KSME International Journal, Vol. 15, No. 7, pp. 839~846, 2001

A Study on the Warm Deep Drawability of Sheets in Cr-Coated Die

Jae Dong Lee, Young Moo Heo, Sung Ho Chang
Sungkyunkwan University Graduate School, Kyunggi-do 440-746, Korea
Yi Chun Choi
Kia Motors Corporation, Seoul 152-838, Korea
Heon Young Kim
Department of Mechanical Engineering, Kangwon University, Kangwon-do 200-701, Korea
Dae Gyo Seo*
Department of Mechanical Engineering, Sungkyunkwan University, Kyunggi-do 440-746, Korea

Some deep drawing characteristics at elevated temperatures were investigated for the SCP1 steel sheets by using a Cr-coated die. For this investigation, six different temperatures between room temperature and 250℃, and six different drawing ratios ranging from 2.4 to 2.9 were considered. As a result, the limiting drawing ratio, the maximum drawing force and the maximum drawing depth were found to be affected sensitively by temperature, and more stable through-thickness strain distribution was observed at elevated temperatures. Some experimental results compared favorably with theoretical results obtained by using the finite element method.

Key Words : Warm Deep Drawing, Maximum Drawing Depth, Limiting Drawing Ratio(LDR), Maximum Drawing Force, Thickness Strain Distribution

1. Introduction

Some automobile parts such as a trunk floor, door inner, oil pan and wheel housing are considered to be formed due to their complicated shapes and deep drawing depth. These parts are usually formed by stamping sheets that have good formability, and require more than two steps of drawing process. But defects such as a crack, stick, wrinkle and scratch are generated frequently during the continuous stamping process, which result in the loss of productivity, lowered quality, and wear and deformation of the die.

The causes of these phenomena are as follows. First of all, the drawing process is very sensitive to the change of material properties because the stable range of drawing is reduced as the drawing depth of the above mentioned product becomes very close to the forming limit of the material (oh, 1999). Secondly, when stamping is done more than 200 strokes without a break, the temperature of the die increases significantly. So, the friction in the die increases due to the reduced clearance between the punch and die, and the inflow of sheet thus becomes difficult (song et al., 1999).

Recently, the method of spraying lubrication oil on the surface of the sheet is widely used to resolve these problems. But the oil should be removed afterwards to provide good quality of welding and painting. It is difficult to develop materials that have a stable forming range. Thus, the warm forming process is suggested to circumvent these problems. This process utilizes the effects of the delayed fracture time due to the increased strength of material by cooling the punch and the improved inflow of sheet due to

* Corresponding Author,
E-mail : dgseo@me.skku.ac.kr
TEL : +82-31-290-7433 ; **FAX** : +82-31-295-1937
Department of Mechanical Engineering, Sungkyunkwan University, Suwon, #300, Chunchun-dong, Jangan-ku, Kyunggi-do 440-746, Korea. (Manuscript **Received** June 23, 2000; **Revised** March 26, 2001)

the decreased strength of material by warming the die. Also, the temperature of die can be maintained uniform in this method (Choi et al., 2000). Ohwue(1987a ; 1987b) studied the effects of the tensile strength and blue brittleness of a material at high temperature on the deep drawing process. Nohara (1990) evaluated the workability of deep drawing and restriking for stainless steel sheets. Watanabe (1992) studied the formability of austenitic stainless steel. He considered the effects of temperature on the deformation-induced martensitic transformation. Shinagawa et al., (1993) predicted the transition of deformation -induced martensitic transformation for STS 304 stainless steel in warm forming process by using the finite element method(FEM). He evaluated the warm formability by utilizing the degree of work hardening caused by the amounts of martensitic transformation. Leighton and Lee (1994) evaluated the warm formability of Aluminum Killed Drawing Quality(AKDQ) steel, and Zeng and Mahdavian (1998) studied the effects of wrinkles generated in the deep drawing process at various temperatures.

Kim, et al. (1993, 1995) performed experiments for the warm formability of STS 304 stainless steel and studied the effects of various blank shapes and forming velocity, and Keum Ryu et al. (1999) and Kim et al. (1999) evaluated the warm formability of aluminum alloy sheet by experimental and numerical analyses, and Song et al. (1999) studied the change of friction coefficient by performing friction tests on the die at various temperatures.

