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# Experimental Investigation of Thickness Distribution in Incremental Sheet Forming for Aluminium

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**Abstract—***Incremental Sheet Forming (ISF) is gaining a lot of attention due to the ease with which it forms metal sheets to required shape and the capability of the process to form custom made products economically. The material used for the experimentation is Aluminium sheet AA1100 grade. This alloy is commercially pure aluminium with excellent forming characteristics. In this paper effect of four parameters namely Tool size, Spindle speed, Step size and Wall inclination on thickness distribution in ISF process is discussed. The results show that formability in ISF is highly variable with input parameters. It was found that the thickness in mid region of forming depth is less than the thickness at the corners. Further it was evident from results that wall inclination below 20° is not possible with single pass forming in ISF.*

## 1. INTRODUCTION

Incremental Sheet Forming (ISF) is gaining lot of attention due to the ease with which it forms metal sheets to required shape and the capability of the process to form custom made products economically. This method does not require use of conventional die sets which are bulky as well as costly. It simply needs a fixture to clamp the sheet and a CNC machine or a robot manipulator for tool movement. A lot of literature is available in this field, however thickness distribution in ISF still needs to be studied. Fig. 1 illustrates how the metal is deformed incrementally in this process.

Kim and Park [2] performed a number of experiments and found that the formability is affected by the process parameters such as: by increasing the tool diameter, pitch and feed rate, the formability of metal decreases. Wei et al [3] performed a series of experiments and concluded that the thickness in incrementally formed part can be predicted by $t = t_0 \cos \theta$ (Cosine Law). Jun-chao et al [4] investigated thickness distribution in incremental sheet forming by simulations and verified it experimentally, they found that the Sine Law is followed mainly in region subjected to pure stretching deformation and its predictive value is slightly less than the real one. The authors claim that minimum thickness value much more associated with the tool diameter. Mugendiran & Gnanavelbabu [5] found thickness distribution in cone shapes is better than thickness distribution in square shapes. They also concluded that restrictions to tool path reduces flow of material thus decreasing the formability.

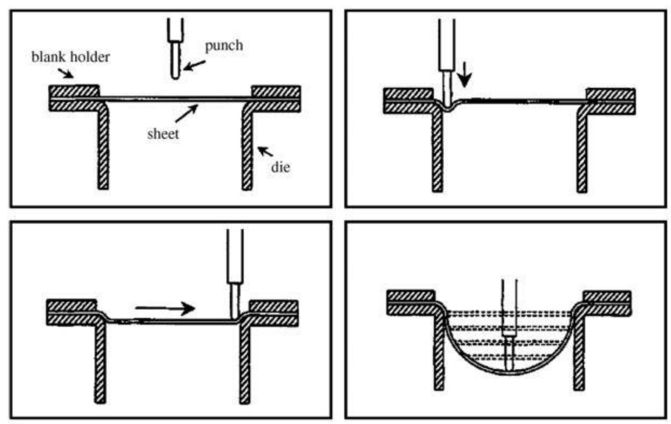


**Fig. 1: Deformation in sheet metal during incremental sheet forming process [1]**

In the present work effect of four parameters namely Tool diameter, Spindle speed, Step size and Wall inclination was tested on thickness distribution of Aluminium AA1100 sheets in ISF process.

## 2. MATERIAL & METHODOLOGY

### 2.1 Material

The material used for the experimentation is Aluminium sheet AA1100 grade. The thickness of sheet is 0.5 mm. This alloy is commercially pure aluminium with excellent forming characteristics. It is commonly used in heat exchanger fins, rivets, reflectors, sheet metal works, decorative parts and cooking utensils. It is suitable for cold working. This alloy contains minimum 99% of Aluminium, maximum 0.1% of Zinc, 0.05-0.2% Copper, 0.05% of Manganese & maximum 0.95% of Iron and Silicon. [6] The various material properties are mentioned in Table 1.

Formability mainly depends on the material properties such as tensile strength, strength coefficient, strain hardening and percentage of elongation [2]. Percentage elongation in material plays a dynamic role in metal forming processes. More the elongation of sheet metal more is the formability.

