Technical Report

Improvement of the Square Shell Drawability of the NSSC 2120™ Sheet Using a Servo Press Machine

Takuya SAKURABA* Eiichiro ISHIMARU
Masatomo KAWA

Abstract

We aim to expand the NSSC 2120 market share by replacing SUS304 in sheet applications. SUS304 has diverse uses, so the formability of NSSC 2120 into sheets is a requirement. We explored methods of enhancing the square shell drawability, using a servo press machine whose press motion can be freely configured. Adopting a step motion avoids crack formation by controlling material inflow. In this way, square shell drawability similar to that of SUS304 was achieved in NSSC 2120.

1. Introduction

Lean duplex stainless steel is a resource-saving steel with high price stability as compared with austenitic stainless steel since the addition of rare metals such as Ni and Mo that imply the possibility of large price fluctuation is suppressed. Nippon Steel Stainless Steel Corporation has independently developed the lean duplex stainless steel of NSSC 2120 and NSSC™ 2351 capable of replacing SUS 304 and SUS316. One of the features of the steel is high strength as compared with that of existing austenitic stainless steel. Thickness and weight reduction realized by the properties has been propagated as a benefit to be enjoyed by users, and the expansion of the area of application is anticipated. Meanwhile, in the field of sheet usage, accompanied by the development of press-forming technology, the demand for press-forming configurations has become more complicated. Therefore, switching to NSSC 2120 from SUS304 that has high ductility and is formable to various configurations is anticipated to be difficult.

Therefore, we are developing a forming technology to enhance the formability of the duplex stainless steel using a servo press machine. Since a servo motor drives the crank shaft of a servo press machine, the selection of any press motions such as acceleration and/or deceleration of the punching speed, and the intermittent stop motion are readily possible. The formability enhancing effect by selecting an appropriate servo motion has been reported as follows: improvement of spring back generated in the bending work of high tensile strength steel material,[1, 2] the control of the press machine motion to enhance the deep drawing formability by utilizing the servo press function,[3] and the utilization of pulse motion.[4] This article reports the result of the study conducted to enhance the square shell drawability of NSSC 2120 to the level of SUS304 by referring to these reports.

2. Formability of NSSC 2120

2.1 Composition, microstructure, and tensile properties of NSSC 2120

The sample used in this study was taken from a steel sheet of the 2B product with a thickness of 1.0 mm of commercially produced NSSC 2120 (hereinafter referred to as N2120). In **Table 1**, the representative chemical composition is shown for comparison with that of SUS304. In N2120, the rare metals of Ni and Mo are reduced, and N is richly contained to stabilize the austenite phase. **Figure 1** shows the microstructure on the L-section. The grey part in Fig. 1 shows the ferrite phase (α phase) and the white part shows the austenite phase (γ phase). The microstructure of N2120 is a dual phase microstructure consisting of about 50% of the α phase and 50% of the γ phase. **Table 2** shows the tensile properties of N2120 and SUS304. The tensile test condition conforms to JIS Z 2241, and the strength was measured with JIS13 B test specimens taken in the direction of rolling. Comparing the tensile properties obtained, N2120

Table 1 Chemical composition

(mass%)

Material	C	Si	Mn	Cr	Ni	Mo	Cu	N
NSSC 2120	0.02	0.5	3.2	21.4	2.1	0.6	1.1	0.18
SUS304	0.06	0.4	0.8	18.3	8.6	0.2	0.3	0.04

* Researcher, Processing Technology Dept., Research & Development Center, Nippon Steel Stainless Steel Corporation
3434 Ooaza-shimata, Hikari City, Yamaguchi Pref. 743-8550

has 0.2% proof stress and tensile strength higher than those of SUS304. However, ductility is lower. **Figure 2** shows the true stress - true strain curves. In SUS304, the deformation-induced martensite phase is formed by deformation, work hardening takes place continuously, and it exhibits excellent uniform elongation by transformational induced plasticity (TRIP). On the other hand, in N2120, work-hardening is small, the n-value equivalent to that of ferritic stainless steel is exhibited, and the TRIP effect of the constituent phase of the γ phase does not take place.

2.2 Formability of N2120

To evaluate the formability, the Erichsen value and the limiting drawing ratio (LDR) were evaluated. The Erichsen test conformed to JIS Z 2247 B wherein the fold pressure was set at 10 kN, and the punching speed was 20 mm/min. The LDR measurement test was conducted as follows: Punch diameter: 40 mm, die diameter: 42 mm, blank diameter: 80 to 90 mm wherein the drawing ratio was changed by a 2 mm incremental change of the blank diameter. The folding pressure was set at 10 kN, and the punching speed was set at 20 mm/min, the punch was moved until drawing by the punch was completed and the punch passes throughout the die. LDR is the value of the maximum blank diameter that allows normal drawing with the punch throughout the die divided by the punch diameter. The result of measurement is shown in **Table 3**. N2120 having low ductility has a lower Erichsen value. The value of LDR that shows deep drawability is equal to that of SUS304.

