

# A Comparison of Single Point Incremental Forming Formability between Carbon Steel and Stainless Steel

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**Abstract**—In sheet metal forming process, raw material mechanical properties are important parameters. This paper is to compare the wall's incline angle or formability of SS 400 steel and SUS 304 stainless steel in single point incremental forming. The two materials are ferrous base alloyed, which have the different unit cell, mechanical property and chemical composition. They were forming into cone shape specimens having 100 mm diameter with different wall's incline angle: 90°, 75° and 60°. The investigation was continued until the specimens formed surface fracture. The experimental result showed that the smaller the wall incline angle higher the formability with the both materials. The formability limit of the ferrous base alloy was approx. 60° wall's incline angle. By nature, SS 400 has higher formability than SUS 304. This result can be used as the initial data in designing the single point incremental forming parts.

**Keywords**—NC incremental forming, Single point incremental forming, Wall incline angle, Formability.

## I. INTRODUCTION

AN industrial application of single point incremental forming (SPIF) process is dramatically increasing due to its flexibility and economic process of the SPIF. There are a lot of process parameters that have affected to the quality of the SPIF such as material, tool size, tool geometry, tool speed, toolpath, depth step side step, lubrication and part geometry. Nowadays, the SPIF research subject was pointed to study the formability of different kinds of materials such as titanium, aluminum, steel and polymer. However, there are some limitations of the ductile material and the materials that get formed at high temperature. Stainless steel is the ferrous base alloy that is sensitive to hardening and stress crack after forming or delay cracking (See Fig. 1).

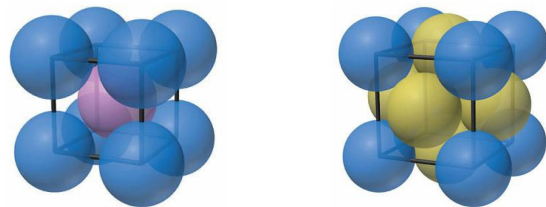


Fig. 1 Delayed cracking after deep drawing of austenitic stainless steel with different drawing ratio [1]

Stainless still can be classified into 5 groups depending on its microstructure. In this research the austenitic stainless steel SUS 304 was selected to compare with SS 400 steel because

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it's a low cost stainless steel, has better mechanical properties than normal steel, and doesn't corroded in atmospheric environment. The atomic arrangement of SUS 304 is "Face Center Cubic" which differs from "Body Center Cubic" in steel (See Fig. 2). And the mechanical property and chemical composition of both are shown in Table I and II. The aim of this research was to compare the formability between SS 400 steel and SUS 304 stainless steel in term of wall's incline angle. The SPIF process is characterized by increased material formability, higher strains over 300% than observed in deep drawing [2]-[5].



(a) SS400 atomic arrangement (b) SUS304 atomic arrangement

Fig. 2 Atomic structure (a) SS400 steel (BCC) and (b) SUS304 stainless steel (FCC) [6]

TABLE I  
MECHANICAL PROPERTIES OF SS 400 AND SUS 304

Name of material	SS 400	SUS 304
Density (kg/m <sup>3</sup> )	7860	8000
Young's Modulus (GPa)	190-210	190
Tensile Strength (MPa)	400 – 510	520
Yield Strength (MPa)	205-245	240
Poisson's ratio	0.26	0.27-0.30
Brinell Hardness (HB)	160	88
Melting Point (°C)	1430	1400-1450

TABLE II  
CHEMICAL COMPOSITION OF SS 400 AND SUS 304

Name of material	SS 400	SUS 304
Carbon (C)	≤0.2%	≤0.08%
Silicon (Si)	not controlled	≤1.00%
Manganese (Mn)	not controlled	≤2%
Phosphorus (P)	≤0.05%	≤0.045%
Sulphur (S)	≤0.05%	≤0.030%
Nickel (Ni)	-	≤8-10.5%
Chromium (Cr)	-	≤18-20%

The recent studies have shown that the SPIF forming limit that plotted in the FLDs plane in Fig. 3 was a straight line with a negative slope over the conventional process forming limit curve [7]. Regarding other investigations, the initial thickness of the material has an impact upon the formability of the material according to the simple geometry [8]-[11]. It is

recognized that the material behaviour and maximum formability in SPIF can be described conveniently by the maximum value of the wall's incline angle [12]-[15]. As this angle increases when the thickness reduction reaches a minimum value where fracture occurs as a consequence.