**Table 1: Material parameters**

| Parameter | Value |
|---|---|
| Material | Aluminium AA1100 |
| Density | 2710 Kg/m3 |
| Poisson ratio | 0.33 |
| Young's modulus | 70 GPa |
| % elongation | 12 % |
| Yield Strength | 105 MPa |
| Tensile strength | 110 MPa |

## 3. METHODOLOGY

To carry out the experiments, numerically controlled milling machine SURYA VF 30 was used. The fixture used during this research work along with the Vertical Machining Centre (VMC) is shown in Fig. 2(a). The Fig. 2(b) portraits hemispherical tools used. The blank (250 X 250 mm) is rigidly clamped in fixture.

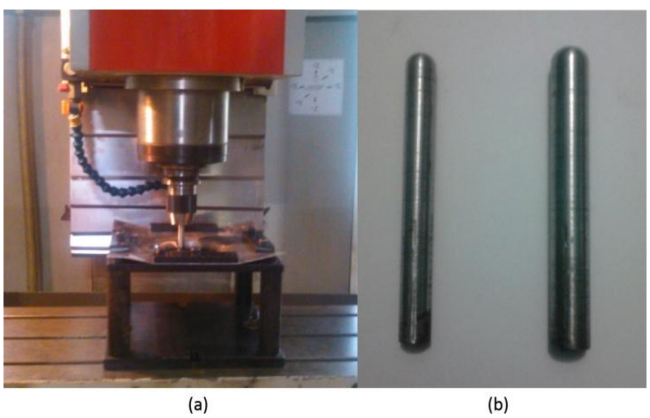


**Fig. 2: (a) VMC machine (b) Tools used**

The geometry chosen for experimentation is a truncated cone with diameter 130 mm. The tool trajectory is determined from the CNC program. CNC machine controls the tool motion and defines the tool trajectory. Rotating tool caused local plastic deformation and tool movement causes biaxial stretching and plane stretching which leads to deformation in sheet. The programming was done using NX 7.5 manufacturing module. The desired part geometry and the tool path trajectory are shown in Fig. 3.

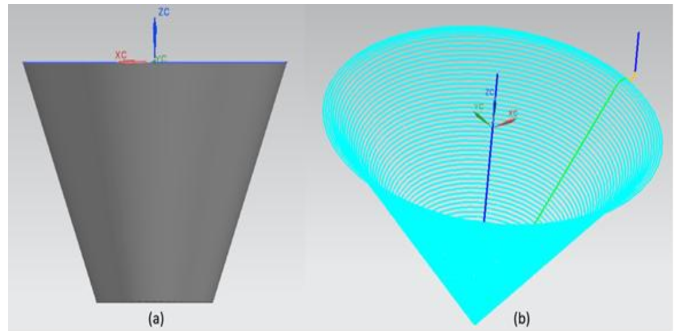


**Fig. 3: (a) Desired geometry (b) Tool path trajectory**

The experiments were designed with Taguchi's orthogonal tables to reduce the number of total experiments needed to perform. The four factors with their levels used are shown in Table 2.

**Table 2: Experiment design**

| Exp. No. | Step size (mm) | Wall inclination (Degrees) | Tool diameter (mm) | Rotational Speed (RPM) |
|---|---|---|---|---|
| 1 | 0.1 | 20 | 8 | 100 |
| 2 | 0.1 | 30 | 10 | 500 |
| 3 | 0.1 | 40 | 10 | 1000 |
| 4 | 0.5 | 20 | 10 | 1000 |
| 5 | 0.5 | 30 | 10 | 100 |
| 6 | 0.5 | 40 | 8 | 500 |
| 7 | 1 | 20 | 10 | 500 |
| 8 | 1 | 30 | 8 | 1000 |
| 9 | 1 | 40 | 10 | 100 |

In all these experiments the feed rate was kept constant to 800 mm/min. Each experiment is repeated two times to avoid environmental error. A lubricant was used to reduce the friction coefficient and thus wear of sheets. The wall inclination angle is with respect to vertical reference.

