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The body can be viewed from the next page.

Warm Press Forming of Stainless Steel Sheets*

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1 Introduction

So-called "warm deep drawing", in the region where the decrease in resistance to deformation of the flange is larger than the decrease in resistance to fracture when deformation temperature rises, has been attempted in the past with non-ferrous alloys and carbon steel.[1] Some attempts have also been made to apply warm deep drawing to stainless steels,[2] but no example has been found, however, of study of the interrelationships of materials used (austenitic and ferritic stainless steels), working conditions (drawing and restriking) and the heat-resistant lubricant. In particular, the deformation behavior of austenitic stainless steel shows strong temperature dependence, as shown in the example[3] of uniaxial tensile deformation of SUS 301 in **Fig. 1.** In addition, the fact that the temperature dependence is seen in the temperature region slightly above room temperature is extremely interesting in view of the possibility of applying warm deep drawing to actual press working, in comparison with the high drawing temperature of hundreds degrees centigrade used with the above-mentioned non-ferrous alloy and carbon steel.

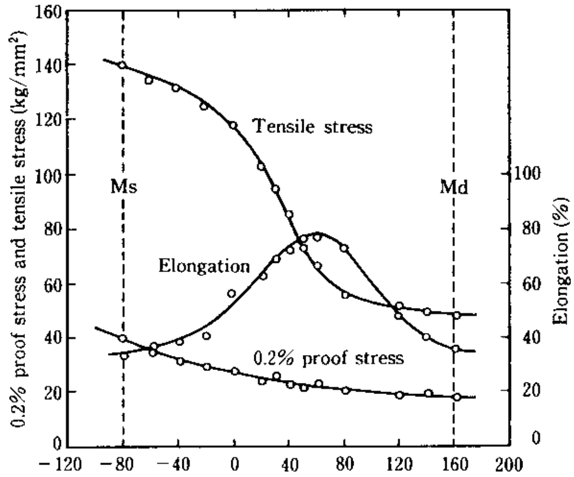

Fig. 1 Temperature dependance of tensile properties of SUS 301 austenitic stainless steel

This paper describes tests on austenitic and ferritic stainless steel sheets for their drawability in warm press forming and restriking performance, and examines the development and application of a heat-resistance lubricant which is excellent in working efficiency and remova-

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bility, which were previously considered very important problems in warm press forming.

2 Test Method

The tool was of a comparatively large oblong cylinder type, measuring 200 × 270 mm, which has posed problems in ordinary deep drawing of stainless steel sheets. The straight portion of the tool had a camber of 700 mm$R$; the side wall, a 2° taper. Dimensions are shown in **Table 1**. Taking into consideration the practical application of the technique, the die temperature T_d and punch temperature T_p were indirectly regulated by a warm-oil circulation system (a buried-type electric heating system is also suitable) and cooling water feeding system, respectively.

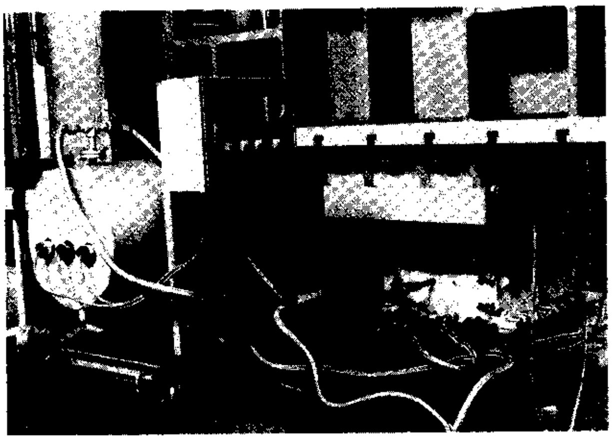


Photo 1 Appearance of hydraulic press and heating system

The machine was a double-action hydraulic press with an inner force of 400 t and outer force of 250 t, and a stroke velocity of about 600 mm/min. The external appearance of the equipment is shown in **Photo 1**. Specimens used were austenitic stainless steels such as SUS 304, SUS 301 and R304UD (Cu-bearing steel)[4] and ferritic stainless steels such as SUS 430 and R430LT (Ti-bearing steel)[5]. The sheet thickness was 1.0 mm (0.5 mm for SUS 301), and chemical compositions and properties were as shown in **Table 2**. The shape and dimensions of the blank used in the test is shown in **Fig. 2**. As lubricants, a newly developed water-soluble heat-

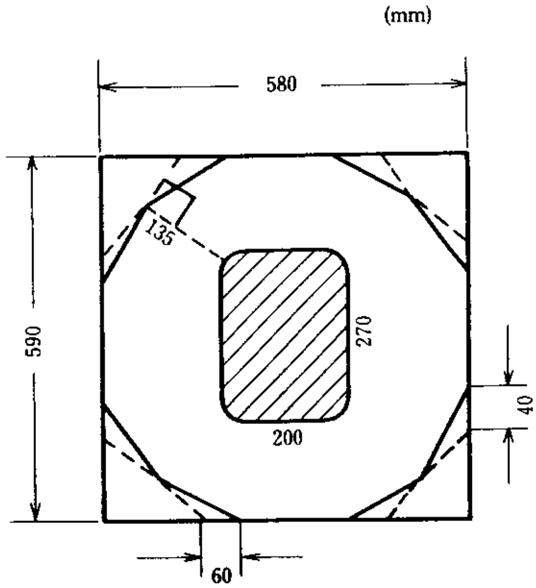


Fig. 2 Dimensions of blank

Table 1 Tool dimensions

Tool	Material	Size (mm)	r_P (mm)	r_d (mm)	r_C (mm)	Clearance (mm)	Camber (mm)	Taper on wall
Punch	241M	198.9×268.9	17	—	50	1.1 (side) 1.3 (corner)	700R	2°
Die	AMPCO metal	200×270	—	10	50		700R	—
Blank holder	AMPCO metal	—	—	—	—	—	—	—