In this study, in order to obtain the material properties required for numerical analyses, preliminary experiments, friction and tensile tests, have been conducted first. Also, a warm deep drawing test with SCP1 sheet is carried out. And then these experimental results are compared with those of numerical analyses using an FEM code (DYNA-3D). Finally, several methods for improving the formability of SCP1 sheet are presented by considering the effects of warm forming and the forming variables.

2. Experimental Methods

2.1 Preliminary experiments

As a preliminary experiment, a friction test and a tensile test were performed with a SCP1 sheet of 0. 7 mm thickness. All of these tests were done at various temperatures between room temperature and 250℃.The chemical composition of SCP1 sheet, which is exclusively used in the drawing process of automobile parts, is presented in Table 1, and material B has been selected for this study. In the tensile test, data was measured along the rolling direction and the mean value was calculated. The friction test was performed under the holding pressure of 2 MPa on the Cr-coated die. It is shown in Table 2 that as temperature increases, the tensile strength(T. S.), elongation(El.), strength coefficient(P. C.), and strain hardening coefficient(S. H. C.) decrease. But the friction coefficient(F. C.) increases a little due to the generation of very highly deformed layer on the friction surface of the sheet.

Table 1 Chemical compositions of materials

Material \ Composition (wt%)		C	N	Mn
A	SCP3C	0.002	0.0025	0.15
B	SCP1	0.007	0.004	0.15
C	SCP1	0.024	0.0018	0.20
D	SCP1	0.034	0.0020	0.18

Table 2 Various material properties at various temperatures(T.S., P.C. unit : kgf/mm^2)

Temp. ℃	T.S.	El.	P.C.	S.H.C.	F.C.
R.T.	29.89	44.9	58.032	0.2493	0.241
50	29.55	43.7	56.804	0.2407	0.246
100	28.03	40.2	54.120	0.2429	0.255
150	26.62	37.9	50.810	0.2367	0.267
200	25.64	36.3	49.146	0.2372	0.262
250	23.98	35.3	46.405	0.2408	0.271
300	23.13	33.7	44.970	0.2330	

Table 3 Part lists for experimental apparatus in Fig. 1

No.	Name	No.	Name
①	Holder cooling part	⑥	Heating pipe
②	Holder heating part	⑦	Insulation panel
③	Thermocouple	⑧	Punch
④	Die heating part	⑨	Cooling water input
⑤	Die cooling part	⑩	Cooling water output

Table 4 Properties of punch, die, blank holder shown in Fig.1

Part	Material	Surface	Size(mm)	Rp	Rd	Rc
Punch	GC30	Cr-Coated	60×60	5	-	5
Die	GC30	Cr-Coated	66×66	-	7	8
Blank Holder	GC30	Cr-Coated	61×61	-	-	6

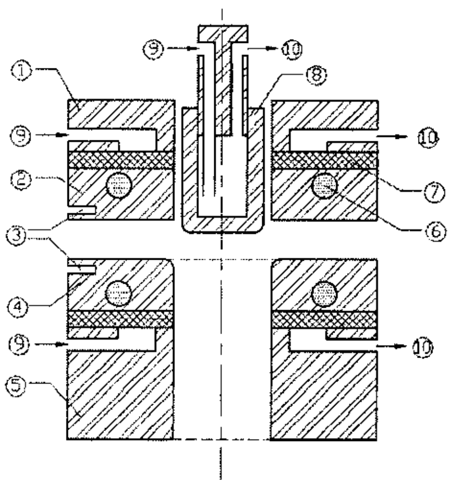


Fig. 1 Schematic diagram of warm forming tester

2.2 Drawing tests

Figure 1 shows the device used in the experiments and the details are summarized in Tables 3 and 4. In Table 4, Rp, Rd and Rc are the punch profile radius, die profile radius, and corner radius of the punch, die and blank holder, respectively. The punch, die and blank holder were made of GC30 and coated with hard Cr on their surfaces. The punch is designed in such a way that cooling water could circulate through the cooling channels in the punch. Also, a heat pipe of 1 kW capacity was installed in the die and the blank holder and proper insulation was provided to prevent heat transfer to other equipment parts. A temperature regulator was used to maintain a constant temperature.

