On the Forming Load and the Forming Torque in Forming a Groove with Wide Flanges by Cold Roll Forming

By

Jun-ichi KOKADO* and Yoshitomi ONODA*

(Received September 6, 1974)

Abstract

The effect of forming conditions on the forming load and the forming torque of sheet steel in forming a circular arc groove with wide flanges has been experimentally investigated by changing several factors.

It is found that both the forming load and the forming torque are in proportion to the $(2+n)$ power of the thickness of the specimen (n = index of work hardening of the specimen); and they increase with the increase in the width of the specimen, ranging from the length measured along the roll profile to twice this length. Also, they have constant values for a width of specimen over twice the length measured along the roll profile, and increase symmetrically with the increase in the absolute value of the inlet angle of the specimen, ranging from $-4°$ to $+4°$. Finally, they have proportional relations mutually. The forming load is hardly affected by the ratio of surface velocities of the flat parts of rolls and the ratio of maximum convex to minimum concave roll diameters. However, the forming torque is greatly affected by the ratio of surface velocities of the flat parts of rolls.

On the basis of the experimental results mentioned above and the theory of the plastic bending of plate, an equation for estimating the forming load was experimentally formulated. The calculated forming load from this equation is in good agreement with the experimental results, and the difference between both loads is at most 10%.

Furthermore, the forming load of sheet steel in forming a trapezoidal groove with wide flanges by a tandem roll forming was estimated by a die pressing method with sufficient accuracy.

1. Introduction

Both the forming load and the forming torque in cold roll forming are closely related with each other and some investigations on the relation between them have been carried out mainly on the forming of a narrow profile without flanges.

In Japan, 1965, it was reported by Dr. Masuda and Dr. Murota[1] that the upper (convex) roll torque of aluminum strip and sheet steel in forming a circular

* Department of Mineral Science and Technology.

arc section by a single roll mill was closely connected with the position of equal velocity of the upper and the lower rolls, and was less than about one tenth or one third of the lower roll torque. Both the forming load and the forming torque were in proportion to the second power of the thickness of the specimen. Dr. Suzuki and Dr. Kiuchi[2)~5)] have experimentally investigated the relation between the forming condition and both the forming load and the forming torque in forming a circular arc, V and a trapezoidal shape by single and tandem roll mills since 1969. As a result, it was reported that the forming load increased exponentially with the increase in the thickness of the specimen, and this index was 1.1~1.35. The forming torque was determined by the state of distribution of contact pressure between the rolls and the specimen, and the difference between the real point and the designed point of equal velocity.

The authors have carried out experimental investigations on the deformation process and both the forming load and the forming torque in forming single or double trapezoidal grooves with wide flanges by cold roll forming according to the method of transforming a circular arc groove into a trapezoidal groove since 1963[6)~8)].

This paper deals mainly with the estimation method of the forming load.

2. Roll Profiles and Dimensions of Rolls

The circular arc section of the roll profile is determined by five factors: the pass height (h), the opening width of the groove (l), the length measured along the roll profile (S), the transverse bending radius of the groove and shoulder parts of the roll profile (R) and (r), and the bending angle (θ). Taking the notation as shown in Fig. 1, the following three expressions can be obtained for the convex roll profile.

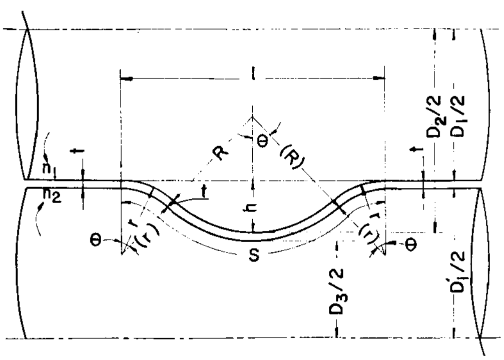

Fig. 1 Notations of roll profile.

$$\left.\begin{aligned}(R+r)(1-\cos\theta)&=h\\ 2(R+r)\,\theta&=S\\ 2(R+r)\sin\theta&=l\end{aligned}\right\}$$

The convex roll profiles for the forming of the circular arc groove with wide flanges by a single roll mill are shown in Fig. 2. The dimensions of the rolls used for the experiment are shown in Table 1.