Table 2 Stainless steel specimens used

Steel	Thickness (mm)	Composition (wt %)								Properties					
		C	N	Si	Mn	Ni	Cr	Cu	Ti	HV	*PS* (kg/mm²)	*TS* (kg/mm²)	*El* (%)	Er	CCV
SUS 304	1.0	0.07	0.018	0.51	1.65	9.06	18.72	—	—	160	27	65	58	12.8	45.5
R 304 UD	1.0	0.08	0.039	0.49	1.50	6.9	13.7	2.9	—	139	24	69	58	14.8	43.7
R 430 LT	1.0	0.0010	0.009	0.44	0.45	—	16.5	—	0.55	153	34	50	31	9.4	45.1
SUS 301	0.5	0.12	0.020	0.67	1.05	7.05	17.1	—	—	187	27	78	56	14.9	44.5
SUS 430	1.0	0.06	0.015	0.5	0.6	—	18.2	—	—	160	35	45	28	8.8	48.1

resistant lubricant[5], in addition to commercially available MoS_2 and plastic film, were used. Warm forming performance and lubricating effectiveness were thus examined.

3 Test Results and Discussion

3.1 Drawing

3.1.1 Formability

Changes in limited drawing depth h_l when die temperature T_d is changed, at a constant value of punch temperature T_p of 20°C, are shown in **Fig. 3** (with lubricant MoS_2). Improvement in formability due to die warm drawing, compared with that in room temperature drawing, was great for both austenitic and ferritic steels, but was particularly conspicuous in the former, causing "drawn through" ($h_l \geq 200$ mm) at $T_d \geq 60$°C. If SUS304, with the highest austenite stability among prepared specimens, is heated excessively, i.e., beyond $T_d = 160$°C, it softens near the die shoulder, causing fracturing at the shoulder. In any case, the deep drawing formability of stainless steels was greatly improved when the die temperature was raised to about 100°C and the punch temperature was maintained at a low level. The effect of the mutual relation of T_d and T_p on formability was investigated for austenitic R304UD, as shown in **Fig. 4**. A region of optimum combination of T_d and T_p exists, where T_p tends to become higher as T_d rises. If T_p is relatively higher than T_d, *a* fracture is liable to occur at the punch shoulder, whereas if T_d becomes excessively high relative to T_p, cracking occurs at the die shoulder, as mentioned above, rendering continued forming nearly impossible.

As factors which greatly affect warm press formability of austenitic and ferritic materials, austenite stability Md_{30} (temperature at which 50% of the austenitic phase is transformed into the martensite phase when the material is given 0.3 uni-axial tensile strain[6]) and C content are important, as can be seen from **Figs. 5** and **6**. As mentioned above, the effect of warm drawing on austenitic steels is great, and since this effect is related to the temperature dependence of martensitic transformation, it may be predicted that the optimum temperature region will be governed by the austenite stability of the material, as borne out experimentally and indicated in Fig. 5. As shown in the figure, the optimum temperature region changes with Md_{30}, and is also related to

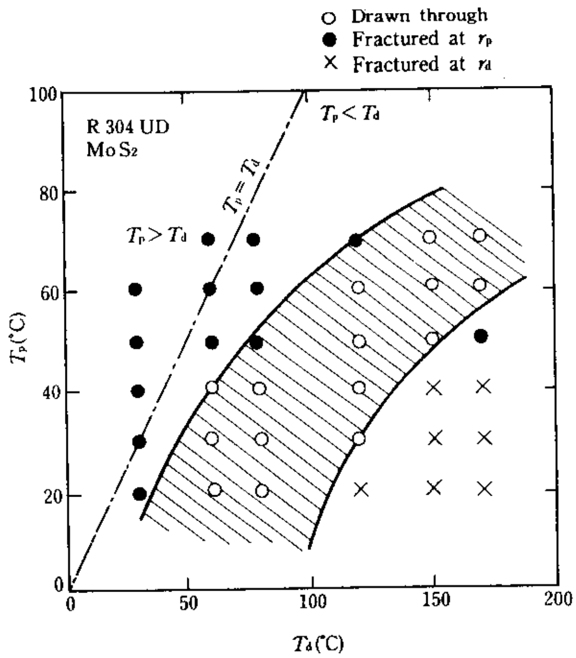


Fig. 4 Change in optimum drawing temperature on the basis of combination of die temperature (T_d) and punch temperature (T_p) in austenitic stainless steel

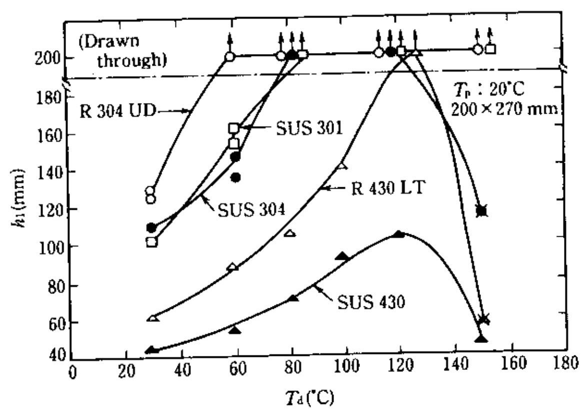


Fig. 3 Relation between die temperature (T_d) and limited drawing depth (h_l) when punch temperature (T_p) is kept constant at 20°C by cooling