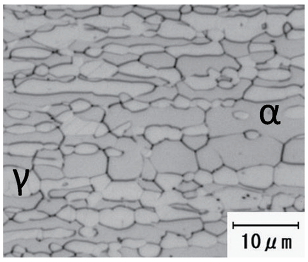


Fig. 1 Microstructure of NSSC 2120 (α phase: gray, γ phase: white)

Table 2 Mechanical properties of material

Material	thick-ness (mm)	0.2%PS (MPa)	TS (MPa)	EL (%)	n-value	r-value average
NSSC 2120	1.0	601	793	29.9	0.19	0.76
SUS304	1.0	324	694	51.7	0.43	0.98

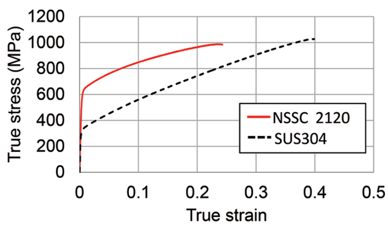


Fig. 2 True stress - true strain curve

Table 3 Forming properties

Material	Er-value (mm)	LDR
NSSC 2120	10.3	2.05
SUS304	12.4	2.05

3. Development of Forming Method by Utilizing Servo Press Machine

3.1 Test method

To evaluate the press formability, the square shell form was selected. In the square shell forming, draw forming and punch stretch forming are mixed. Therefore, we considered that the square shell forming is an effective method for evaluating the forming properties of a material. A servo press machine (DFS-N1-1500 of Aida Engineering, Ltd.) that allows the free selection of a servo motion was selected as the test press machine. **Table 4** shows the dimensions of the mold and the shape of the blank used in this test. One mm sheets of N2120 and SUS304 were used for the test. The blank shape was 170 mm square with its corners cut by 30 mm. Lubrication was provided by a thin coat of Johnson wax #122. Additionally, since image data processing was used for the measurement of the strain of the formed sample, the test sample was covered on both sides with a polyvinyl chloride (PVC) sheet to protect markers on the surface.

In **Table 5** and **Fig. 3**, the forming condition and the servo motion are shown, respectively. Two types of servo motion were set, and the evaluation of the formability of a square shell formed to a height of 50 mm was conducted. Spm shows the number of reciprocations of the punch per min, and the step motion shows the servo motion wherein the motion comes to a halt temporarily at a predetermined position during press forming and is restarted after a preset time. The step position was set at 20 mm from the bottom dead point and the step time was 1.0 s.

The result of the press-forming was evaluated as follows: visual inspection as to the occurrence of forming cracking, analysis of the transition of the punching load, comparison of the form and thickness distribution and strain analysis. 3D models were obtained using a scanner type 3D shape measuring instrument (VL-300 of Keyence Corp.), and the form was compared. The thickness was measured by an ultrasonic sheet thickness measuring instrument (MG45 of Olympus Corp.). The strain distribution was obtained by calculation using an image correlation method (ARGUS of GOM GmbH).

3.1.1 Square shell drawability by crank motion

Table 6 shows the results of press forming of two steels by the

Table 4 Mold dimensions and blank shape

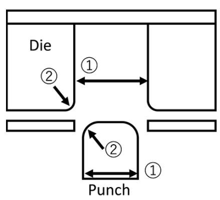
(a) Mold dimensions

	①Size	②Shoulder radius	③Corner radius
Punch	70×70 mm	8 mm	10 mm
Die	72×72 mm	6 mm	11 mm

(b) Blank shape and lubrication condition

	④Size	⑤Corner cut	Lubrication condition
Blank	170×170 mm	30 mm	PVC sheet+Johnson wax

(c) Mold



(d) Blank

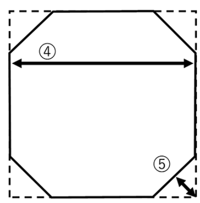


Table 5 Parameter of servo motion

Material	Servo motion	Spm	Real spm	Step		BHF
		number/ min	number/ min	Step position (mm)	Step time (s)	(kN)
NSSC 2120	Crank	5	5	–	–	150
	Step	5	3	20	1.0	150
SUS304	Crank	5	5	–	–	150

