial for the successful forming of the components. Generally, profile and helical tool paths are employed on a CNC machine tool to obtain a desired shape. In profile tool path, the tool moves in a single plane and reaches to its initial point then it takes a step depth in the vertically downward direction. This process continues till the complete shape is formed. In SPIF, sheet is squeezed locally by the tool; hence, study of forming forces becomes much important regarding fracture mechanism and precision of the formed part. It is also important to estimate maximum forming force to ensure the safe utilization of forming hardware. Forming force is the force required to deform the sheet at the tool-sheet interface. Fig.1 shows the force components in Cartesian coordinate system. The force components F_x, F_y and F_z along x, y and z directions respectively can be measured with the help of dynamometer or load cell. The measured data can be recorded with the help of data acquisition system, charge amplifier and PC based environment.

II. LITERATURE REVIEW

Rauch et al. [4] investigated influence of feed rate for different tool path strategies on AA5086 sheets. The forming force was found to increase with increase in feed rate. Oleksik et al. [5] investigated effects of different tool diameters (12, 16, 20 mm) on forming forces in SPIF and elaborated mathematical models. Forming forces in axial direction was much higher than those occurred in x-direction. Arfa et al. [6] studied influence of different sheet thickness for profile and spiral tool path on AA3003- O sheets by experiments and simulation with ABAQUS with a set of standard parameters. Results showed that forces increases directly with increase in

sheet thickness for both types of tool path and there was 2 % and 3 % error between FEM and experimental results of forces, respectively for the smallest and greatest values of sheet thickness (1.2 mm and 2 mm). Liu et al. [7] also studied the influence of the sheet thickness on vertical forming forces. The maximum vertical force was 6792.4 N with 2.54 mm thickness and 1.5 mm step-down size. Aerens et al. [8] studied effects of tool diameters on AA3003 sheets and showed that tangential force (F_t) is small and remains nearly constant but force in z-direction increase with tool diameter. Al-Obaidi et al. [9] studied influences of feed rate with induction heating on forming force on DC04 sheets and showed that at 35 kW power and a feed rate of 2500 mm/min, force values was higher (approx. 1450 N) than force value (approx. 900 N) at a feed rate of 500 mm/min. Li et al. [10] investigated influence of sheet material to produce a truncated cone and a truncated pyramid by experimental tests on AA7075- O sheets. It was found that the predicted forces were in good agreement with the experimental results. Davarpanah et al. [11] experimentally examined effects of wall angle on polymer sheets using SPIF. Results showed that there is an increase in the axial forces with an increase wall angle.

Literature reveals that axial force (Fz) produced during SPIF is of great importance as it determines forming capacity of machine tool. Hence, it is necessary to investigate axial force component for safe utilization of the machine tool. SPIF is characterized with different input parameters which regulate this forming process. This die-less process is still limited in manufacturing industry due to lack of information about the effecting process variables like wall angle, tool diameter and sheet thickness etc. [12-13]. This work focuses on studying influence of sheet thickness, wall angle and tool diameter on axial peak forces on AA2024-O sheets. AA2024-O aluminum alloy finds application in aerospace and automobile industries. Conical frustums of constant wall angle have been formed with hemispherical headed forming tools. Table 1 shows the process parameters investigated with their levels. Each parameter is studied at three levels taking other process variables constant as tool diameter 11.60 mm, wall angle 64°, spindle speed 1000 rpm, feed rate 1500 mm/min, sheet thickness 1.2 mm and step size 0.5 mm. Castrol lubricant oil Alpha SP 320 was applied on sheet in order to reduce friction at tool-sheet interface.
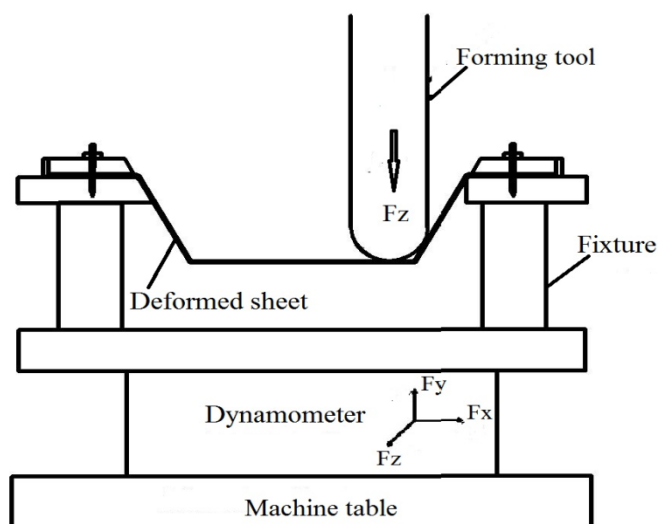