The drawing test was done on a Universal Testing Machine(UTM). Square blanks were made of 0.7 mm thick SCP1 sheets, and drawing ratios(DR) of 2.4, 2.5, 2.6, 2.7, 2.8 and 2.9 were used. Here, the drawing ratio means the ratio of the side length of the blank sheet(L_b) to that of the punch profile(L_p), L_b/L_p. The clearance between the die and punch is 3 mm, which is 4.3 times the SCP1 sheet thickness. The tests were performed at 6 different temperatures, i. e., 25℃, 50℃, 100℃, 150℃, 200℃, and 250℃. The cooling water temperature was maintained at 15℃, and the blank holding pressure of 2 MPa and the forming velocity of 50 mm/min were used in the experiment. Each blank was deep drawn at each temperature until the blank was fractured or was formed up to the maximum drawing depth, i. e., until the edge of the flange of the blank was flown into the die profile without fracture.

Table 5 Experimental results at various temperatures with various drawing ratios(Drawing depth=40mm, ○ : successful, × : fracture)

Temp. \ DR	2.4	2.5	2.6	2.7	2.8	2.9
25℃	○	×	×	×	×	×
50℃	○	○	×	×	×	×
100℃	○	○	○	×	×	×
150℃	○	-	○	○	×	×
200℃	○	-	-	○	×	×
250℃	○	-	-	-	○	×

3. Experimental Results and Discussion

3.1 Drawability at elevated temperatures

Table 5 shows the results of the drawing tests at each temperature as the drawing ratio increases. For the drawing depth of 40 mm, the drawing ratios and the limiting drawing ratio are found to

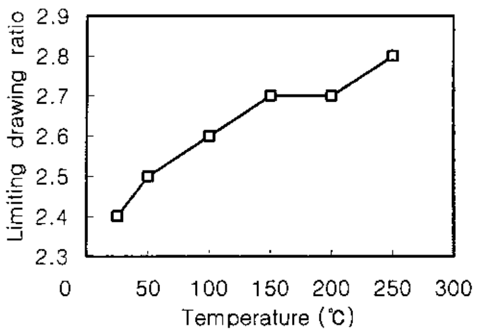


Fig. 2 Limiting drawing ratio at various temperatures

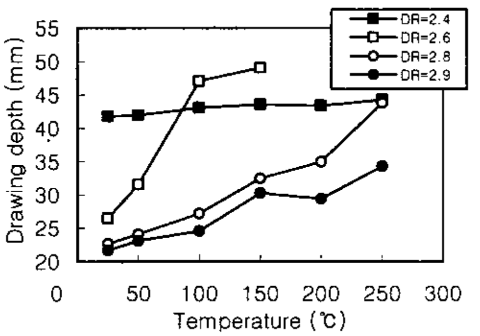


Fig. 3 Drawing depth versus temperature for various drawing ratios

Fig. 4 Drawn specimens for various temperatures and DR values

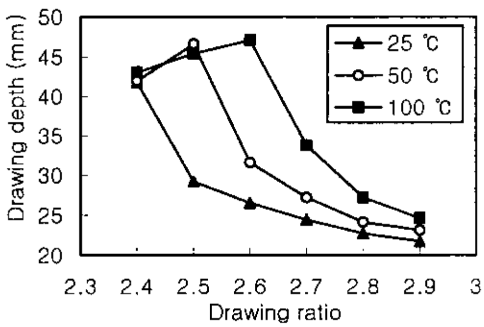


Fig. 5 Drawing depth versus drawing ratio at various temperatures

increase gradually as the temperature increases. Figure 2 shows the limiting drawing ratio(LDR) versus temperature. The LDR increases as the temperature increases. Figure 3 shows the drawing depth versus temperature for various DR values. For the drawing ratio(DR) of 2.4, it is observed that drawing up to the maximum drawing depth is possible at all temperatures. Thus, nearly uniform drawing depth is obtained for that drawing ratio. For the DR of 2.6, the drawing depth is shown to be about 26 mm at room temperature. But it is observed that drawing up to the maximum drawing depth is possible at over 100℃. Despite of the friction coefficient increase, it is considered that the effect of warm deep drawing method overcomes the forming resistance. For the DR of 2.8, the drawing depth at which fracture occurs increases as the temperature increases and it is only possible to draw up to the depth of 40 mm at 200℃. For the DR of 2.8 at 250℃, drawing depth is 1.8 times that at room temperature. For the DR of 2.9, drawing is impossible up to the depth of 40 mm at any temperature. For the DR of 2.9 at 250℃, it was 1. 6 times larger than the value measured at room temperature. Figure 4 shows the photographs of the drawn specimens for various temperatures and various DR values.