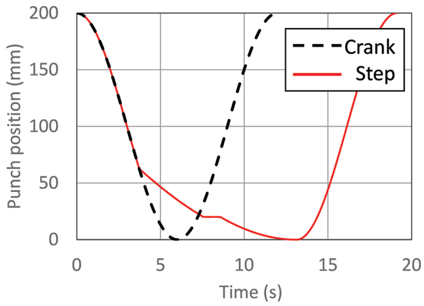


Fig. 3 Servo motion

Table 6 Results of press test

Material	Servo motion	Results	Cracking position
NSSC 2120	Crank	No good	Bottom of corner
SUS304	Crank	Good	No crack

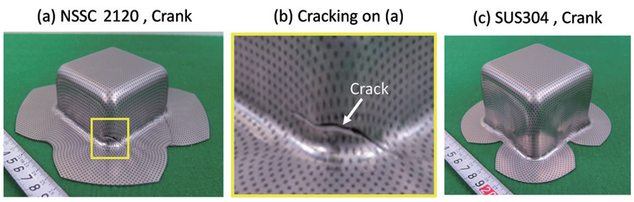


Fig. 4 Press sample of crank motion

crank motion, and **Fig. 4** shows the appearances of the press-formed samples. In N2120, a crack was developed when the forming height reached 30 mm. On the other hand, in SUS304, forming up to the height of 50 mm was possible. As shown in the enlarged center photo, the N2120 crack progressed from a point at 10 mm above the die R section, and progressed toward a section at the end of the straight side section (end of the corner R section) on the flange boundary. This N2120 cracking mode agrees with that of the wall break.

3.1.2 Square shell drawability of step motion

In **Table 7**, the result of press forming by the step motion, and in **Fig. 5**, the appearance of the sample formed by the step motion are shown. Due to the application of the step motion, forming up to a height of 50 mm without cracking was realized, and it was confirmed that a forming height equivalent to that of SUS304 is obtained.

3.2 Effect of servo motion on formability

3.2.1 Punching load transition

Figure 6 shows the punching load transitions of the press test using the crank motion and the step motion. The maximum load in pressing by the crank motion approximately agrees with that of the step motion. The following two points were confirmed in the load transition. The first is the drop of the load during the step motion, and the second is the increase of the load value immediately after restarting of the motion, as well as the growth to a value higher than the load of the crank motion. A similar study has reported that this phenomenon is a stress-relaxation effect.[5)]

Table 7 Results of press test

Material	Servo motion	Results	Cracking position
NSSC 2120	Crank	No good	Bottom of corner
	Step	Good	No crack

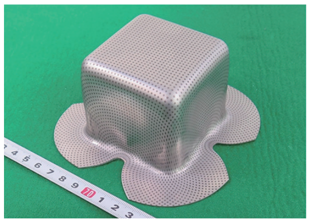


Fig. 5 Press sample of step motion

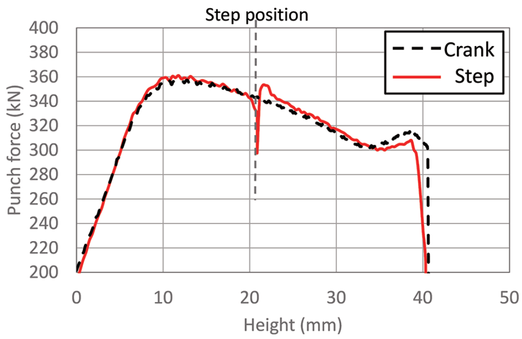


Fig. 6 History of punch force

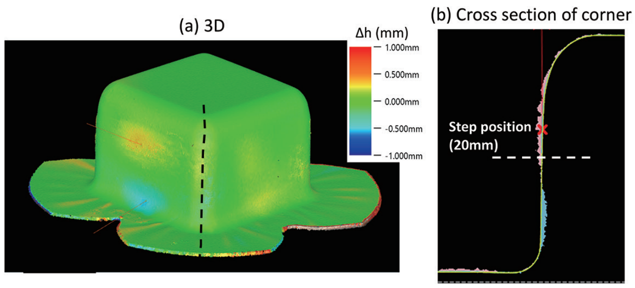


Fig. 7 Shape comparison results of 3D and cross section of corner

3.2.2 Result of comparison of 3D form

The 3D measurement of the form was conducted by photographing the entire circumference outlook of the press-formed sample using a scanner type 3D shape measuring instrument, and the 3D form was produced based on the positional information. A plain face on the punch side was registered as the tool reference plain, and the comparison and the evaluation of the form was conducted by visualizing the finite height difference.