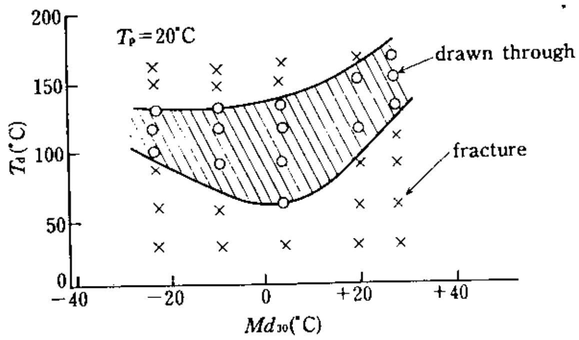


Fig. 5 Relation between austenite stability (Md_{30}) and drawing (die) temperature (T_d) in austenitic stainless steel (punch temperature T_p: 20°C)

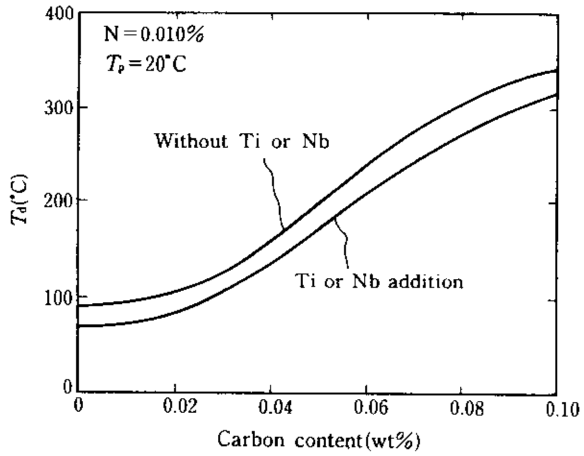


Fig. 6 Change in optimum drawing (die) temperature (T_d) with carbon content in ferritic stainless steel (punch temperature: 20°C)

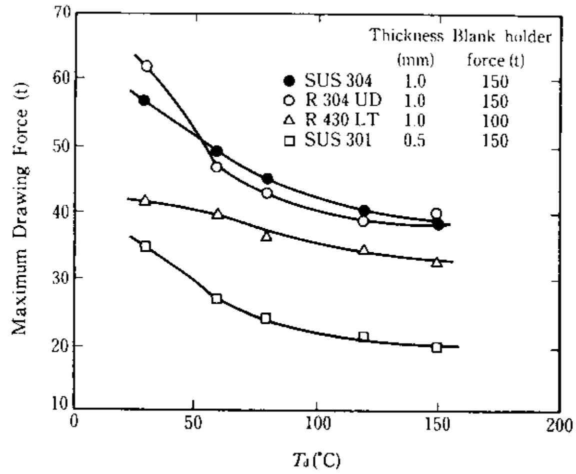


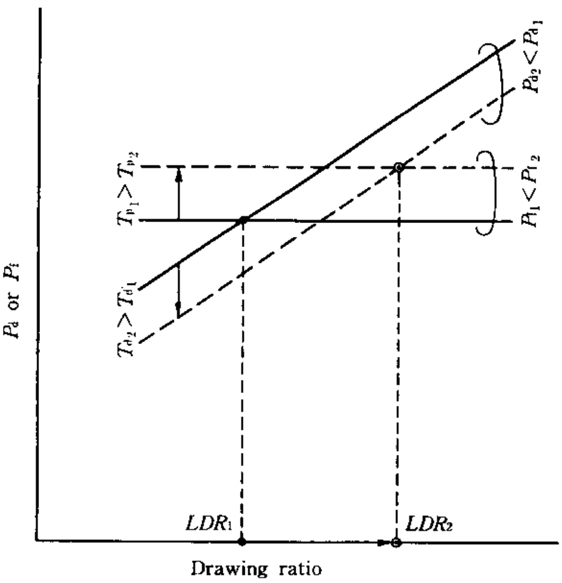
Fig. 7 Relation between die temperature (T_d) and maximum drawing force (punch temperature T_p: 20°C)

composition (wt%) and grain size number (G.S.N.), as in following equation[7]:

$$Md_{30} = 551 - 462(\mathrm{C} + \mathrm{N}) - 9.2\mathrm{Si} - 8.1\mathrm{Mn} - 13.7\mathrm{Cr} - 29.0(\mathrm{Ni} + \mathrm{Cu}) - 18.5\mathrm{Mo} - 68\mathrm{Nb} - 1.4(\mathrm{G.S.N.} - 8.0) \quad \cdots\cdots\cdots (1)$$

On the other hand, since the temperature dependence of strength in ferritic steel and consequently its flange deformation resistance are mainly governed by C content, the minimum value of T_d for drawing a blank down to the required depth 200 mm (while T_p is constant at 20°C) greatly varies with C content as shown in Fig. 6. If the C content is great, the minimum value of T_d will become extremely high, causing problems in facilities and equipment and in the use of lubricants. If T_d is below 200°C, neither these problems, nor deterioration of operational circumstances will occur.

The reason that improved formability is brought about by warm drawing, i.e. by raising T_d and lowering T_p, is the fact that maximum drawing force decreases with rising T_d, as shown in **Fig. 7**. (Proper conditions for conventional room temperature drawing can also be obtained, but it is necessary to cool the punch in order to prevent its becoming heated due to thermal conduction from the periphery of the blank.) More precisely, the raising T_d ($T_{d1} < T_{d2}$) and lowering T_p ($T_{p1} > T_{p2}$) decreases drawing force P_d ($P_{d1} > P_{d2}$) and increases fracture force P_f ($P_{f1} < P_{f2}$), as shown schematically in **Fig. 8**, and consequently leads to an increase in the limited drawing ratio LDR ($LDR_1 < LDR_2$), given by the intersection of straight lines P_d and P_f. This brings about improvement in formability.