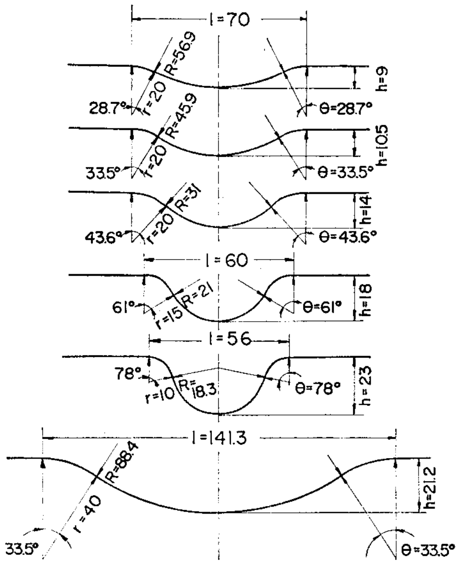

Fig. 2 Geometries of several convex roll profiles used for the experiment.

Table 1 Dimensions of rolls and roll profiles.

Length measured along the roll profile S [mm]	Barrel diam. of male roll D_1 [mm]	Max. diam. of male top roll D_2 [mm]	Barrel diam. of female roll D_1' [mm]
77	110	128	110
77	110	131	110
77	110	138	110
77	95	131	95
77	95	141	95
150	120	162.4	120

Min. diam. of female bottom roll D_3 [mm]	Ratio of roll diams. $i=D_2/D_3$	Pass height h [mm]	Opening width of groove l [mm]	Forming ratio h/l
78	1.64	9.0	70	0.128
78	1.68	10.5	70	0.15
78	1.77	14	70	0.2
57	2.3	18	60	0.3
51	2.76	23	56	0.41
75.6	2.15	21.2	141.3	0.15

Besides, the specimen used for the experiment is SPC-1 (JIS•G3310) and the stress-strain relation of this specimen is shown in Fig. 3.

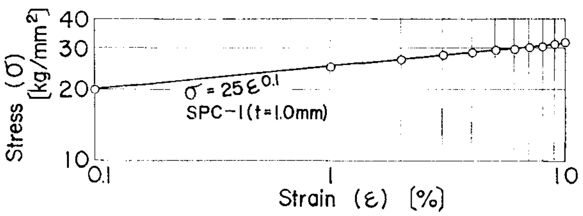

Fig. 3 Stress–strain curve of the specimen used for the experiment.

3. Relations between Forming Conditions and both the Forming Load and the Forming Torque in a Single Stand Roll Forming

3.1 Effect of the width of the specimen on both the forming load and the forming torque

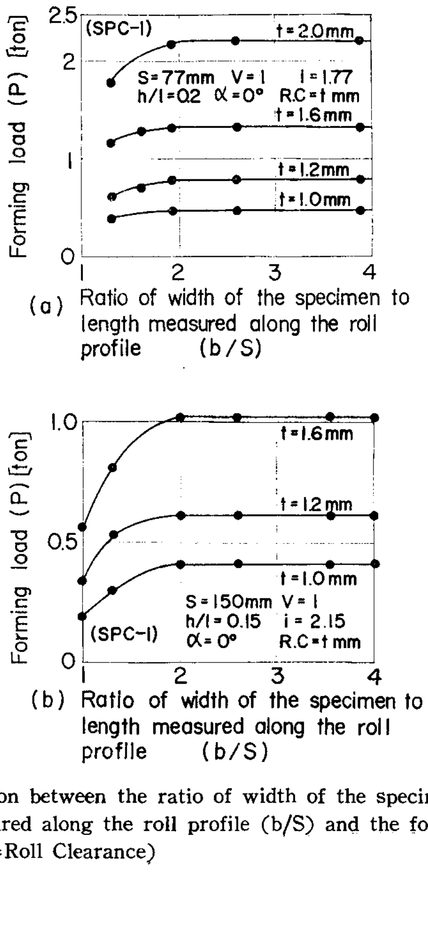

Fig. 4 Relation between the ratio of width of the specimen to length measured along the roll profile (b/S) and the forming load (P). (R.C=Roll Clearance)

Figure 4 (a) shows the relation between the ratio of the width of the specimen to the length measured along the roll profile (b/S) and the forming load (P), taking the thickness of the specimen (t) for the parameter, where the length measured along the roll profile S=77mm, the opening width of the groove $l=70$ mm, the pass height h=14mm, the ratio of the forming height to the opening width of the groove $h/l=0.2$, the ratio of the surface velocity of the flat part of the lower roll to that of the upper roll V=1.0, the ratio of the maximum convex to the minimum concave roll diameters i=1.77 and the inlet angle of the specimen to the rolling axis $\alpha=0°$.

The inlet angle of the specimen to the rolling axis α is defined by the following expression.

$\alpha=\tan^{-1}(H/L)$, where:

L=distance between the guide and the mill rolls

H=height difference between the biting parts of the flat rolls in the guide and the mill

α is positive when the guide rolls are higher than the mill rolls.

In the case of S=150mm, $h/l=0.15$ and i=2.15, this relation is shown in Fig. 4 (b).