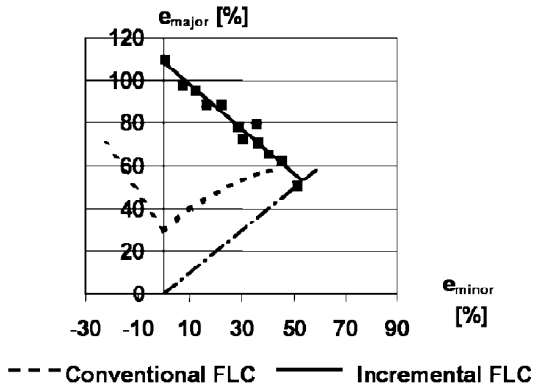


Fig. 3 Conventional FLC of AA1050 and Incremental FLC [3]

## II. EXPERIMENT

Many parameters can influence the SPIF process and some can be considered as not so important as well. For this reason, this experiment was designed to demonstrate only the formability in terms of wall's incline angle. Then many other parameters were assumed as fixed parameters: the configuration tool had a hemispherical 10 mm diameter, the average surface roughness of tip was about 0.21 micron; the rotational tool speed was 100 rpm; the feed rate of the tool was 3140 mm/min with 1 mm depth step and 3 mm side step and it was lubricated with SAE 46 oil.

The 3 axis CNC milling machine "Bridgeport VMC 600X" was used in experiment, the machine specification is shown in Table III. The all equipment of SPIF and CNC machine tool are shown in Fig. 4. The thickness of the blank sheet was 0.8 mm with 250 mm diameter that was clamped at the periphery by a blank holder.

The toolpath was generated by economics CAM program (UG NX-3) as a repeated reversed spiral until the final profile was finished, and its directions were accordingly to the vector of rotational speed to avoid the sliding movement and rubbing between tool and blank sheet. The blank sheet was formed into the 100 mm diameter cone shape with 90°, 75° and 60° wall's incline angle. The formability was evaluated by fracture or tearing of formed specimens on the CNC milling machine.

## III. RESULT AND DISCUSSION

It could point out that thinning of SPIF specimen plays a basic role in SPIF process. The thinning in SPIF is larger than in conventional deep drawing due to the stress and strain conditions in the process. The experimental results are shown in Figs. 5-7. In Fig. 5, the depths of SS 400 and SUS 304 with 90° wall's angle forming specimens were equal to 12 mm. before tearing was occurred. The specimens were tearing at the bottom corner radius. The specimen's wall appeared to be

the thickest. The specimens in Fig. 6 were at 75° wall's angle, SS 400 was 22.5 mm. depths until fracture, but SUS 304 was approx. 3 mm. lower than SS 400. The specimen's wall was moderate thinning, and the tearing was occurred at the bottom corner radius too. And 60° wall's angle was formed specimens as shown in Fig. 7 with a fracture at the apex of cone because the forming tool was pressed against the bottom without tool movement (tool feed rate is 0 mm/min). The depth of SUS 304 was approx. 9 mm lower than SS 400. The specimen's wall was the most thinning one.

TABLE III  
THE CNC MACHINE TOOL SPECIFICATION

CNC MACHINE TOOL	BRIDGEPORT VMC600X
CNC controller	Fanuc 18i
Number of axis	3 axis
Machine travel capacity	X = 600, Y = 410, Z = 520 (mm)
Max. and Min. spindle speed	100-12,000 [rpm]
Table	X= 840, Y = 420 (mm)