T_d: die temperature
T_p: punch temperature
P_d: drawing force
P_f: fracture force
1: conventional press forming
2: warm press forming

Fig. 8 Schematic comparison of limited drawing ratio in warm press forming (LDR_2) with that in conventional press forming (LDR_1)

3.1.2 Shape fixability

Anisotropy Δl of the residual flange width in drawing an oblong cylinder is defined as follows:

$$\Delta l = l_X - \frac{l_L + l_C}{2} \quad \cdots\cdots\cdots\cdots\cdots\cdots (2)$$

where l_C, l_L, and l_X represent the longer side, shorter

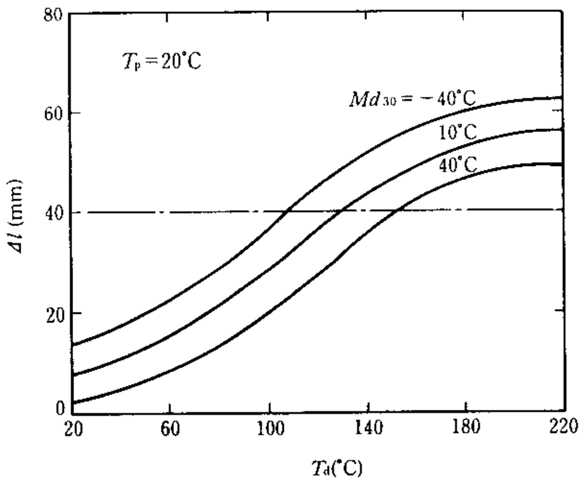


Fig. 9 Change in anisotropic parameter related to residual flange width (Δl) with die temperature (T_d) in austenitic stainless steel

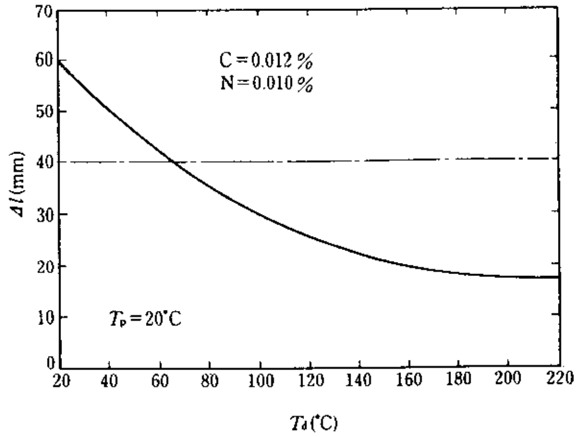


Fig. 10 Change in anisotropic parameter related to residual flange width (Δl) with die temperature (T_d) in ferritic stainless steel

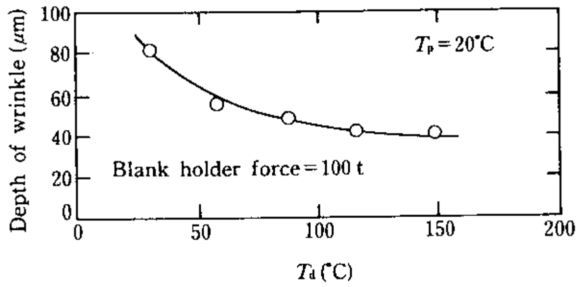


Fig. 11 Change in depth of wrinkle on flange of R304UD with die temperature (T_d)

side, and corner of the residual flange width, respectively. If Δl becomes excessive, not only does restriking and secondary forming of the flange become difficult, but the size of the blank must also be increased, thereby lowering product yield and hindering drawing formability. According to the results of the present experiments, Δl changed when warm drawing was adopted, and in addition, contradictory results were found with austenitic and ferritic stainless steels with regard to this tendency. In **Fig. 9**, test results for austenitic stainless steel are shown for various values of Md_{30}, −40, 10, and 40°C. In all the cases, Δl increased as the die temperature T_d rose (with punch temperature T_p maintained at a constant value of 20°C), and a tendency towards saturation was observed in high or low temperature regions. With steels of higher Md_{30}, namely, those in which the austenite phase is less stable, Δl is smaller. If Δl is stipulated, for instance, to be 40 mm or below, the upper limit temperature of T_d is restricted to values below the intersection of the solid and broken lines in Fig. 9. The result of the test on ferritic stainless steel is shown in **Fig. 10** (T_p = 20°C). As T_d rises, Δl decreases steadily (and is not affected by C content). This tendency is contradictory to the test results with austenitic stainless steel. If Δl is stipulated, for instance, to be 40 mm or below, the lower limit temperature of T_d is restricted to values (about 65°C) above the intersection of the solid and broken lines in the figure. The fact that the anisotropy parameter shows the above-mentioned die temperature dependence is considered attributable to the dependence of the macroplastic flow of the steel on deformation temperature.

An example of the result of investigation of whether the degree of flange wrinkling is dependent on warm drawing or not is shown in **Fig. 11**. This figure indicates the degree of wrinkles on the flange, when R304UD was drawn with a dodecagonal blank (see Fig. 2) at a blank holder force of 100 t; wrinkle height was measured with a roughness meter. Wrinkles became insignificant as die temperature T_d rose, but no marked change was observed at temperatures exceeding 60°C. Other austenitic and ferritic steels also gave similar results, namely, that warm forming is advantageous for preventing wrinkles.

3.1.3 Delayed fracture and ridging

Defects which frequently occur when austenitic and ferritic stainless steel sheets are subjected to deep drawing are delayed fracture and ridging, respectively. These problems sometimes constitute factors restricting increases in drawing limit[8].