Figure 5 shows the variation of the drawing depth with respect to DR at 25℃, 50℃ and 100℃. As a function of drawing ratio, the curves exhibit gradual increase up to the limiting drawing ratio and sharp falls after the limiting drawing ratio. The drawn specimens are shown in Fig. 6. The variation of the drawing force during forming process is shown in Fig. 7, which shows that the variation of drawing forces during the forming process decreases as the temperature increases.

The maximum drawing forces, as shown in Fig. 8, decrease as the temperature increases. Compared with that at room temperature, the maximum drawing force reduces by 21% for the drawing ratio(DR) of 2.4 and by 12% for DR of 2.9. This phenomenon is in good agreement with the result of tensile test; i.e. the tensile strength and the plastic coefficient decrease as the temperature increases as shown in Table 2. At the temperature of 250℃, a thermal defect, i.e. a stick slip, occurred on the material surface and a rapid propagation of corrosion was observed after forming. The

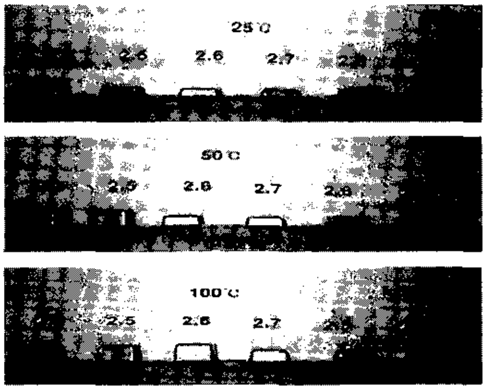


Fig. 6 Drawn specimens for various DR values and temperatures

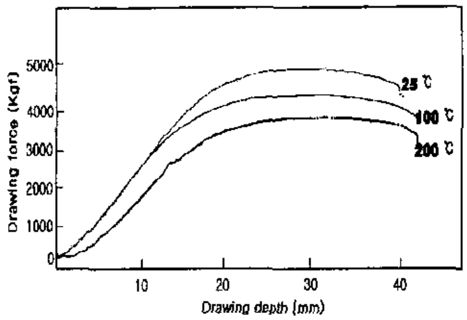


Fig. 7 Variation of the drawing force in forming process(DR=2.4)

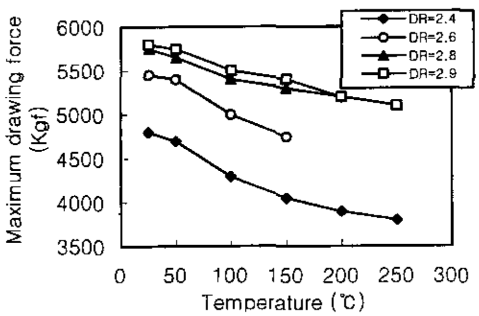


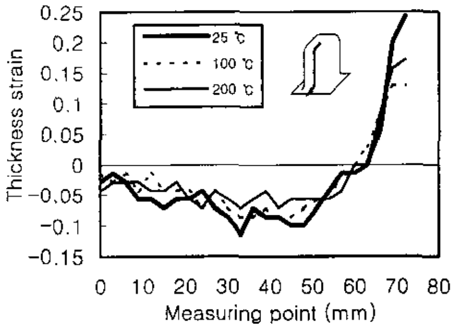
Fig. 8 Maximum drawing force versus process temperature for various drawing ratios

SCP1(B) material used in this experiment is less carbonaceous than the other SCP1 materials(C, D) in Table 2. There is no decrease of formability due to the blue brittleness effect below 200℃.

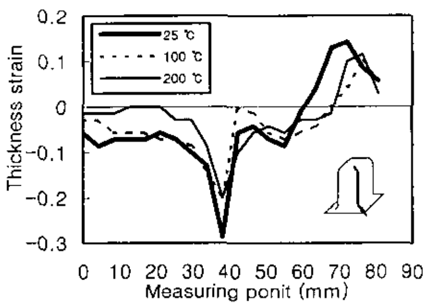
Despite the reduced elongation and increased friction coefficient as the temperature increases in the tensile test, the formability of material is improved. This result is due to the effect of warm forming process in which the punch was cooled and the die was heated. It seems that, in other words, the strength of material affects more than the other factors that decrease the formability.

