On the Forming Temperature and Effective Heat for Tube-end Spinning

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Summary

In the Tube-end Spinning, "softening" of a tube stock with frictional temperature generated with a die and a tube stock, is considered as the most important fundamental principle, and so, knowing about the forming temperature and effective heat to soften the tube materials is required to discuss the formabilities for Tube-end Spinning.

In this paper, the mean temperature θ_{m1} of forming portion and effective heat Q_1 softening the tube materials are formulated as follows,

for the temperature θ_{m1}

$$\theta_{m1} = \theta_M - \gamma(N_D/f_w)^{\lambda}$$

for the effective heat Q_1

$$Q_1 = \frac{a \cdot f_s^{m-1}}{2 \cdot \tan\alpha}\{(1-K)D - 2 \cdot b \cdot f_s^{n+1} \cdot \tan\alpha\}$$

1. Introduction

The formabilities of Tube-end Spinning depend on the correlation between the frictional temperature generated during the forming and the suitable forming speeds decided by die revolutions, die angles, and the feedings of tube stocks. The excessive forming speed that is not proper to the ductilities of tube materials causes to fracture and excessive temperature becomes the cause of Seizure. While all of these frictional temperatures do not usually contribute to forming, but a part of them flow into the forming portion and used to soften the forming portion, the residuals are spended as heat losses.

In this paper, it is tried that the formulations were made about forming portion temperature θ_{m1} calculated from the temperature distributions of the forming tube and about the effective heat Q_1 correlated to the several kinds of forming conditions for softening the forming portion.

2. Experimental equipments and methods

SHOUN-CAZENEUVE lathe HB-500 (12 HP 3200~40 rpm) is used to form tube stocks. According to "The Design of Factorial Experiment," 9 kinds of dies and several forming conditions are combined in various ways as 3 factors-3 levels, and 4 factors-3 levels. The experiments are performed for various wall thickness copper tubes. (Table 1)

Torque and thrust at conical nose forming to reduction ratio $K = 0.5$ are observed and the heat Q_1 is calculated by temperature distributions of forming tubes at the same time.

The following methods are adopted to measure the temperature; that the constantan wires are fixed at inner-face of copper tube with springs and thermo couple circuit is constracted with constantan wire-copper tube, measuring the temperature at five points as shown in Fig 1. It is said[1] that the temperature got in this way, is affected with the size of contact area, and shows the mean temperature of contact area. Because the purpose of the measurement is to calculate

Table 1 Test cnditions

Die	
Material	SKD 4
Die angles 2α°	30, 45, 60,
Relief area Ar %	12. 5, 25, 50,
Copper tube	
Material	DCu T 1
Compornent	Cu 99. 94%, p 0. 012%,
Hardness	92HR (F),
Dimensions mm	Outside dia. × thickness × length 25. 4, × (0. 8, 1. 0, 1. 2) × 70
Forming conditions	
Die revolutions N_D rpm	1250, 2000, 3200,
Tube feedings fw mm/rev	0. 1, 0. 225, 0. 5,

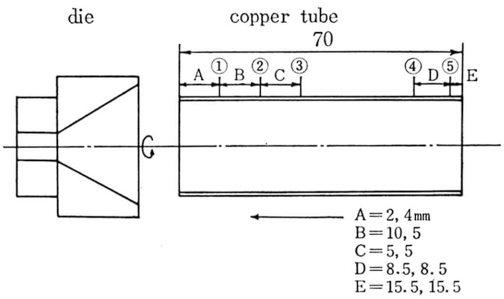

Fig. 1. Points of temperature measurment

the mean temperature of the forming portion of tube and to use same equipments in repeat, we avoid to sharpen the top of constantan wire, and polish lightly by emery paper (♯100) until the top of constantan wire becomes about 0. 2R, then that contact resistance is under 0. 3 Ω.

3. Experimental results and discussions

3-1 Temperature θ_{m1} of forming portion

The temperature distributions of the forming tube are shown in Fig 2. The head end of the formed portion tends to have higher temperature than the back end for a while after beginning of working. As the forming progressed, the local diffirences in the temperature risings of forming portion are apt to disappear, further progressed the temperature of the head end rather decreases. These tendencies are often seen when the feedings of tube are small; forming time is long. As the each lengths of the formed portion at every reduction ratio are measured in the same figure, we get the mean temperature of the forming portion at each reduction ratio by integral means using the same figure.