## 4. RESULT & DISCUSSION

The parameter of interest in this study was the thickness after incrementally forming sheet. The experiments were carried out and afterward the thickness of each sheet was measured at an interval of 1 cm. the sheets were cut in pieces so as to measure the thickness accurately.


**Fig. 4: (a) Formed sheet (b) Measurement Method**

The successfully formed components are shown in Fig. 4 (a). The thickness was measured using micrometre, measurement method is shown in Fig 4(b).

The Table 3 provides results of experimentation, whether forming was successful or not, average sheet thickness after forming and the minimum sheet thickness values. The sheets in which crack was initiated prior to reaching the desired depth were considered unsuccessful.

It is evident from the table that the ISF process is highly sensitive to the input parameters. Five of the nine experiments were unsuccessful.

**Table 3: Result of experiment, average & minimum thickness**

| Exp. No. | Result | Average thickness | Minimum thickness |
|---|---|---|---|
| 1 | Unsuccessful | - | - |
| 2 | Successful | 0.343 | 0.29 |
| 3 | Successful | 0.44 | 0.37 |
| 4 | Unsuccessful | - | - |
| 5 | Unsuccessful | - | - |
| 6 | Successful | 0.452 | 0.41 |
| 7 | Unsuccessful | 0 | - |
| 8 | Unsuccessful | 0 | - |
| 9 | Successful | 0.425 | 0.39 |

It is observed that when the wall inclination was small i.e. 20°, the cracks were developed prior to reaching desired depth. Cracked sheets are shown in Fig. 5.

**Fig. 5: Cracked sheet**

The apparent reason can be excessive tool – sheet contact which causes high wear in sheets leading to cracks. A graph was plotted for measured thickness as a function of forming depth for five experiments, as shown in Fig. 6.

The thickness in all sheets decreases rapidly in first 10 mm of forming indicated by a steep curve. The similar effect is seen on other end of curve i.e. on closed end of sheet. The thickness values increases in bottom part of sheet. The explanation for observed phenomenon can be given as in centre of forming depth the material is stretched on both the sides, whereas at the ends of the sheet sufficient material is available at one end for deformation which is mainly bending deformation. The thickness in middle depth remains fairly constant over certain depth.

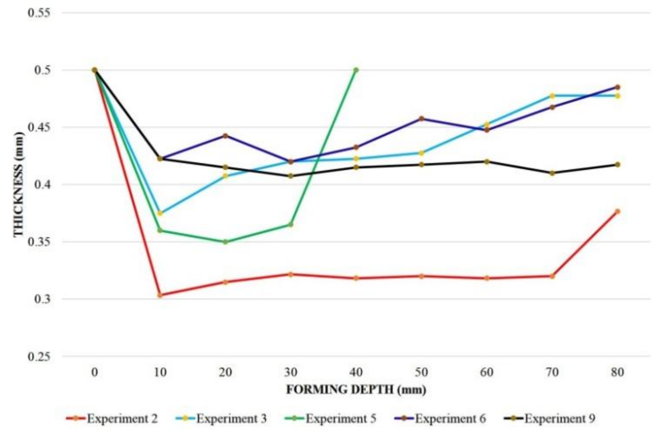


**Fig. 6: Graph of Thickness value vs. Forming depth**

## 5. CONCLUSIONS

The experiments were performed and the results were analyzed. Following conclusion can be drawn from the present study:

- Sheet formability in incremental sheet forming is highly dependent on input parameters as different sheet input parameters lead to different results for the same geometry.
- The sheet thickness at ends of sheet is higher as compared to the central region depth. The reason for observed results is, the uniaxial stretching from both side is experienced by material in this region.
- The results show that the sine law is obeyed by the process with actual thickness little more than that of predicted thickness in accordance with Jun-chao et al [4].
- The results show that, wall angle below 20° is not possible to form with single pass incremental forming. Multi-pass forming may be useful for that.

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