Figure 7 shows the result of the comparison of the form obtained by the crank motion with that by the step motion, and a comparison of the shape of the cross section. The form obtained by the step motion is considered as the base, and the red color region shows the outward deformation of the form (convex) while the blue region shows the inward deformation of the form (concave). It is confirmed that in both the straight side section and the corner sec-

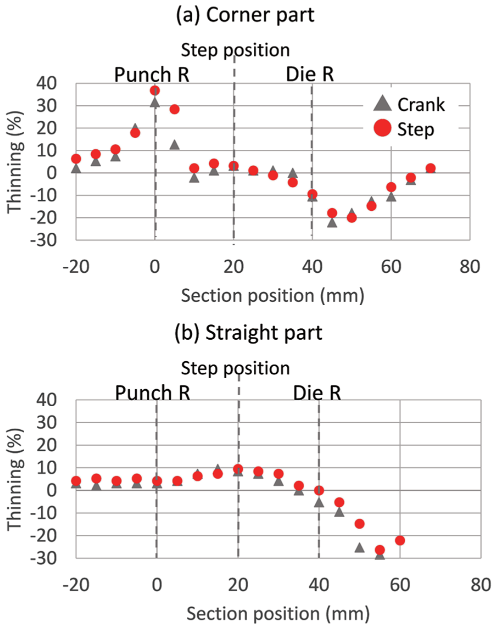


Fig. 8 Distribution of thinning

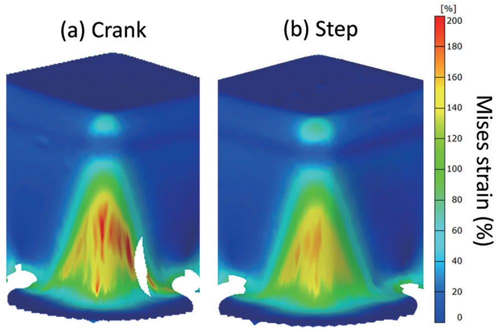


Fig. 9 Mises strain distribution map

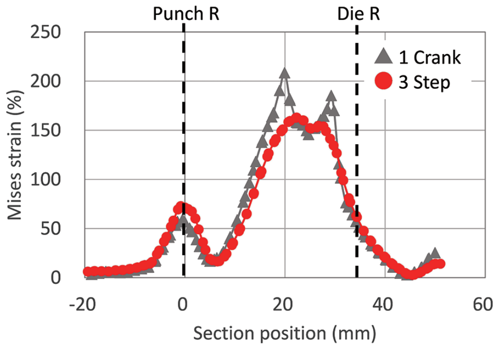


Fig. 10 History of Mises strain on corner

tion, the upper part of the wall is convexed while the lower part of the wall is concaved. Comparing the extent of deformations of the corner section and the straight side section, the deformation of the straight side section is larger. In Fig. 7(b), the definite shape difference of the corner section is shown, confirming that: the shape change of the corner section takes an S shape wherein the deformation of the top side is convexed and that of the bottom side is concaved, the material inflow in the press-forming by the crank motion is larger than that by the step motion, and surplus material exists in the side wall.

3.2.3 Result of measurement of sheet thickness

The measurement of the thickness was conducted in a non-destructive manner using an ultrasonic sheet thickness measuring instrument. The center point of the R section was considered to be the point of origin, and the measurement was conducted at a 5 mm pitch for the corner section and the straight side section.

The result of the sheet thickness measurement is shown in **Fig. 8**. Near the punch R section of the corner section, sheet thinning by the step motion is larger than that by the crank motion. Contrarily, the sheet thickness of the straight flange side section in the crank motion is larger than that in the step motion. In the corner punch R section and in the straight flange side section, the difference in sheet thickness due to the difference in press motions is significant. The shape difference confirmed in the previous paragraph and the sheet thickness distribution are considered to exhibit a similar trend. For instance, in the crank-motion pressed material that exhibited the S-letter shape, the material inflow is promoted, the overhang deformation is alleviated, and the sheet thinning is suppressed.

3.2.4 Result of strain distribution measurement

The strain distribution measurement was conducted by calculation using the image correlation method. On the surface of the sample before pressing, 1 mmφ dots with 1 mm separation were patterned, and then press-formed. Positions of the dots on the press-formed sample were image-analyzed, and the strain was obtained by measuring the amount of position change between before and after the press-forming.

In **Fig. 9**, the results of analysis of the strain at the corner section are shown and compared. Strain occurs only in the corner section regardless of the press motion. The difference in the press motions is clearly recognized as the remarkable difference in the amount of strain. In the crank motion, the region in which strain is largely concentrated is recognizable, exhibiting an inverted V shape. **Figure 10** shows a comparison of the strain in the center of the corner. It is clear that, in the punch R section, the amount of strain in the step motion is larger than that in the crank motion, and this agrees with the result of the sheet thickness measurement. The largest strain lies at the point about 20 mm away from the punch R section on the corner wall, and the difference in the amount from that in the step motion is obvious. From this strain distribution, the cracking of N2120 developed in the crank motion is confirmed as a wall break.