Fig 3 shows the mean temperature θ_{m1} changes during the forming, which show temperature risings from the room temperauure, the θ_{m1} is higher as die revolution N_D is larger and as the feeding f_w is smaller. On the contrary, θ_{m1} is lower as die revolution N_D is smaller and as the

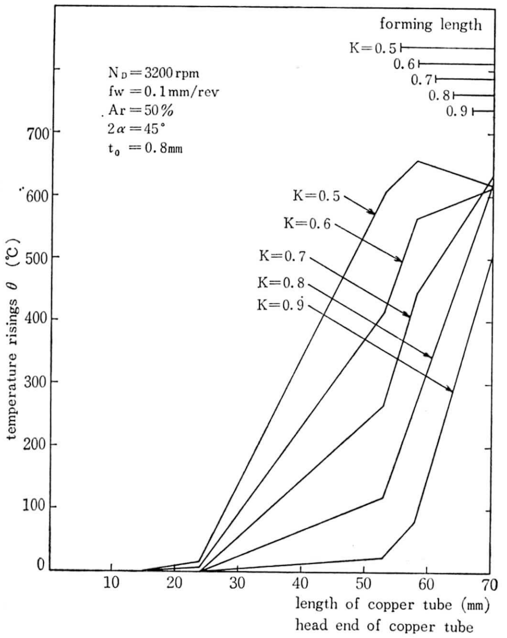

Fig. 2. Temperature distributions during forming

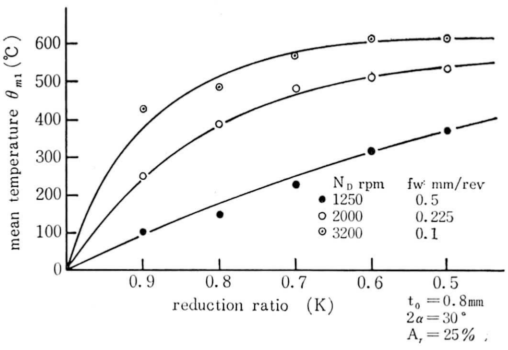

Fig. 3. Changes of temperature during forming

feeding f_w is larger.

Die revolution N_D, tube stock feeding f_w, heat relief area ratio Ar, and die angle 2α can be considered as the factors influenced upon the temperature, for the formabilities of Tube-end Spinning.

Fig 4 shows the relation between those factors and the temperature θ_{m1} of forming portion. The curves in Fig 4 are indicated by the means of levels among each factors, since the combination of the experiments was made to be equal the influences of the reference factor to that of other factors, according to the Factorial design. The arrows in Fig 4 show confidence limits 95 %. In this Fig 4, we can know that the temperature θ_{m1} increases with the increase of die revolution N_D, and decreases with the increase of feeding f_w and the changes of the heat relief area ratio Ar, die angle 2α has little influence on it.

Table 2 Results of analysis of variance (θ_{m1})

$t_0 = 0.8$ K = 0.7

Factors	S	ϕ	V	F	ρ	
A(N_D)	5124021.5	2	2562010.75	28.1507	27.3%	**
B(fw)	8872421.5	2	4436210.75	48.7439	48.0%	**
C(Ar)	1276374.8	2	638187.4	7.012	6.0%	**
D(2α)	—	—	—	—	—	—
A×B	—	—	—	—	—	—
A×C	—	—	—	—	—	—
B×C	1369107.4	4	342276.85	3.706	6.6%	*
e	1456168.4	16	91010.52	—	—	