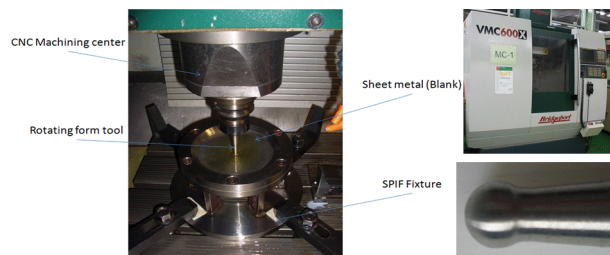


Fig. 4 The SPIF equipment, tool and CNC machine tool

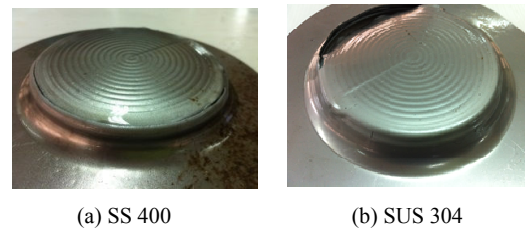


Fig. 5 90° Wall's incline angle (a) SS 400, (b) SUS 304

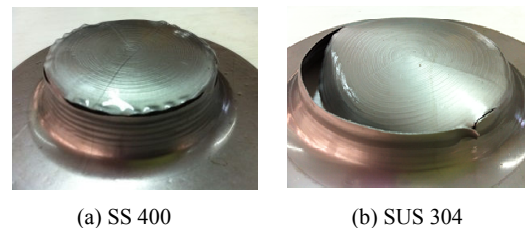


Fig. 6 75° Wall's incline angle (a) SS 400, (b) SUS 304

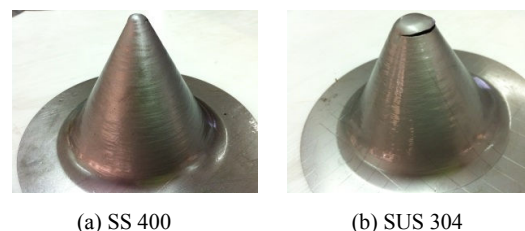
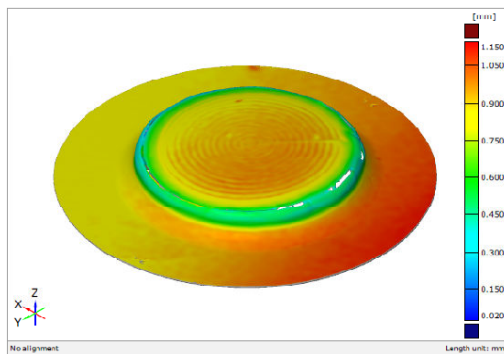


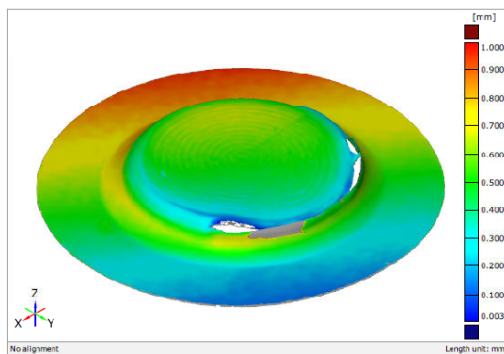
Fig. 7 60° Wall's incline angle (a) SS 400, (b) SUS 304

The experimental specimens were evaluated for their thickness distribution by GOM 3D scan technic according to the results as show in Figs. 8 through 10. It can be seen that the thickness distribution was dependent to the wall's incline angle. Decreasing wall's incline angle, the thickness uniformity was increased. In Fig. 8, the thinnest specimen was located at the bottom corner radius. The thinning observed at the flank and shoulder radius of both was less.

As Fig. 9 shows, the most critical areas for SS 400 and SUS 304, the two specimens are located at the corners as same as shown in Fig. 8. And in Fig. 10 the thinness specimens of both SS 400 and SUS 304 are demonstrated. There was a smooth thinning distribution, the wall thickness was about 0.3 mm.