4. Improvement of Square Shell Drawability by Applying Servo Motion

One study has reported the improvement of sheet formability by optimizing servo motion[6], and the effect of dispersing strain by repeated lubrication and/or stress relaxation. Judging from its features as described above, the cracking that occurred in the crank motion square shell drawing test is considered as a wall break. A wall break is considered to be a cracking developed by the shearing strain at the point where there is a remarkable difference between the amount of inflow of the material at the corner section and that at the straight side section, and the difference in the amounts of the inflow becomes largest.[7] As is obvious from the result of measurement of the amount of strain in Fig. 9, the region wherein strain is concentrated is inverse-V-shaped, and the shape of the cracking is similar to the one observed in the wall break. A possible cause of the occurrence of the wall break is as follows: although the material inflow at the corner was promoted by the corner cutting of the blank material, the

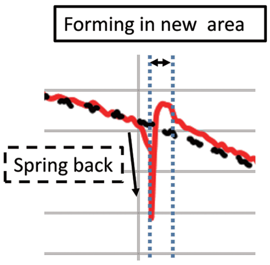


Fig. 11 Punch force before and after step motion

material inflow at the center of the straight side section is extremely significant, and the difference in the inflow rate increased markedly in the flange section.

On the other hand, in the step motion where cracking did not occur, although strain takes place in an inverse-V shaped region similarly to that of the crank motion, a concentrated region did not occur. As a factor that changed the strain distribution in the step motion, a spring back effect that takes place in the material at the step (halt) is considered. **Figure 11** shows the enlarged view of the punching load transition before and after the step. Decrease of the punching load at the step and the remarkable increase of the load upon restarting of the motion are confirmed, and the load reached the same level as that of the crank motion. This decrease of the load is considered to be attributed to the deformation of material by spring back. Due to this deformation, high strain points have moved, developing the dispersion of strain. Further, increase of the load upon restarting of the motion is considered to be due to work hardening newly generated in other places by the material spring back. The step-motion press-formed material has better press-formed form than that of the crank-motion press-formed material, and the effect of restrike is also generated.

From the above results, the factors of the step motion that improve formability are considered to be the following:

1) With the spring back at the stoppage of motion,
 (i) Remarkable material inflow takes place at the straight side section.
 (ii) Although material inflow takes place at the corner section to alleviate tension, the amount of inflow is small due to constraint.

2) At the restarting of the motion,
 (iii) Deformation is promoted at the straight side section to eliminate the surplus material caused by excessive inflow.
 (iv) In the corner section, the strain-concentrated point moves slightly, and deformation is restarted.
 (v) The difference in the amount of inflow of the material between the one at the straight side section and the one at the corner section decreases, preventing the occurrence of the wall break.

5. Conclusion

We developed a press-forming method to improve the square shell drawability of NSSC 2120 by utilizing a servo press machine, and obtained the following results.

(1) NSSC 2120 shows 0.2% proof stress of 600 MPa with 30% of fracture elongation, and exhibits the tensile properties of high strength, low ductility as compared with SUS304.
(2) Regarding forming properties, although the r-value is as low as 0.78, the steel exhibits the limiting drawing ratio (LDR) of 2.05 that is equivalent to that of SUS304.
(3) In the square shell forming test of NSSC 2120 conducted by crank motion press-forming under the same press-forming condition with that of SUS304, a wall break occurred.
(4) By forming with step motion press-forming, the square shell drawability of NSSC 2120 is improved, and the forming height equivalent to that of SUS304 is realized.
(5) The improvement of the formability by step motion press-forming is considered to be attributed to the relaxed rate of material inflow due to the deformation caused by spring back at the time of the stoppage of motion.

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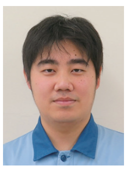

Takuya SAKURABA
Researcher
Processing Technology Dept.
Research & Development Center
Nippon Steel Stainless Steel Corporation
3434 Ooaza-shimata, Hikari City, Yamaguchi Pref.
743-8550

Eiichiro ISHIMARU
General Manager, Dr. of Eng.
Processing Technology Dept.
Research & Development Center
Nippon Steel Stainless Steel Corporation

Masatomo KAWA
Senior Researcher
Plate, Bar & Wire Rod Research & Development Div.
Research & Development Center
Nippon Steel Stainless Steel Corporation