First, concerning dalayed fracture, to avoid the fracture after room temperature drawing and secure excellent drawability, it is necessary to strictly control austenite stability Md_{30}[6] and chemical composition as shown in **Fig. 12.** Namely, Fig. 12 shows formability of an oblong cylinder at room temperature, when Md_{30} of Cu-bearing austenitic stainless steel is variously changed by balancing its chemical composition based

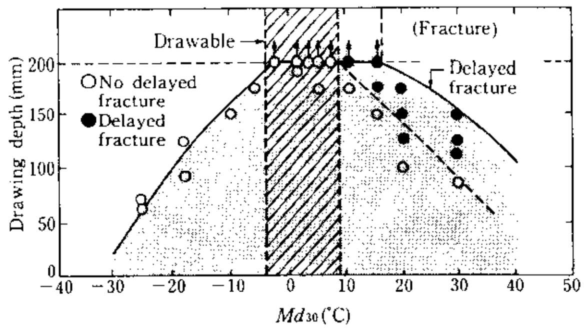


Fig. 12 Relation between drawing limit and austenite stability (Md_{30}) in drawing room temperature

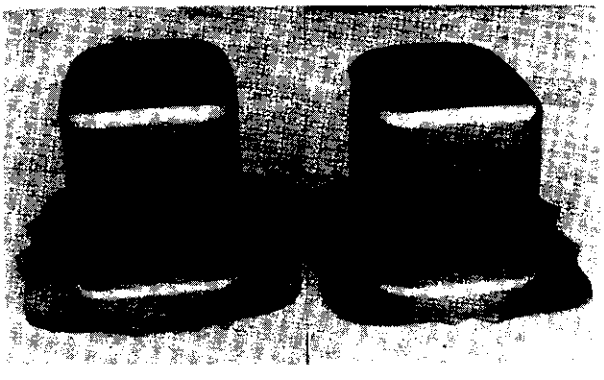
Table 3 Delayed fracture test result at various drawing (die) temperature

Steel	Md_{30}		RT (30°C)	60°C	80°C	120°C	150°C
R 304 UD	7°C	A	○	○	○	○	○
		B	×	○	○	○	○
SUS 301	22°C	A	×	○	○	○	○
		B	×	×	○	○	○

A: RT (30°C) × 10d in air
B: 80°C × 1 h in water
○: No delayed fracture
×: Delayed fracture

on Eq. (1)[6]. When Md_{30} is adjusted within the hatched area, press forming to reach a drawing depth of 200 mm, which corresponds to drawn through, becomes possible without causing drawing fracture or delayed fracture (R304UD is a Cu-bearing austenitic stainless steel which has been adjusted in this way[3]). If Md_{30} is lower than this range, the steel develops drawing fracture before drawn through. If Md_{30} is higher than this range, the steel develops delayed fracture (Md_{30} = 8 to 13°C), even if drawn through (drawing depth: 200 mm), or develops drawing fracture before drawn through (Md_{30} > 13°C). Even if drawing is suspended before drawing fracture occurs in the latter case, drawing down to the depth above the rightward descending dotted line in the figure will cause delayed fractures, as shown by black dots. On the other hand, if warm press forming is performed as in the present test, not only drawability (see Fig. 3) but also delayed fracture resistance is improved, as shown in **Table 3**. In fact, not only in R304UD, but also even in SUS 301, which shows Md_{30} of as high as 22°C and is essentially inferior in delayed fracture resistance, application of warm press forming at a die temperature of 80°C or above (the drawn through state) will prevent the occurrence of delayed fracture even in an accelerated delayed fracture test in water at 80°C × 1 h. **Photo 2** shows the external appearances of drawn bodies of R304UD after room temperature press forming–in which delayed fracture occurred at a drawing depth of 200 mm, that is, corresponding to drawn through–and after 80°C press forming–in which no delayed fracture occurred at a drawing depth of 200 mm, corresponding to drawn through–when subjected to an accelerated delayed fracture test. These results suggest the possibility, with application of warm press forming, of using lower grade steels, which would be of great advantage for practical press forming.

The above test results have a close relation to the temperature dependence of stress-induced martensitic transformation.[9] Measurements were made of the



T_d = 20°C T_d = 80°C

Photo 2 Appearance of drawn bodies of R304UD with or without delayed fracture after drawing at room temperature (20°C) or warm temperature (80°C) (T_d: drawing die temperature)

volume fraction of martensite phase generated at the corners of press-formed bodies, where delayed fracture susceptibility is high, after warm press forming was applied to materials having various degrees of austenite stability at several die temperatures. The results are shown in **Fig. 13**. As the value of Md_{30} was smaller and as the forming temperature became higher, the amount of martensitic transformation decreased. In order to prevent the occurrence of delayed fracture, it is necessary to reduce the amount of martensite to 10% or below. Warm press forming can easily satisfy such conditions.

With regard to ridging, which poses a problem in deep drawing of ferritic stainless steel, this phenomenon seems basically unaffected by warm press forming. However, when forming temperature is raised, the tendency towards ridging shows signs of somewhat decreasing even with equal forming depths. This may be due to the fact that deformation is more uniform with warm press forming, showing a less marked strain distribution. Therefore, although the fundamental solution to

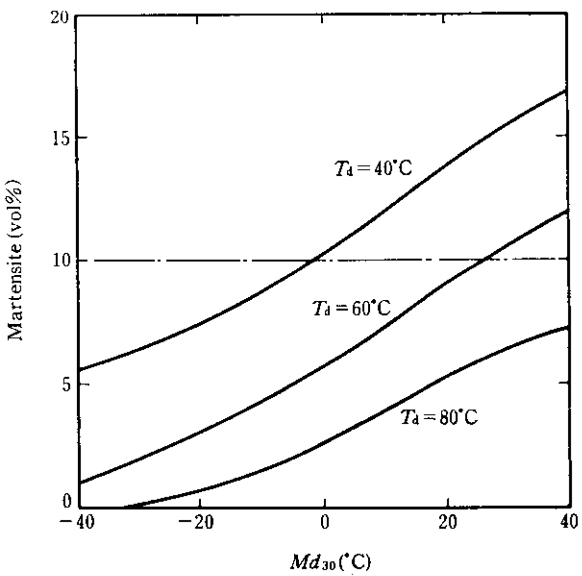


Fig. 13 Change in martensite volume ratio after drawing of austenitic stainless steel with austenite stability (Md_{30}) and die temperature (T_d)

the problem of ridging is improvement in material quality itself, warm press forming at least produces no negative effect.