Fig. 1: Schematic representation of forming force measurement set-up

Table 1. Process parameters and their levels

Parameter	Level 1	Level 2	Level 3	Level 4
Tool diameter (mm)	7.52	11.60	15.66	-
Wall angle (°)	52	56	60	64
Sheet thickness (mm)	0.8	1.0	1.2	1.4

Table 2. Chemical compositions of aluminum alloy used

Chemical composition (weight %)									
AA 2024-O	Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn
	91.50	0.10	4.60	0.30	1.70	0.80	0.50	0.10	0.20

III. MATERIALS AND METHODS

Experimental work has been performed on a 3-axis VMC. Chemical compositions of AA-2024 alloy sheets are given in Table 3. Forming tools are made of HSS and hardened to 64 HRC before finishing operation. Conical frustums of 120 mm upper diameter and 70 mm height are formed for selected wall angles. Helical tool path has been used in CAM package for tool trajectory. Forming forces in axial direction (Fz) have been measured using a strain gauge based dynamometer which was mounted below the fixture as shown in Fig.2. A data logger system equipped with Microscada software has been provided to dynamometer in order to facilitate the processed force values in PC based environment. ADC 0808 analog to digital converter has been used in data logger system.
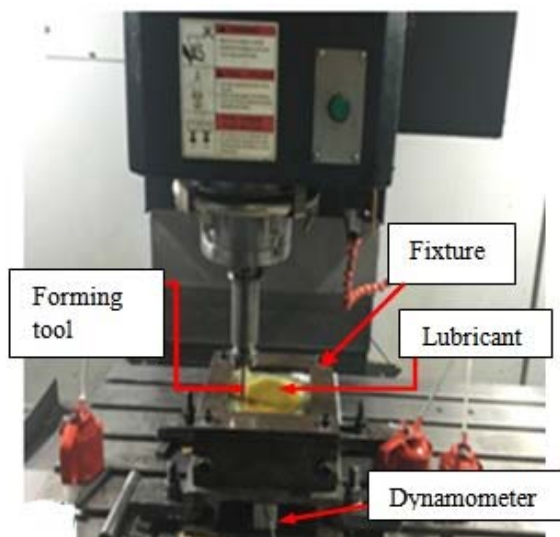

Fig. 2: Experimental set up

IV. RESULTS AND DISCUSSION

Table 3 shows the test results of experiments performed for wall angle, tool diameter and sheet thickness on axial peak forces (Fz max.). Influence of wall angle with different tool diameters has been depicted in Fig.3. Results showed that axial peak forces increases with increase in tool diameter and wall angle. For higher tool diameter, more material has to be pressed by the forming tool which leads to increase in required forming force. Similarly, for larger tool diameter, larger contact area is induced at the tool-sheet interface which results in increasing required forming force. This could become a limiting factor for hardware used for forming operation and should be avoided. Axial peak force was found to increase approximately 15.14%, 18.89%, 19.58%, and 20.03% for 52°, 56°, 60° and 64° wall angles respectively when punch diameter was increased from 7.52 mm to 15.66 mm. Similarly, axial peak force was increased by 26.71%, 28.67%, and 30.93% for 7.52 mm, 11.60 mm and 15.66 mm tool diameters respectively when wall angle was increased from 52° to 64°.