Further, the relations between (b/S) and both the upper (convex) roll torque (T_v) and the lower (concave) roll torque (T_c), under the same conditions, are shown in Fig. 5 (a) and Fig. 5(b).

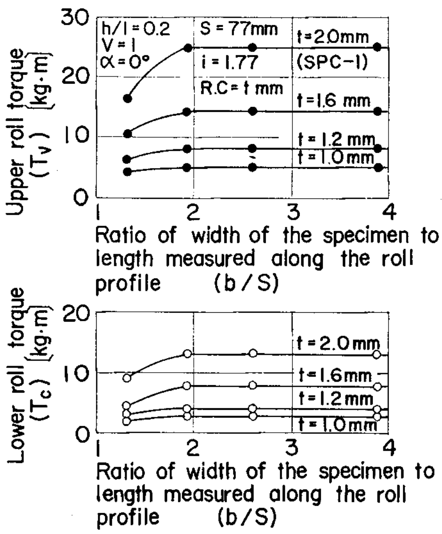

Fig. 5 (a) Relations between the ratio of width of the specimen to length measured along the roll profile (b/S) and both the upper (convex) roll torque (Tv) and the lower (concave) roll torque (Tc) in the case of S=77mm, $\alpha=0°$, V=1 and h/l =0.2.

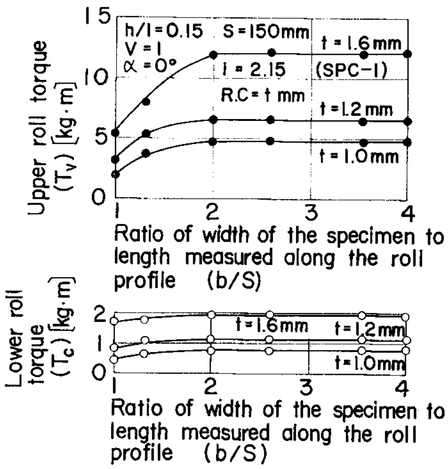

Fig. 5 (b) Relations between the ratio of width of the specimen to length measured along the roll profile (b/S) and both the upper roll torque (Tv) and the lower roll torque (Tc) in the case of S=150mm, $\alpha=0°$, V=1 and $h/l=0.15$.

From these figures, it is found that both the forming load and the forming torque increase with the increase in b/S, and have almost constant values for b/S ≥ 2.

3.2 Effect of the ratio of the forming height to the opening width of the groove on both the forming load and the forming torque

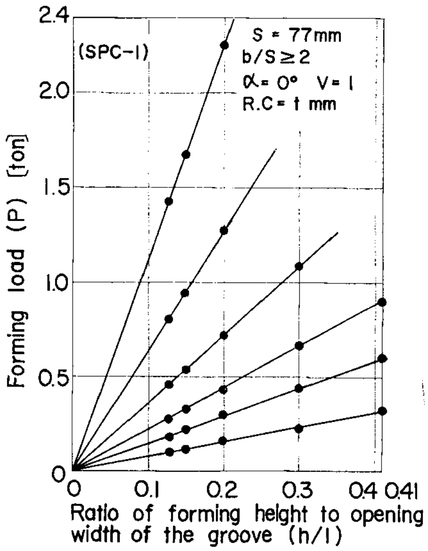

Fig. 6 Relation between the ratio of forming height to opening width of the groove (h/l) and the forming load (P).

Figure 6 shows the relation between the ratio of the forming height to the opening width of the groove (h/l) per single roll mill and the forming load (P), taking the thickness of the specimen (t) for the parameter, where S=77mm, V=1.0, $\alpha=0°$ and b/S≥2.

From this figure, it is found that the forming load increases proportionally to the ratio of the forming height to the opening width of the groove in any value of the parameter (t).

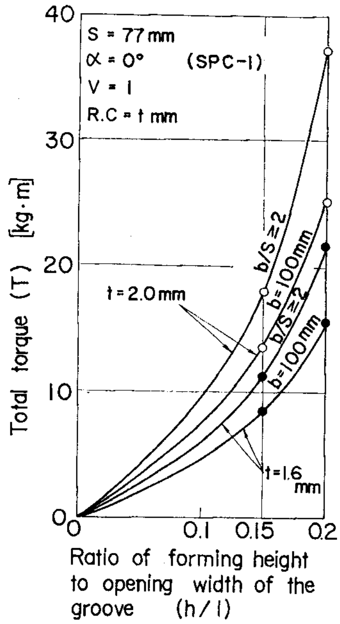

Fig. 7 Relation between the ratio of forming height to opening width of the groove (h/l) and the total torque (T=Tv+Tc).