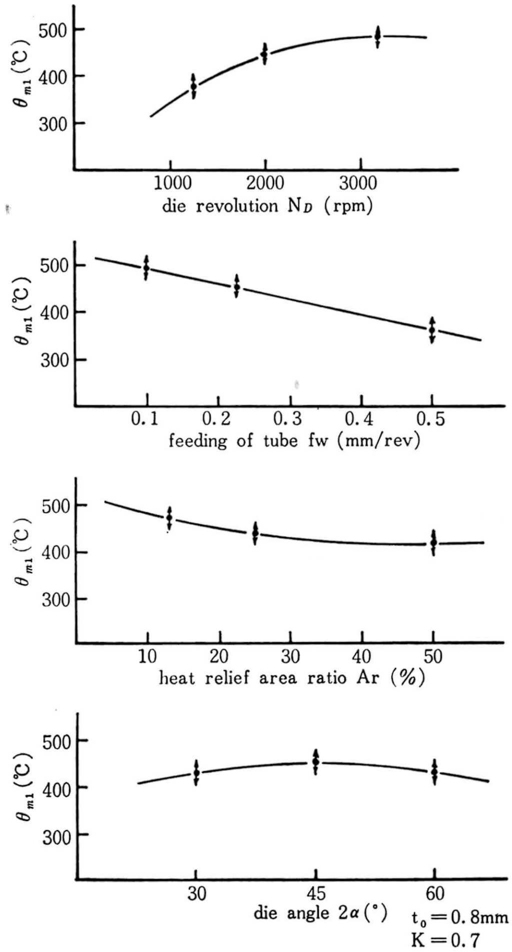

Fig. 4. Relation between forming condition and forming temperature (by arithmetical means of levels)

After the combinations of those factors and levels are layed out to L27 (3^{13}) as 4 factors-3 levels, the analysis of variance is made. The result is shown in Table 2. The reason why the column of 2α in the Table 2 is blank is that effect of the factor 2α was so small that it was pooled into the error. From the result of Table 2, it is found that the most effectable factor on the temperature is a feeding f_w, die revolution N_D is next effectable and heat relief area ratio Ar and die angle 2α are little effective on θ_{m1}. After the factor Ar and 2α which has little influence on θ_{m1} are fixed to Ar $= 25\%$, $2\alpha = 45°$, die revolution N_D, feeding f_w and reduction ratio K are varied to do analysis variance as 3 factors–3 levels. Table 3 shows the results that the reduction ratio K has naturally the greatest influence among three factors adopted.

The relation between the changes of θ_{m1} during the forming at each reducton ratio (K = 0.9, 0.7, 0.5) and N_D/f_w are shown in Fig 5. It is found that $\theta_M - \theta_{m1}$ may be described as a function of (N_D/f_w).

$$\theta_M - \theta_{m1} = \gamma(N_D/f_w)^{\lambda} \tag{1}$$

Table 3 Results of analysis of variance (θ_{m1})

$t_0 = 1.0$ Ar = 25%

Factors	S	ϕ	V	F	ρ	
A(N_D)	49686.556	2	24843.278	205.367	12.85%	**
B(fw)	113723.556	2	56861.778	470.049	29.5 %	**
C(K)	209729.556	2	104864.778	866.866	54.46%	**
A×B	1877.778	4	469.445	3.881	—	—
A×C	3441.112	4	860.278	7.112	0.77%	**
B×C	5218.890	4	1304.723	10.786	1.36%	**
e	967.757	8	120.970	—	—	—

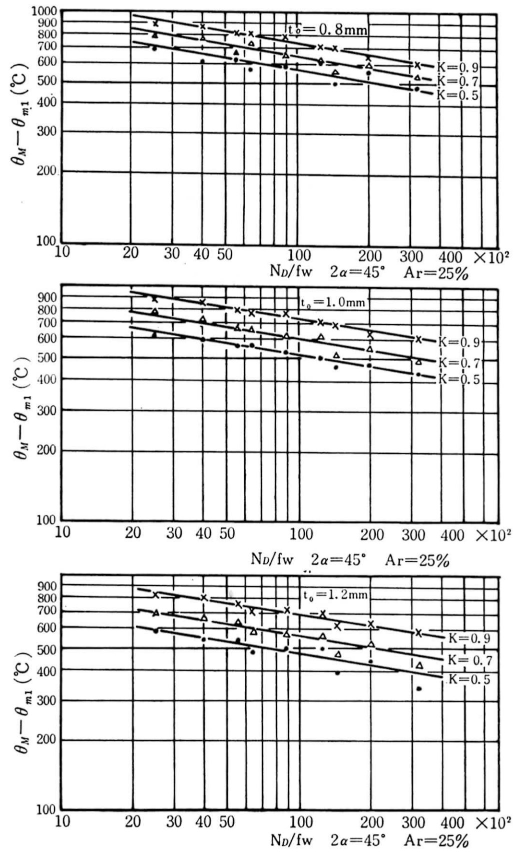

Fig. 5. Relation between $\theta_M-\theta_{m1}$ and N_D/fw

where θ_M: melting point of copper

γ: exprimental constants determined by reduction ratio (K) and wall thickness of tube (t_0)