3.2 Through-thickness strain distribution

The distribution of through-thickness strain for each temperature was studied along the central and diagonal directions of the cup that was formed 42 mm deep for a constant DR(DR=2.4). In Figs. 9(a) and (b), thickness strain distributions exhibit rather uniform patterns as the temperature increases. It may also be seen in these curves that the difference between the maximum and mini-

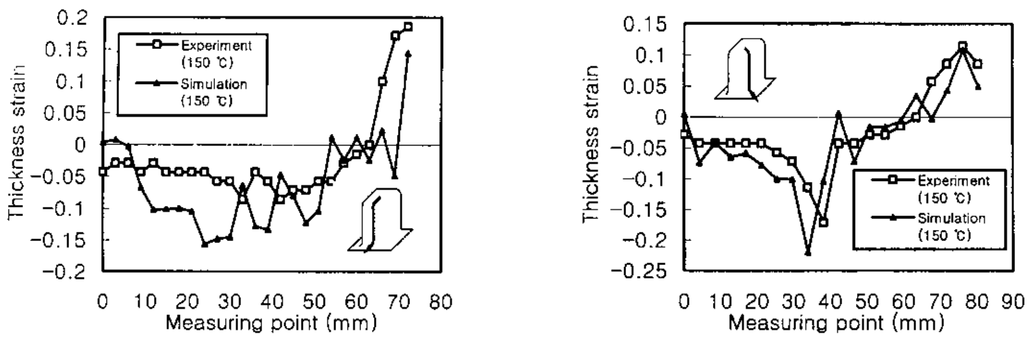


(a) Along the center line



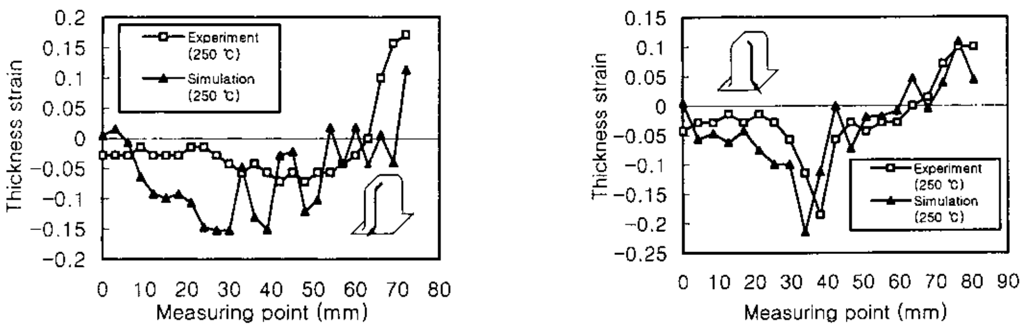
(b) Along the diagonal line

Fig. 9 Thickness strain distribution of drawn specimens(DR=2.4)



(a) Along the center line (b) Along the diagonal line

Fig. 10 Comparison of thickness strain distribution between experimental and numerical analyses(DR=2.4, Temp.=150℃)



(a) Along the center line (b) Along the diagonal line

Fig. 11 Comparision of thickness strain distribution between experimental and numerical analyses(DR=2.4, Temp.=250℃)

mum values is decreased as the temperature increases.

The thickness strain distribution at the flange also decreased as the temperature increases. This result means that the higher the temperature becomes, the smaller the change of thickness of blank and the easier inflow of blank can occur.

4. Numerical Analysis

DYNA-3D explicit code was used for the finite element analysis(FEA). The numerical blank model was divided into a cooling zone and a heating zone. The temperature of the heating zone was gradually increased and, during the computation, temperature-dependent material properties were used. The numbers of elements and nodes are 4225 and 4429, respectively.

Among the numerical simulation results, the trends of through-thickness strain distributions at the temperatures of 150℃ and 250℃ agreed well with the experiments as shown in Figs. 10 and 11. But, a big discrepancy is observed on the head of the punch. The reason for this phenomenon seems to be the fact that the heat transfer effect between the punch and blank is not considered in the simulation. New numerical methods that incorporate the heat transfer effects are required to obtain more accurate results.

5. Conclusions

Results of this study on the warm forming of SCP1 sheet with a cooled punch and heated die are summarized as follows.

(1) The limiting drawing ratio and the maximum drawing depth increase and the maximum drawing force decreases as the die temperature increases.