On the other hand, Fig. 7 shows an example of the relation between (h/l) and the total torque ($T=T_v+T_c$), where it is found that the forming torque increases proportionally to 2.2~2.4 power of the ratio of the forming height to the opening width of the groove. This is the matter which must be carefully considered in the necessary power for the design of cold roll forming equipment.

3.3 Effect of the inlet angle of the specimen to the rolling axis on both the forming load and the forming torque

Figure 8 (a) and Figure 8 (b) show the relations between the inlet angle of the specimen to the rolling axis (α) and the forming load (P) for 1≤b/S<2 and b/S≥2 respectively, taking the thickness of the specimen (t) for the parameter, where S=77mm, h/l=0.2, i=1.77 and V=1.0.

Further, the relation between (α) and both the upper and the lower roll torques

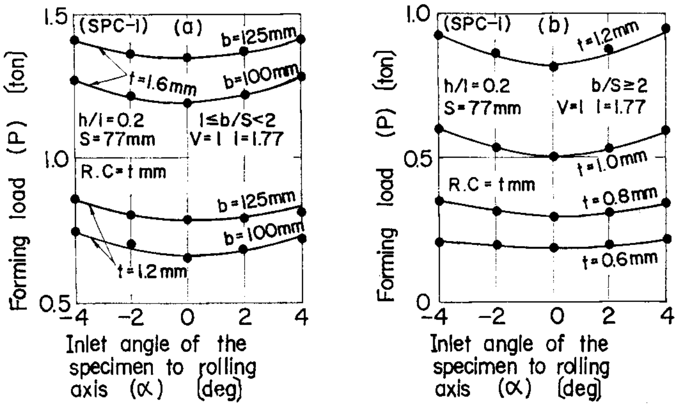

Fig. 8 Relation between the inlet angle of the specimen to rolling axis (α) and the forming load (P).

(T_v, T_c), under the same conditions, is shown in Fig. 9 in the case of b=300mm (b/S>2).

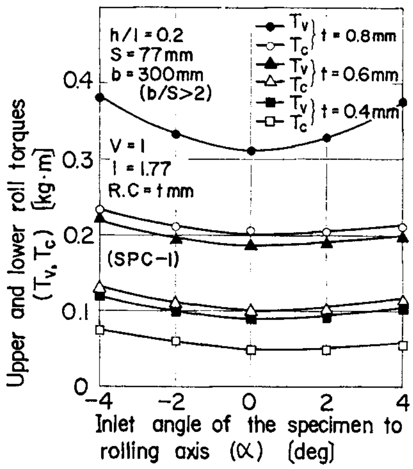

Fig. 9 Relation between the inlet angle of the specimen to rolling axis (α) and both the upper and the lower roll torques (Tv, Tc).

From these figures, it is found that both the forming load and the forming torque have minimum values for $\alpha=0°$, and increase symmetrically with the increase in the absolute value of α for $/\alpha/\leq 4°$, which prevents any edge wave and buckling.

3.4 Effect of the thickness of the specimen on both the forming load and the forming torque

Figure 10 shows the relation between the thickness of the specimen (t) and the forming load (P), taking the ratio of the forming height to the opening width

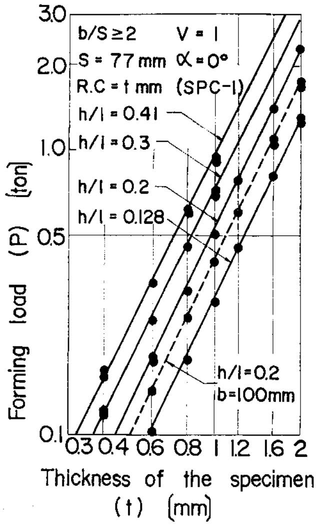

Fig. 10 Relation between the thickness of the specimen (t) and the forming load (P).

of the groove (h/l) for the parameter, where S=77mm, V=1.0, $\alpha=0°$ and b/S≧2. In this figure, the dotted line shows an example of this relation for h/l=0.2 and 1<b/S<2.

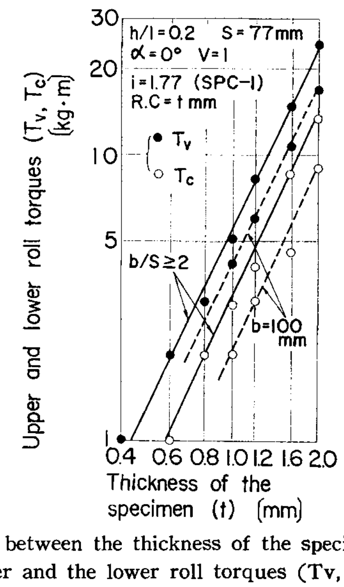

Fig. 11 Relation between the thickness of the specimen (t) and both the upper and the lower roll torques (Tv, Tc).