3.2 Restriking

In the manufacture of conventional extra-deep drawn products, restriking is normally performed to correct the postdrawing shape. Thus, an examination was made of the relation between restriking and warm press forming.

First, using R304UD specimens, an investigation was made into effect of die temperatures during drawing and subsequent restriking (denoted T_1 and T_2, respectively, with punching temperature constant at room temperature in both cases) on restriking depth Δh (with primary drawing depth constant at $h_1 = 150$ mm). The results are shown in **Fig. 14**. With T_1 set to the warm press forming temperature, when T_2 was within the range from 20°C to 80° C, Δh increased greatly, and became nearly constant at $T_1 \geq 80$°C. At $T_1 \geq 60$°C, Δh decreased as T_2 rose and reached its maximum at $T_2 = 20$°C. As shown here, it is desirable to perform press forming at high T_1 and low T_2 in order to obtain satisfactory restrikability. In contrast to the Δh of about 8 mm with conventional press forming (with both T_1 and T_2 of room temperature), Δh increased to as much as $\Delta h = 43$ mm under the conditions $T_1 = 120$°C and $T_2 = 20$°C. Owing to a conspicuous appearance of magnetism at $T_1 = 20$°C, discussed later, conditions such as $T_1 = 80$°C and $T_2 = 60$°C, for instance, are desirable in actual practice. Even with these conditions, $\Delta h = 32$ mm; it is thus possible to perform restriking about four times as great as that with conventional press forming.

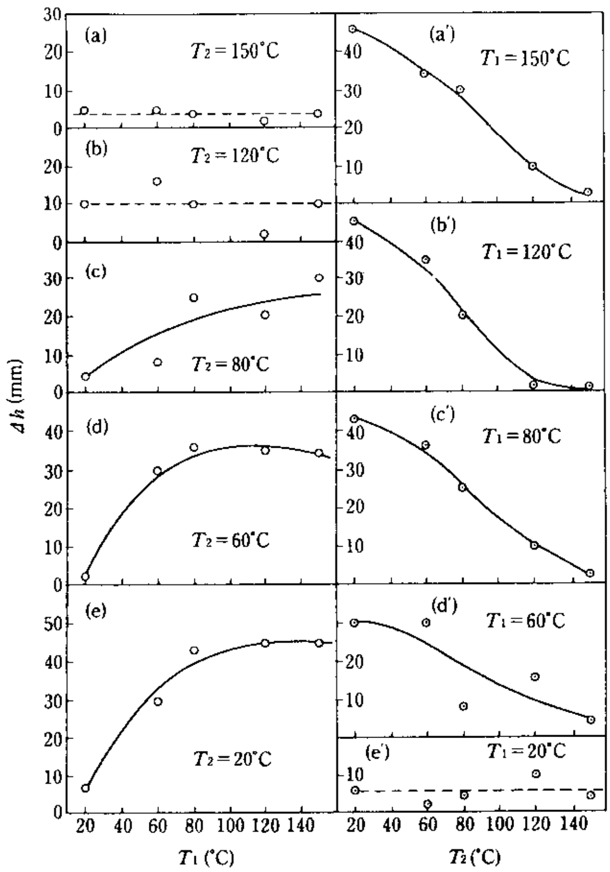


Fig. 14 Change in restriking depth Δh with primary drawing temperature T_1 and subsequent restriking temperature T_2(primary drawing depth h_1: 150 mm)

Next, the effects of drawing depth h_1 on Δh were investigated for various specimens under conditions of $T_1 = 80$°C and $T_2 = 20$°C. The results are shown in **Fig. 15**. As h_1 increased, the total forming depth h_2 ($\equiv h_1 + \Delta h$) decreased, but the value of Δh itself and its h_1 dependence varied with types of steel; specifically, Δh for each h_1 value was greatest in R304UD, and smallest in R430LT. The Δh of SUS 301 showed almost no dependence on h_1, and, although the mechanism is unknown, this can be said to be advantageous for actual processes.

Further, results of tests of the performance of formed bodies after restriking are described in the following. First, **Fig. 16** shows the distribution of the quantities of martensite occurring at various parts of formed bodies after restriking. With R304UD as material, and conditions of $T_1 = 80$°C, $h_1 = 160$ mm, and $\Delta h = 20$ mm, restriking temperatures of $T_2 = 20$, 60, and 80°C were used. Results indicate that restrikability is good at $T_1 = 20$°C, but, as described above, martensite is induced in great volume centering around the punch shoulder, and magnetism appears. Even in this case, the

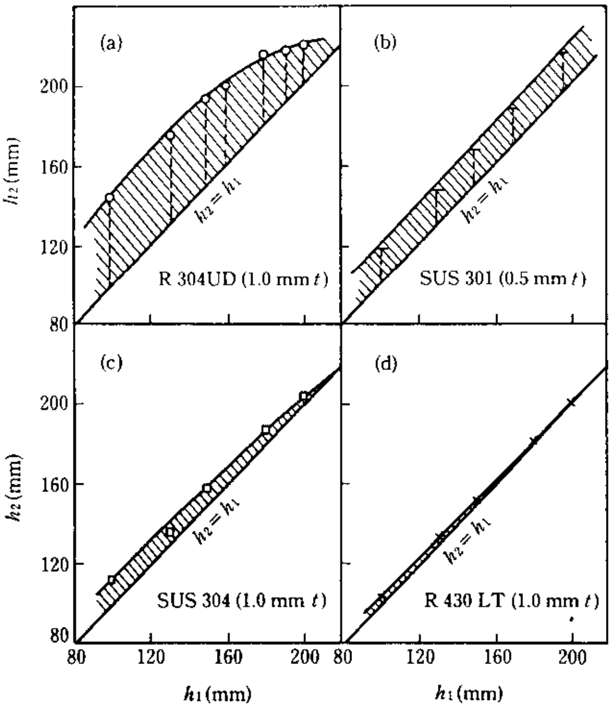


Fig. 15 Change in total press forming depth after restriking (h_2) with drawing depth (h_1) when warm press forming is applied (drawing temperature T_1 = 80°C, restriking temperature T_2 =20°C)