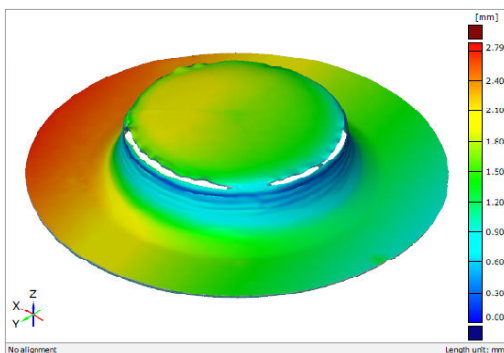


(a) SS 400 thickness distribution

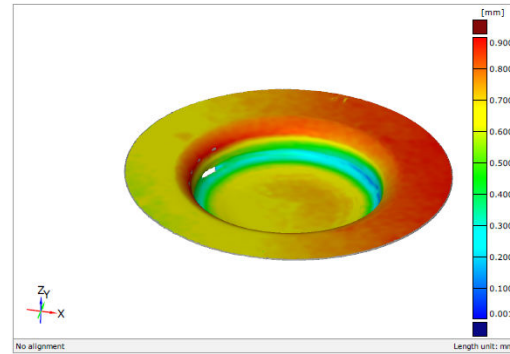


(b) SUS 304 thickness distribution

Fig. 8 Thinning of 90° Wall's incline angle (a) SS 400, (b) SUS 304

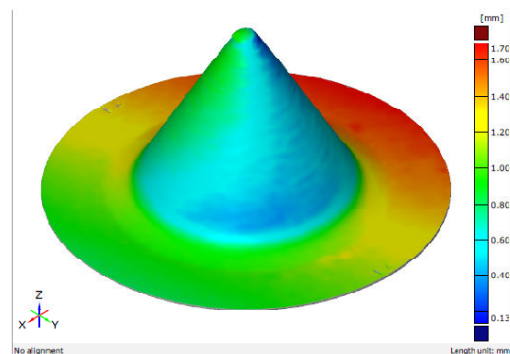


(a) SS 400 thickness distribution

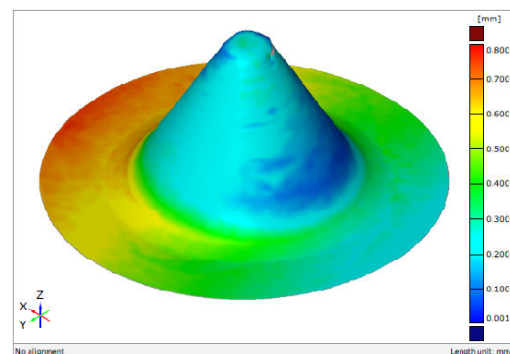


(b) SUS 304 thickness distribution

Fig. 9 Thinning of 75° Wall's incline angle (a) SS 400, (b) SUS 304



(a) SS 400 thickness distribution



(b) SUS 304 thickness distribution

Fig. 10 Thinning of 60° Wall's incline angle (a) SS 400, (b) SUS 304

#### IV. SUMMARY

In this study, the experiment was conducted to evaluate and compare the formability between SS400 steel sheet and SUS 304 stainless sheet by the use of single point incremental forming. In the experiment, collections of specimen cones were produced by varying the wall's incline angle in 3 steps 90°, 75° and 60° in order to investigate the maximum wall's angle which forming without fracture or tearing of the specimen wall. The results demonstrated that formability limit of SS 400 steel and SUS 304 stainless steel which formed by SPIF process were accordingly to the maximum wall's incline

angle approx.  $60^\circ$ . From the observation of specimen wall tearing, it was concluded that the maximum tearing occurred in the 2-axis tensile strain. Some observations were made and found out that the fracture or tearing of  $90^\circ$  and  $75^\circ$  wall's incline angle specimen were appeared at the corner of specimen's bottom. The tearing was caused by necking mechanism of material under tensile stress. The stress crack after forming of SUS 304 specimen or delayed cracking was not occurred. It can be assumed that SPIF process induced the less residual stress in the specimen wall than deep drawing process. This result could be used as the initial data in designing the single point incremental forming parts; a designer is able to design the SPIF part which has the wall's incline angle of less than  $60^\circ$ .

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