Figure 11 shows the relation between (t) and both the upper and the lower roll torques (T_v, T_c), where S=77mm, V=1.0, $\alpha=0°$, h/l=0.2 and i=1.77. In this figure, the dotted line shows an example of this relation for 1<b/S<2.

From these figures, it is found that both the forming load and the forming torque increase proportionally to 2.1 power of the thickness of thes pecimen in any value of the parameter (h/l) and (b/S).

Consequently, for the reason that the index of work hardening of this specimen (n) is 0.1 and this deformation process consists mainly of the bending process, it is considered that both the forming load and the forming torque are in proportion to the (2+n) power of the thickness of the specimen.

3.5 Effect of other forming conditions on both the forming load and the forming torque

In other forming conditions, not only the ratio of the surface velocity of the flat part of the lower roll to that of the upper roll (V) but also the ratio of maximum convex to minimum concave roll diameters (i) are factors which cannot be overlooked.

Firstly, the ratio of the surface velocity of the flat part of the lower roll to that of the upper roll (V) affects the forming load (P) but little. Therefore, the effect of this factor on the forming load can be neglected. On the other hand, the forming torque is greatly affected by this factor, as shown in Fig. 12. Figure 12 shows the relation between the forming torques (T_v, T_c, T) and the ratio of

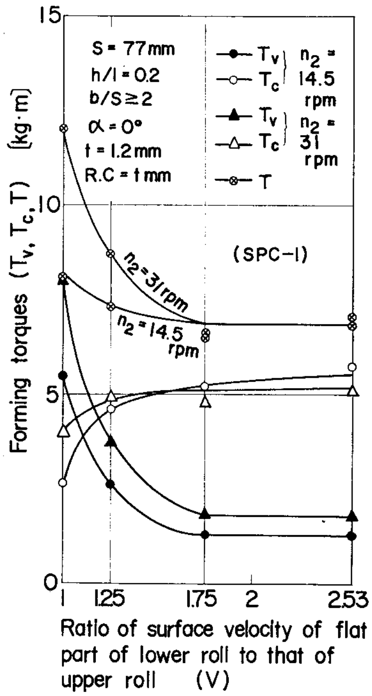

Fig. 12 Relation between the forming torques (Tv, Tc, T) and the ratio of surface velocity of flat part of lower roll to that of upper roll (V).

the surface velocity of the flat part of the lower roll to that of the upper roll (V), taking the number of rotations of the lower roll (n_2) for the parameter, where S=77mm, i=1.77, $\alpha=0°$, t=1.2mm and $b/S \geq 2$.

From this figure, it is found that both the upper roll torque (T_v) and the total torque (T) decrease with the increase in V, and the lower roll torque (T_c) increases with the increase in V, having approximately constant values for about $V>1.75$.

Therefore, the relation between the magnitude of the upper and the lower roll torques changes according to the value of V. However, if we consider the biting force of the rolls to the specimen and the abrasion occurred on the specimen, it is desirable for V to be selected from a range of 1 to 1.25 in practical application.

Secondly, both the forming load and the total torque increase fractionally with the increase in the ratio of maximum convex to minimum concave roll diameters (i), but the effect of this factor on both the forming load and the torque can be neglected in practical application.

3.6 Relation between the forming load and the forming torque

Both the forming load and the forming torque are closely related with each other. They are affected approximately the same by individual forming conditions other than the ratio of the surface velocity of the flat part of the lower roll to that of the upper roll and the ratio of the forming height to the opening width of the groove, as stated before.

Figure 13 (a) and Figure 13 (b) show the relation between the forming load (P) and both the upper and the lower roll torques (T_v, T_c) in the case of $h/l=0.15$, S=150mm and i=2.15 and $h/l=0.2$, S=77mm and i=1.77, where V=1.0 and $\alpha=0°$.

From these figures, it is found that both the upper and the lower roll torques increase approximately proportionally to the forming load. The inclinations of these straight lines vary according to the forming conditions, and show the product of the apparent coefficient of friction and the so-called torque arm.

4. Equation for Estimating the Forming Load

In cold roll forming, as the specimen shows the three dimensional deformation surface through rolls and there are some obscure points on the state of contact between the specimen and rolls, it is almost impossible to obtain analytically the forming load and the forming torque regarding the difference of the deformation surface due to the forming conditions.