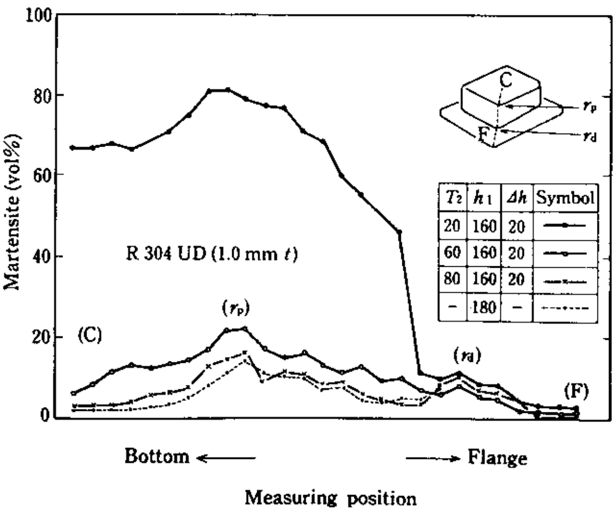


Fig. 16 Amount of martensite transformed at different positions of bodies during primary drawing (Temperature T_1 = 80°C, depth h_1 = 160 mm) and subsequent restriking (Temperature T_2 = parameter, depth Δh = 20 mm)

danger of delayed fracture is nil, for the following two reasons: (1) generation of martensite near the die shoulder is slight, and (2) it is mainly stretch-type flange deformation which occurs in restriking, with none of the compression-type flange deformation element seen in primary drawing. However, since magnetism should be avoided in the forming of sinks, a process which minimizes the generation of martensite is desirable. Taking into consideration the above-mentioned restrikability (Fig. 14) and side wall warping, mentioned later, T_1 = 80°C and T_2 = 60°C (with R304UD) are desirable.

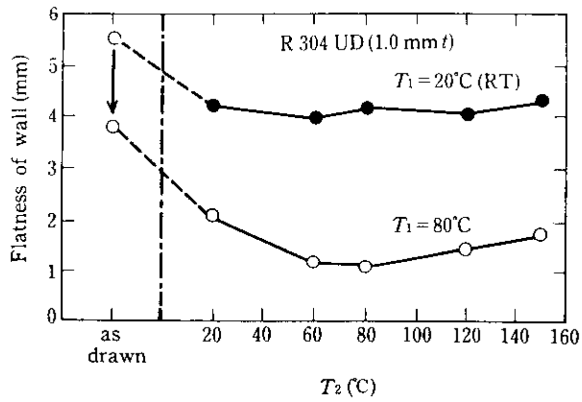


Fig. 17 Influence of drawing temperature T_1 and restriking temperature T_2 on flatness of wall body (drawing depth: 150 mm)

As the second matter in the performance of post-restriking formed-bodies, side wall warping was investigated using a dial gauge. The results are shown in **Fig. 17.** When first drawing temperature is T_1 = 20°C (room temperature), warping of 5 mm or more is seen in the as-drawn state. This warping is not greatly decreased by restriking, and changes in warping in response to changes in subsequent restriking temperature T_2 are also small. In contrast, at T_1 = 80°C, a decrease can be seen in as-drawn warping in comparison with that at T_1 = 20°C. Warping is greatly reduced by restriking, and reaches its minimum near T_2 = 60°C. This is one reason for selecting T_1 = 80°C and T_1 = 60°C as optimum conditions for R304UD, as mentioned earlier.

Further, as the third item concerning the performance of the formed bodies after restriking, changes in flange bending load after restriking at T_2 = 20°C were measured at various primary drawing temperatures T_1. Results are shown in **Fig. 18.** According to these results, post-restriking flange bending load was greatly reduced by warm press forming, and a decrease in load by a maximum of about 25% compared with that for room temperature forming was achieved. The reason for this was the reduction in work hardening at the flange of the blank brought about by warm press forming. Accordingly, warm press forming also improves so-called secondary formability. Changes in bending load with restriking temperature T_2 were small.

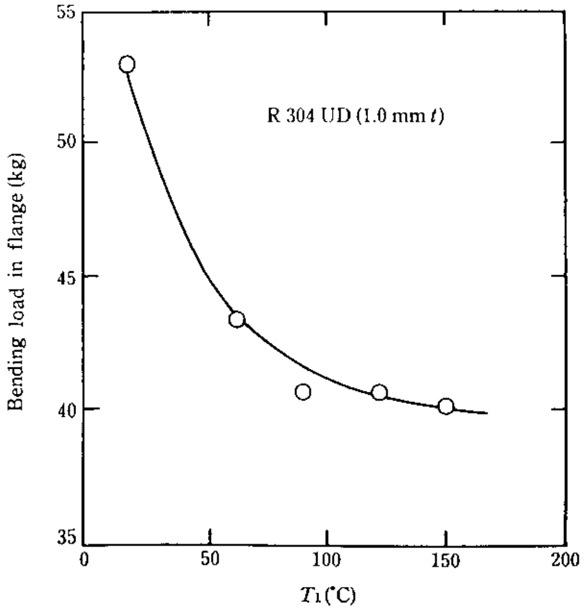


Fig. 18 Change in bending load in flange after restriking at 20°C with primary drawing temperature T_1 (drawing depth = 150 mm, depth after restriking = 180 mm)

3.3 Heat-resistant Lubricant

One of the key points in realizing commercial application of the warm press forming and warm restriking method is development of a lubricant with good heat resistance, satisfactory workability and removability, and excellent lubricating performance, while of moderate cost. Existing heat-resistant lubricants, MoS_2 which was used in this study, WS_2, and heat-resistant plastic film are available, but all of these are poor in coating applicability, workability, and removability, and not suitable for continuous press forming.

