Experimental investigation on AISI 304 steel sheets formed by multi stage incremental forming

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Abstract. Incremental sheet forming (ISF) is an sheet metal process which can be used widely in the area of automobile, medical and aeronautical application. The required shape of the final product is achieved by moving the rotating tool along the pre-determined path controlled by computer numerical controlled (CNC) milling machine. This paper explains the multi stage process to achieve the maximum wall angle in the cylindrical cup shaped component. The experiments were conducted using austenitic stainless steel AISI304 of 0.8mm thickness. In this work multi stage forming process was carried out in two stages (i). Starting from wall angle of 50° and (ii). Increasing the wall angle from 50° to 70° by keeping the tool traversing (1000 mm/min) and incremental depth (0.5mm) as constant for various tool rotational speeds of 600, 800 and 1000 rpm to maximum possible depth without the occurrence of fracture. In multi stage forming, with a wall angle of 70°, the maximum depth achieved was 21.3 mm before fracture at a tool parameters of 1000 rpm tool speed, 1000 mm/min tool traversing speed and 0.5mm incremental depth within the experimented process parameters.

Keywords: Incremental forming, Wall angle, AISI 304, tool rotational speed, tool traverse speed

1. Introduction

Incremental forming, also known as a die less forming process, is one of the non-traditional sheet metal forming processes. It is used for rapid prototyping which is widely used in automobile, aeronautic and bio-medical industries. The required size and shape of the final product is achieved by a hemispherical tool which rotates at constant rpm and travels in the predefined path using CNC vertical milling machine. The maximum wall angle and depth of the component is attained by varying the process parameters like step down size, tool speed and tool feed.

Incremental sheet forming process is performed on different sheet materials like aluminium alloys, magnesium alloys, titanium and stainless steel sheets. Researchers have studied the incremental forming of stainless steel sheet material using single stage process [1, 2] for various wall angle and maximum depth. Sa'id Golabi and Hossain Khazaali [2] have reached maximum depth of 11.75mm at wall angle of 68° in 0.5mm thickness AISI304 sheet. Moayedfar et al. [3] have studied the optimum parameters to achieve the maximum possible wall angle and depth in a pyramid shaped component. It
was concluded that the maximum wall angle of 60° with 25mm depth was reached at a spindle speed of 1000rpm and feed rate of 500mm/min. Increase in wall angle produced thinning and fracture when the desired depth is more in case of single stage incremental forming.

To overcome this, recently few researchers attempted multi stage incremental forming process [4-8] by performing the forming in two or three stages. Among these, Tingting Cao et al.[5] were able to achieve a wall angle of 60° for a depth of 60mm in 1mm thick AA5052 and LiJunchao et al.[8] have reached a depth of 30mm with a wall angle of 60° in 0.8mm thick DC06 steel sheet. To further investigate researchers [9-17] have used 5 stages of forming operation to attain a maximum wall angle and part depth. Kurra Suresh et al.[15] have reached maximum wall angle of 85° in a depth of 30mm in 1mm thick EDD steel sheet whereas Skjoedt et al.[11] have attained a 90° wall angle in a depth of 70mm in 1mm thick AA1050 sheet. Apart from the different stages of performing incremental process, few researchers have experimented with multiple tools [18-20] to achieve the maximum possible wall angle. Iseki and Naganawa used spherical and cylindrical rollers to reach maximum wall angle of 90° with 4mm depth in 0.3mm aluminum sheet.

From the literature survey, the following observations have been made: The researchers have investigated the effect of various process parameters on the success of forming in single stage incremental forming. But the design parameter of the component especially wall angle imposed difficulty in forming in most of the materials. So attempts have been made to overcome this difficulties by adopting the multi stage incremental forming process mostly in aluminum and magnesium alloy. Very few researchers have investigated using stainless steel but unable to achieve the required wall angle. The aim of this research work is to attain a maximum wall angle and a part depth in the multi stage incremental forming of stainless steel AISI304 sheet.

2. Experiment Procedure

2.1 Sheet Material and Tool

In this multi stage incremental process austenite stainless steel AISI304 of 120*120*0.8mm plate as received is used to produce a truncated cone shaped component. Table 1&2 shows the chemical composition and important tested mechanical properties of AISI304 respectively.

| Elements | C   | Cr  | Ni | Mn | Si   | P   | S   | Fe    |
|----------|-----|-----|----|----|------|-----|-----|-------|
| Wt %     | 0.075 | 18.47 | 8.45 | 0.827 | 0.563 | 0.037 | 0.002 | Balance |

Table 1. Chemical Composition of AISI304

| Property                   | Observed values |
|----------------------------|-----------------|
| Yield Strength (MPa)       | 295             |
| Ultimate Tensile Strength (MPa) | 691         |
| % Elongation              | 64.5            |
| Hardness (Vickers)        | 205             |

Table 2. Mechanical properties of AISI304

High Carbon High chromium (HCHCr) tool steel is the material used for incremental forming tool which has a hemispherical end with 14mm diameter and overall length of 100mm. The tool is maintained at a hardness of 50 to 52HRc by heat treatment process.