Accordingly, on the basis of the experimental results mentioned above, we

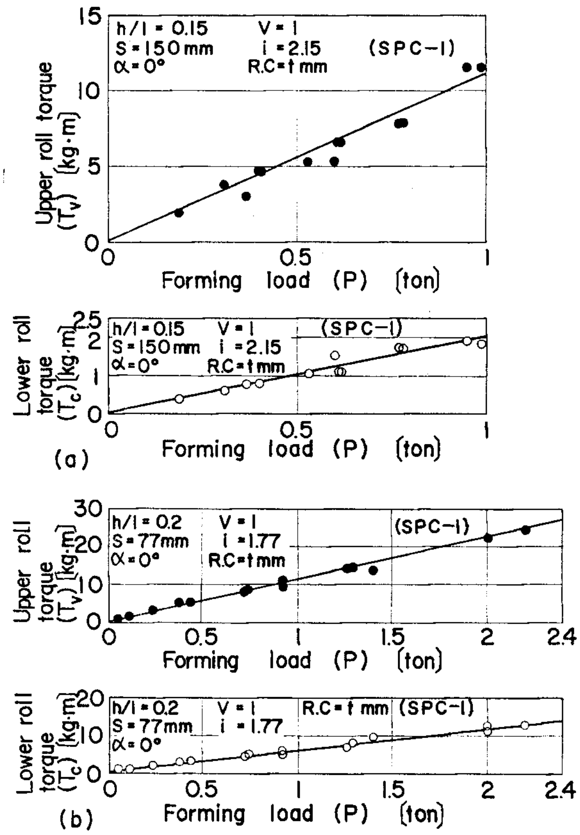

Fig. 13 Relation between the forming load (P) and both the upper and the lower roll torques (Tv, Tc).

obtained experimentally an equation for estimating the forming load in forming the circular arc groove with wide flanges by a single roll mill.

The forming load (P) [kg] is considered to be a function of: the thickness of the specimen (t) [mm], the ratio of the forming height to the opening width of the groove (h/l), the ratio of the width of the specimen to the length measured along the roll profile (b/S), the inlet angle of the specimen to the rolling axis (α) [deg], the transverse bending radius of the convex part of the convex roll (R) [mm], the transverse bending radius of the shoulder part of the concave roll ((r)) [mm] and yield stress of the specimen (σ_e) [kg/mm^2].

Namely,

$$P=f(t,\ h/l,\ b/s,\ \alpha,\ R,\ (r),\ \sigma_e)$$

As stated before, the forming load is in proportion to t^{2+n} and also to h/l, and increases describing a parabola as an axis of symmetry $\alpha=0°$ for $/\alpha/\leq 4°$, and increases describing a quadric curve with the increase in b/S for $1\leq b/S<2$.

This inclination becomes horizontal in b/S=2. Further, from the theory of plastic bending, the forming load is in proportion to σ_e, and is in inverse proportion to R^n and also to $(r)^n$.

Then, in consideration of these matters, we can formulate the following equation.

$$P=a\left\{1-c\left(2-\frac{b}{S}\right)^2\right\}(\alpha^2+d)(R^{-n}+(r)^{-n})\cdot t^{2+n}\cdot\sigma_e\cdot(h/l)$$

where

$a=1.36,\ c=0.45,\ d=69.9$

The calculated forming load from this equation is in good agreement with the experimental results, and the difference between both loads is at most 10%.

5. Estimation of the Forming Load by a Die Pressing Method

The equation for estimating the forming load obtained above is in good agreement with the experimental results. However, when the forming conditions are beyond the limits of the experiment mentioned above, the values of coefficients in this equation may change a little. In this case, as a new experiment needs great expense and much labour, if the exact forming load can be estimated by a certain simple experiment without the use of the roll forming equipment, the use of this simple estimating method is very convenient in practical application.

When the press forming is done by the upper and lower dies which have the

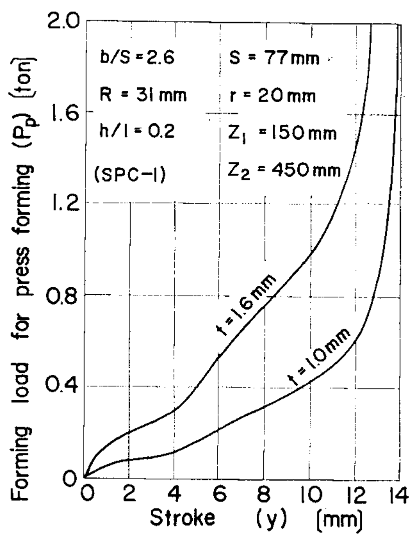

Fig. 14 Transition of the forming load (Pp) for press forming due to the stroke (y) of the die.

same section as the roll profile, the deformation state of the specimen out of dies is very analogous to that of the specimen before rolls in roll forming. The forming load (P_p) for this press forming, as shown in Fig. 14, increases with the increase in the stroke of the upper die (y), and the closer the value of y gets to the forming height h, the greater this increase becomes, and after all the value of P_p becomes infinity in $y=h$. Therefore, in this paper, the value of the load corresponding to $y=(h-1)$mm is defined as the forming load P_p for this press forming.