After studying the drawbacks of the existing lubricants, the authors have developed a new heat-resistant, water-soluble lubricant.[10] Through the combination of the afore-mentioned warm press forming conditions of austenitic and ferritic stainless steels and this newly-developed lubricant, ultra-deep press forming and restriking have now become possible.[11,12]

The newly-developed lubricant is water-soluble and mainly consists of organic boron compounds, to which lubricating oil and a surface active agent are added. When applied to the blank, this lubricant hydrolyzes due to moisture in the air and deposited on the blank surface, and precipitates boric acid on the blank surface, thereby providing excellent heat resistance and lubricity. Examples of chemical compositions of the new lubricant are shown in **Table 4**. The lubricant, which has excellent applicability as mentioned earlier, can be applied to form a film by any method of brushing, spraying, immersion, or roll coating. Its removability by

Table 4 Examples of compositions of new water-soluble lubricant with heat resistance (wt %)

Elment \ Type	A	B	C
Boric trimethyl	10	10	10
Machine oil	—	5	—
Polyethylene glycol	—	—	5
Methanol/1,1,1 trichloroethane	90	85	85

cleaning after forming is also excellent; it can be easily removed by any method of cold water, hot water, or organic solvent washing. Further, as can be seen from the table, it does not contain phosphates or oxalic acid, and thus poses no problems of waste water treatment or water pollution.

Lubricating performance of the newly-developed lubricant (called "414K") which was used for warm drawing and room-temperature drawing of R304UD and SUS301 was measured, in comparison with the conventional lubricant, in combination with lubricants for the punch and die surfaces. The results are shown in **Table 5**. As can be seen from the results of the test, MoS_2 is heat-resistant and is effective in warm forming, but is very poor in workability and removability, in addition to being expensive. In the case of lubricant J, which has conventionally been used as a typical water-soluble lubricant for room-temperature drawing of stainless steel, virtually the same limit drawing depths were obtained in both room temperature drawing and warm drawing (80°C) for both types of steels, completely nullifying the effect of warm drawing. This is because, with a rise in drawing temperature, the lubricant J becomes fluid and its viscosity is greatly decreased. The lubricating performance of the lubricant 414K, in contrast, causes drawn through in warm drawing in particular, and is considered to be superior to that of J and equal to that of MoS_2. Even in room temperature drawing, 414K gives better results in drawing depth than the conventional J lubricant. This is because 414K has a lubricating mechanism and (accordingly, better workability and removability) different from that of the conventional water-soluble lubricants; specifically, a minutely-textured film consisting of micro-crystal groups of solid boric acid is formed on the blank surface by hydrolytic reaction of organic boron compounds. Further, through the combined use of heat-resistant plastic film on the punch surface, the drawability with all lubricants including MoS_2, J, and 414K is improved. Particularly with a combination of 414K and heat-resistant plastic film, room temperature drawing of R304UD developed drawn through under the above test conditions. It must be noted, however, that the use of heat-resistant plastic film has the drawback that the removal of the film after

Table 5 Lubricating performance of newly developed heat resisting lubricant in warm drawing (mm)

Punch side		J**)	PF***)	MoS_2	PF***)	414 K*)			PF***)		
						A	B	C			
Die side		J**)	J**)	MoS_2	MoS_2	414 K*)			414 K*)		
						A	B	C	A	B	C
RT	R 304 UD	125	171	130	170	135	140	148	Drawn	Drawn	Drawn
	SUS 301	95	135	105	132	115	121	130	125	135	151
80°C	R 304 UD	122	170	Drawn	Drawn	Drawn	Drawn	Drawn	Drawn	Drawn	Drawn
	SUS 301	90	130	Drawn	Drawn	Drawn	Drawn	Drawn	Drawn	Drawn	Drawn

* 414 K: Newly developed lubricant[10] (easy working, good removability)
** J: Conventional water-soluble lubricant
*** PF: Heat resisting plastic film
Drawn: Drawn through

press forming is complicated and inefficient.

As mentioned above, the combination of the newly-developed heat-resistant lubricant and warm press forming has made possible ultra-deep drawing and sufficient restriking of stainless steels in actual press forming to satisfy commercial requirements.[11-13]

4 Conclusions

Warm press forming, in which stainless steel is press-formed by heating the die and the blank holder and by cooling the punch, has been examined, with the results summarized below.

(1) When the warm press forming was applied to the drawing of an oblong cylinder, both austenitic and ferritic stainless steels showed remarkable improvement in drawability. Proper drawing temperatures were affected by austenite stability for the former steel and by C content for the latter. These effects were results of a decrease in the drawing force at the die shoulder and by an increase in fracture force at the punch shoulder.

(2) Through a rise in the warm drawing temperature, the anisotropy of flange residual width increased for austenitic stainless steel and decreased for ferritic. With warm press forming, delayed fracture in austenitic stainless steel, and ridging in ferritic both decreased.

(3) When primary drawing was performed by warm press forming, subsequent restrikability was improved. Proper primary drawing temperature and subsequent restriking temperature were about 80°C and about 60°C, respectively, for R304UD, considering the unit consumption of heat and occurrence of magnetism.

(4) A water-soluble heat-resistant lubricant suitable for warm press forming was developed. This lubricant obtains its lubricating performance by forming a fine-textured lubricating film consisting of micro-crystal groups of boric acid on the blank surface, and has excellent workability and removability. Through the combination of this lubricant and warm press forming, ultra-deep drawing and sufficient secondary forming have become possible with even low-grade stainless steels.

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