2.2 Machine and Process parameters

The experiments were performed using 3 Axis CNC Vertical milling machine of make LITZ Hitech MV 800 Model, Mitsubishi M70 controller with maximum spindle motor power of 7.5KW and
spindle speed of 10000rpm. Cimatron E10-SP3P1 software was used to generate the tool path from the 3D model of the component to be made. The workpiece material is clamped in the specially made fixture which has a opening of 90mm diameter. Experiments were conducted using different tool rotational speed of 600, 800 and 1000rpm and maintaining the tool traversing speed (1000mm/min) and incremental depth of 0.5mm as constant. Blasco cut 4000 strong water soluble lubricant was used during forming process. Figure 1 shows the fixture, tool used and forming process.

![Figure 1](image1.png)

**Figure 1.** (a) Fixture used; (b) Incremental forming tool; (c) Incremental forming process

### 2.3 Multi Stage Strategies

From the literature it is found that, in a single stage forming, the component was successfully made with a wall angle of $63^\circ$ but the maximum height achieved was approximately 15.5mm only[2]. Hence the experiments were started in the current multi stage forming process with the wall angle of $50^\circ$ in stage 1 and $60^\circ$ in stage 2. Further experiments were carried out by varying the parameters like tool speed and step down size to identify the maximum depth.

### 3. Results and discussion

During single stage process, the experiments were initiated with a wall angle of $60^\circ$ by setting the process parameters of 600 rpm tool speed and 1000mm/min tool feed rate at step down size of 0.5mm. Table 3 shows the maximum depth achieved at different wall angle in a single stage forming process.

| AISI304  | Wall Angle (degree) | Depth (mm) |
|----------|---------------------|------------|
|          | 60                  | 45         |
| 0.8mm sheet | 65                  | 45         |
|          | 70                  | 17.5       |

It is observed that the part depth of 45mm was achieved for the given parameters without any fracture; hence wall angle of $5^\circ$ was increased for the next experiment to check the influence of same parameters. For $65^\circ$, the depth of 45mm was achieved successfully, but for $70^\circ$ the material fractured at a depth of 17.5mm due to thinning of sheet. Figure 2 shows the components formed with a wall angle of $60^\circ, 65^\circ$ and $70^\circ$. 

![Figure 2](image2.png)
Figure 2. Single stage incremental forming process at different wall angles (a) 60°, (b) 65°, (c) 70°

Figure 3. Shows the two stage process in multi stage incremental process.

Figure 3 shows the multi stage strategy used in Incremental forming. The maximum possible part depth at various tool rotational speeds is shown in Figure 4.

Figure 4. Multi stage process-tool rotational speed vs depth achieved

In First stage, the part depth of 15mm at 50° wall angle was made constant parameters of 0.5mm step down size, tool feed rate of 1000mm/min and 600 rpm tool speed. Without changing the parameters
from single stage, the multi stage process is continued by increasing the wall angle to $70^0$ to achieve the required part depth of 45mm. Forming process was smoothly continued until the depth reaches 21.3mm and fracture has occurred at this depth. The various components produced with a wall angle of $70^0$ at different tool speeds are shown in Figure 4. From the figure 5 it is observed that wrinkling is seen on the surface of the components at the experimented speeds. It may be due to the fact that, at lower tool rotational speeds of 600 & 800rpm, buckling at large lateral deformation causes wrinkle to form. Further increase in the speed to 1000 rpm reduces the formation of wrinkling due to the reduction in the buckling force.

![Figure 5](image)

**Figure 5.** Multi stage process sheets with $70^0$ wall angle at different tool rotational speeds (a) 600 rpm; (b) 800 rpm; (c) 1000 rpm

In order to check further, step down size was increased to 0.6mm by keeping feed rate of 1000mm/min as constant. The tool rotational speeds are same as that of those used in 0.5mm step down experiments. From the result, it is observed that part depth achieved is lesser than the previous one as shown in Figure 6. It is due to the fact that the force between the blank holder and increased pulling effect by the rotating tool increases the thinning and subsequently fracture occurs.

![Figure 6](image)
4. Conclusions

In this study, the experiments were carried for different wall angles, various rotational speeds and two step down size values at a constant tool traversing speed of 1000mm/min for 0.8mm thickness AISI304 stainless steel sheet.

- In single stage process, for 60° and 65° wall angle, part depth of 45mm was achieved successfully for tool rotational speed of 600 rpm and 0.5mm step down size.
- During multi stage process, for 70° wall angle the maximum part depth of 21.3mm was achieved before fracture at a tool rotational speed of 1000rpm with 0.5mm step down size.
- Further study were conducted by increasing the step down size to 0.6mm with same process parameters used for multi stage result in decrease of required part depth.

Further research on five stage incremental forming process is under progress.

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