(2) The distribution of through-thickness

strain is more uniform at elevated temperatures than that at room temperature, and the difference between the maximum and minimum through-thickness strains decreases.

(3) In the results of numerical simulation using an FEM code, the distribution of through-thickness strain generally agreed with the experimental results. But, a big discrepancy at the head of the punch was observed, and the effect of heat transfer between the punch and blank should be considered to obtain more accurate results.

(4) It is expected that the quality and productivity of the difficult-to-form products can be improved if the warm forming process is done within the temperature range of 100℃~200℃ in which deteriorative effects such as thermal defects on the surface do not appear.

Acknowledgments

This paper has been supported by Kia Motors Corporation. The authors would like to express their appreciation for this support.

References

Choi, C. S., Choi, Y. C., Oh, Y. K. and Lee, H. S., 2000, "Reduction of Drawing Process in Warm Forming Steel Sheets Using Oil Pan," *Transactions of Material Processing*, Vol. 9, No. 7, pp. 699~705.

Kim, J. H., Choi, C. S. and Na, K. H., 1995, "Comparison of Warm Deep Drawability of Stainless Steel Sheet Between Crank press and Hydraulic press," *Journal of the Korean Society for Technology of Plasticity*, Vol. 4, No. 4, pp. 345~352.

Kim, J. H., Choi, C. S., Jeong, B. Y. and Lee, G. H., 1993, "Deep Drawing of Stainless Steel in Warm Working Condition Using a Single Crank Press," *Proceeding of the Fourth International Conference on Technology of Plasticity*, pp. 1691~1694.

Kim, S. M., Ghoo, B. Y., Keum, Y. T. and Kim, J. H., 1999, "Finite Element Analysis and Experimental Investigation of Non-Isothermal Processes for Aluminum-Alloy Sheet Metals(part2:Analysis)," *Journal of the Korean Society for Technology of Plasticity*, Vol. 8, No. 3, pp. 252~261.

Leighton, D. E. and Lee, D., 1994, "The Effect of Tooling Temperature on the Formability of Sheets Steel," *Journal of Material Processing Technology* 45, pp. 577~582.

Nohara, K., Watanabe, Y. and Yamahata, K., 1990, "WARM PRESS FORMING OF STAINLESS STEEL SHEETS," *Proceedings of the First International Conference on New Manufacturing Technology*, Chiba 1990, pp. 533~538.

Oh, Y. K., 1999, "Improvement of Deep Drawability for Steel Sheets," Technical Research Report, *Kia Motors Co.*, pp. 1~6.

Ohwue, T., Takechi, H. and Furuno, Y., 1987a, "Deep Drawability of Square Shells in Warm Working Condition," *Journal of the JSTP*, Vol. 28, No. 318, pp. 706~711.

Ohwue, T., Takechi, H. and Furuno, Y., 1987b, "Temperature Dependence of Tensile Properties Drawability of Steel Sheets in Warm Working Condition," *Journal of the JSTP*, Vol. 28, No. 314, pp. 225~231.

Ryu, H. Y., Kim, Y. E., Kim, J. H., Ghoo, B. Y. and Keum, Y. T., 1999, "Finite Element Analysis and Experimental Investigation of Non-Isothermal Processes for Aluminum-Alloy Sheet Metals(part1:Experiment)," *Journal of the Korean Society for Technology of Plasticity*, Vol. 8, No. 2, pp. 152~159.

Shinagawa, K., Takeoka, T., Mori, K. and Osakada, K., 1993, "Finite Element Simulation of Warm Deep Drawing of Type 304 Stainless Steel Sheet with Deformation Induced Transformation," *Journal of the JSTP*, Vol. 34, No. 390, pp. 794~799.

Song, K. H., Lee, J. D., Choi, Y. C. and Seo, D. G., 1999, "Friction and Drawing Characteristics of Sheets for Variable Blank Holding Force and Die Temperature," *Journal of the Korean Society for Technology of Plasticity*, Vol. 8, No. 3, pp. 245~251.

Watanabe, Y., 1992, "ステンレス鋼板の温間絞り加工法," Journal of the JSTP, Vol. 33, No. 375, pp. 396~403.

Zeng, X. M. and Mahdavian, S. M., 1998,

"Critical Condition of Wrinkling in Deep Drawing at Elevated temperature," Journal of Material Processing Technology 84, pp. 38~46.