Table 3. Forming force test results with different process parameters

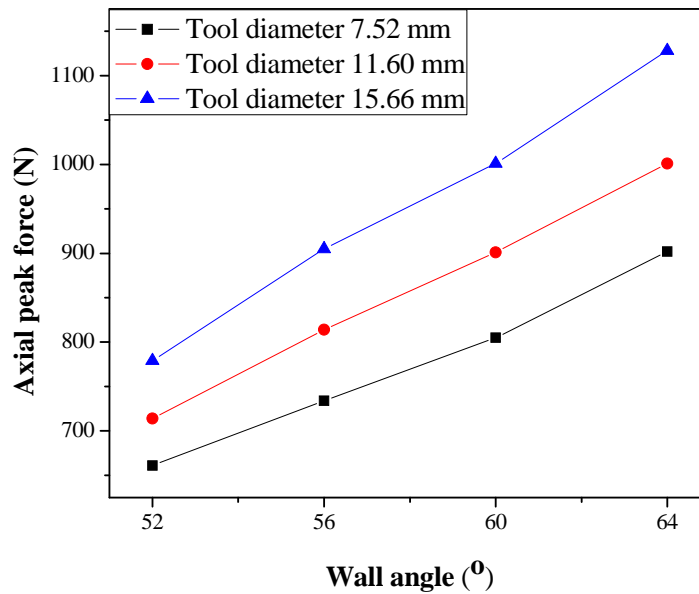| Axial peak force test results for wall angle and tool diameter				Axial peak force test results for sheet thickness and tool diameter			
Sr. no.	Wall angle (^{o})	Tool diameter (mm)	Fz max. (N)	Sr. no.	Sheet thickness (mm)	Tool diameter (mm)	Fz max. (N)
1	52	7.52	661	13	0.8	7.52	709
2	52	11.60	714	14	0.8	11.60	775
3	52	15.66	779	15	0.8	15.66	848
4	56	7.52	734	16	1.0	7.52	792
5	56	11.60	814	17	1.0	11.60	875
6	56	15.66	905	18	1.0	15.66	968
7	60	7.52	805	19	1.2	7.52	903
8	60	11.60	901	20	1.2	11.60	1003
9	60	15.66	1001	21	1.2	15.66	1127
10	64	7.52	902	22	1.4	7.52	1067
11	64	11.60	1001	23	1.4	11.60	1200
12	64	15.66	1128	24	1.4	15.66	1333

Fig. 3: Effects of wall angle and tool diameter on axial peak forces
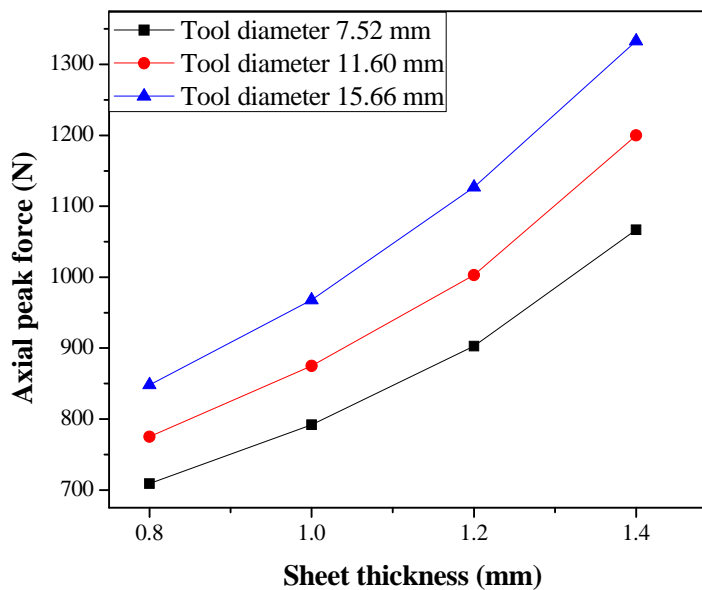

Fig. 4: Effects of sheet thickness and tool diameter on axial peak forces

Influence of sheet thickness with different tool diameters is depicted in Fig.4. Experimental results showed that axial peak force increased with increase in sheet thickness with all levels of tool diameters (7.52, 11.60, and 15.66 mm). This is due to the fact that more metal is subjected to forming per pass of the punch over the sheet requiring higher forming force to form a specific shape. Moreover, sheet fracture was occurred for combination of lower thickness and smaller tool diameter because smaller punch penetrates the sheet material and less material is available for delaying the fracture. This also indicated loss of formability. Axial peak force increased approximately 16.39%, 18.18%, 19.87%, and 19.95% for 0.8, 1.0, 1.2, and 1.4 mm sheet thicknesses respectively when punch diameter was increased from 7.52 mm to 15.66mm. When sheet thickness was increased from 0.8 mm to 1.4 mm, axial peak force was found to increase by 33.55%, 35.41%, and 36.38% for 7.52 mm, 11.60 mm and 15.66 mm punch diameter respectively.

V. CONCLUSION

In this study, influence of wall angle, tool diameter and sheet thickness has been investigated on axial peak forces on AA2024-O sheets experimentally using SPIF process. Conical frustums have been formed using helical tool path. Forming forces were found to increase with the increase in tool diameter, sheet thickness, and wall angle. Combination of larger tool diameter (15.66 mm in this case) and larger sheet thickness (1.4 mm in this case) produced maximum peak force (Fz max. = 1333 N, in this case) in axial direction which is a limitation to the hardware used for forming operation. Moreover, sheet fracture was occurred for combination of lower thickness and smaller tool diameter because smaller punch penetrates the sheet material and less material is available for delaying the fracture. This also indicated loss of formability. Future work would focus on analysis of formability and thickness reduction of the parts which seeks importance and suitability in setting guidelines for industrial application.

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