Letting the length of the specimen within dies and that of one side of the specimen out of dies be Z_1 and Z_2 respectively, the forming load P_p is in proportion to Z_1 in the case of $Z_2=0$. Now, in the case of $Z_1=150$mm, $h/l=0.2$, $t=1.0$ mm, $R=31$mm, $r=20$mm, $S=77$mm and $h=14$mm, the relation between the forming load (P_p) and the length of one side of the specimen out of dies (Z_2) is shown in Fig. 15.

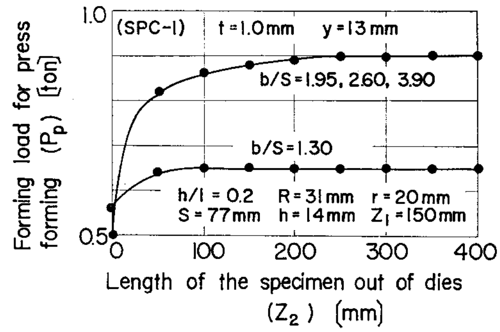

Fig. 15 Relation between the forming load for press forming (Pp) and the length of the specimen out of dies (Z_2).

From this figure, it is found that the value of P_p increases with the increase in the value of Z_2 and has at least a constant value for $Z_2>200$mm. Therefore, in the following experiments, the value of Z_2 is fixed as $Z_2=450$mm.

Figure 16 shows the relation between the forming load (P_p) in press forming and the ratio of the width of the specimen to the length measured along the die profile (b/S). From this figure, it is found that the value of P_p increases with the increase in the value of b/S for $1\leq b/S<2$, and has a constant value for $b/S\geq2$. Also, it is in proportion to the $(2+n)$ power of the thickness of the specimen (n=index of work hardening of the specimen). These are the very same tendencies as those in roll forming shown in Fig. 4.

Consequently, this shows that there is a certain constant similarity between both forming loads in this press forming and roll forming.

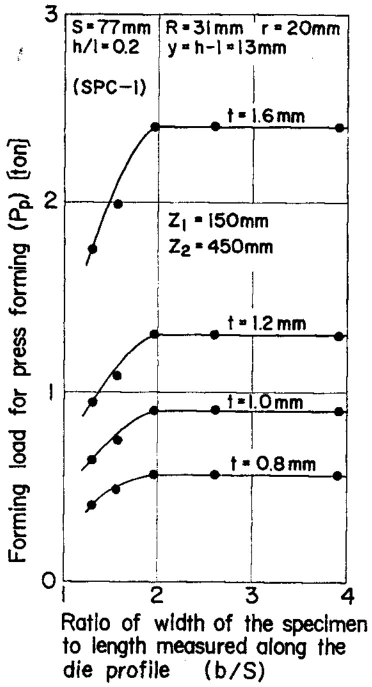

Fig. 16 Relation between the ratio of width of the specimen to length measured along the die profile (b/S) and the forming load for press forming (Pp).

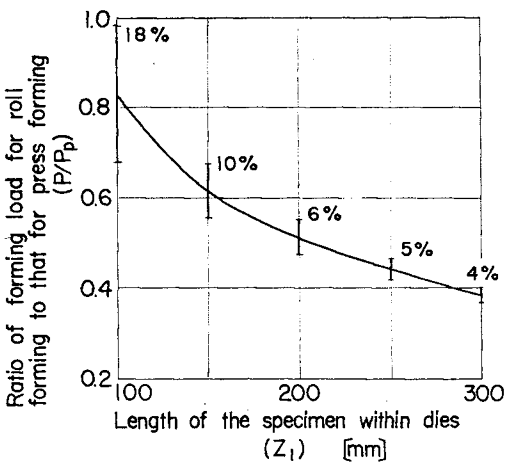

Fig. 17 Relation between the ratio of the forming load for roll forming to that for press forming (P/Pp) and the length of the specimen within dies (Z_l).

Figure 17 shows the relation between the ratio (P/P_p) of the forming load P in roll forming (standard forming conditions $\alpha=0°$, V=1) to the forming load P_p in this press forming due to the dies having the same section as the roll profile and the length (Z_1) of the specimen within the dies for various kinds of thickness of the specimen and the ratio of width of the specimen to the length measured along the roll profile or the die profile.

In this figure, the values of percentage show a scattering in measured values, and it is found that the amount of this scattering decreases exponentially with the increase in the value of Z_1.

If we consider small percentage errors accompanying the measured values of the forming loads and the difficulty with the fabrication of dies, the value of P/P_p for $Z_1>150$mm will be accurate enough for practical usage.

Figure 18 shows the transitions of both forming loads in tandem roll forming ($\alpha=0°$, V=1) and press forming ($Z_1=150$mm, $Z_2=450$mm) in forming sheet steel into a trapezoidal groove with wide flanges due to the roll or the die profiles shown in Fig. 19. In Fig. 18, the ratio of both forming loads in three progressive stages (No. 1, 2 and 3 forming stands or dies) which form the circular arc groove with wide flanges, is about 0.62. This value is in good agreement with the mean value of P/P_p for $Z_1=150$mm in Fig. 17.

Therefore, in the forming of the circular arc groove with wide flanges, the experimental results obtained above to the single stand or die can be applied exactly to the tandem forming. On the other hand, the ratio of P/P_p in the fourth stand or die which forms the trapezoidal groove with wide flanges is about 0.27. This value is quite different from that in the forming of the circular arc groove with wide flanges.

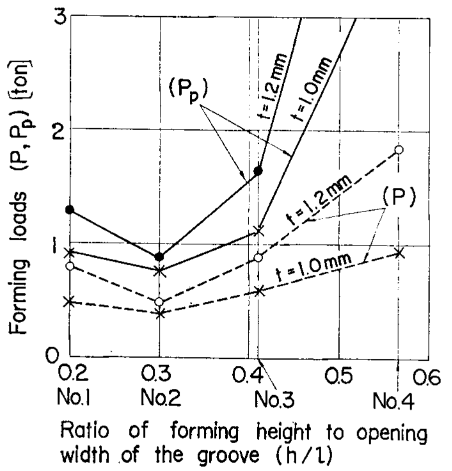

Fig. 18 Transition of both forming loads in roll forming and press forming (P, Pp).

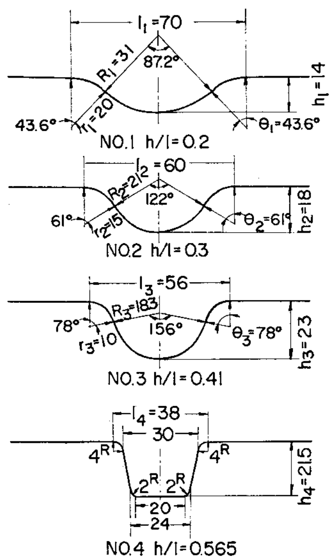

Fig. 19 Roll profiles used for the tandem roll forming of the trapezoidal groove with wide flanges.

6. Conclusion

Firstly, in a single stand roll forming, we obtained experimentally the relations between the forming conditions and both the forming load and the forming torque of sheet steel in the forming of the circular arc groove with wide flanges. This preceded the forming of the trapezoidal groove with wide flanges. On the basis of these experimental results, we formulated the equation for estimating the forming load. As this equation has sufficient accuracy within the limits of this experiment, it can be applied exactly to the design of practical equipment.

Secondly, we examined the estimation of the forming load by the die pressing method as a simpler estimating method. As a result, we showed that the forming load not only in a single stand, but also in tandem roll forming of the circular arc groove with wide flanges, could be easily estimated from the forming load obtained by the die pressing method. This will be true if both the length of the specimen within dies and that of one side of the specimen out of dies are more than 200mm.

Acknowledgement

We are grateful for the financial assistance of the Ministry of Education.

References

1) M. Masuda and T. Murota : Journal of Japan Society for Technology of Plasticity, Vol. 6, No. 54, (Jul. 1965), p 379
2) H. Suzuki and M. Kiuchi : J. of Jap. Soc. for Technol. of Plast., Vol. 10, No. 102, (Jul. 1969), p. 502
3) H. Suzuki and M. Kiuchi : J. of Jap. Soc. for Technol. of Plast., Vol. 11, No. 110, (Mar. 1970), p. 202
4) H. Suzuki and M. Kiuchi : J. of Jap. Soc. for Technol. of Plast., Vol. 11, No. 119, (Dec. 1970), p. 913
5) H. Suzuki and M. Kiuchi : J of Jap. Soc. for Technol. of Plast., Vol. 13, No. 133, (Feb, 1972), p. 83
6) J. Kokado and Y. Onoda : J. of Jap. Soc. for Technol. of Plast., Vol. 13, No. 132, (Jan. 1972), p. 21
7) J. Kokado and Y. Onoda : J. of Jap. Soc. for Technol. of Plast., Vol. 13, No. 142, (Nov. 1972), p. 851
8) J. Kokado and Y. Onoda : J. of Jap. Soc. for Technol. of Plast., Vol. 14, No. 151, (Aug. 1973), p. 612