λ: experimental constants independent of K, and t_0, we get in this paper

$$\lambda = -0.1467$$

i) decision of γ

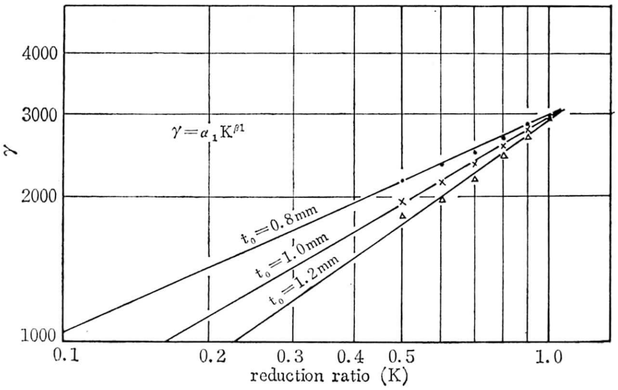

Fig. 6. Relation between (γ) and reduction ratio (K)

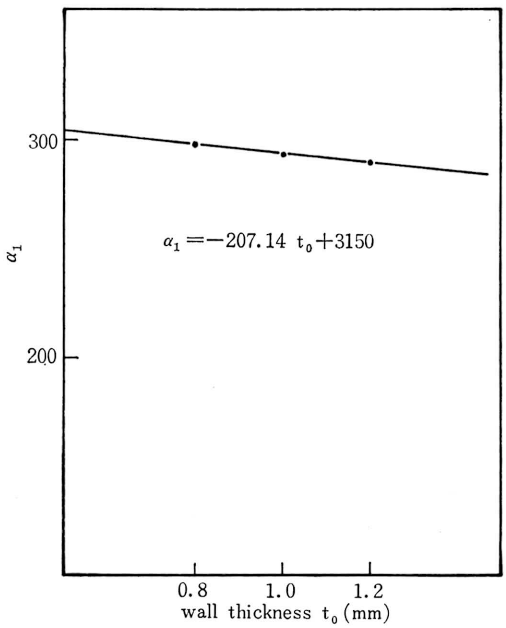

Fig. 7. Relation between constant α_1 and wall thickness t_0

Fig. 6 are plotted the relations between the reduction ratio K and γ for each wall thickness (t_0) on the log-log scale, γ is varied by K,

$$\gamma = \alpha_1 K^{\beta_1} \tag{2}$$

where α_1 is the variables that varied by

$$\alpha_1 = -207.14\, t_0 + 3150.0 \text{ (see Fig. 7)} \tag{3}$$

as for β_1, Fig. 8 shows the relations between β_1 and t_0. So β_1 is given by

$$\beta_1 = 0.583\, t_0 \tag{4}$$

Thus the temperature θ_{m1} during the forming is given by

$$\theta_{m1} = \theta_M - \gamma (N_D/f_w)^{\lambda} \tag{5}$$

where $\gamma = \alpha_1 K^{\beta_1}$

$\alpha_1 = -207.14\, t_0 + 3150.0$

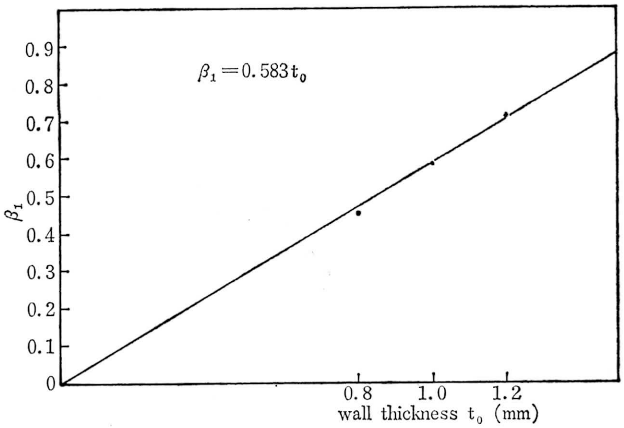

Fig. 8. Relation between β_1 and wall thickness t_0

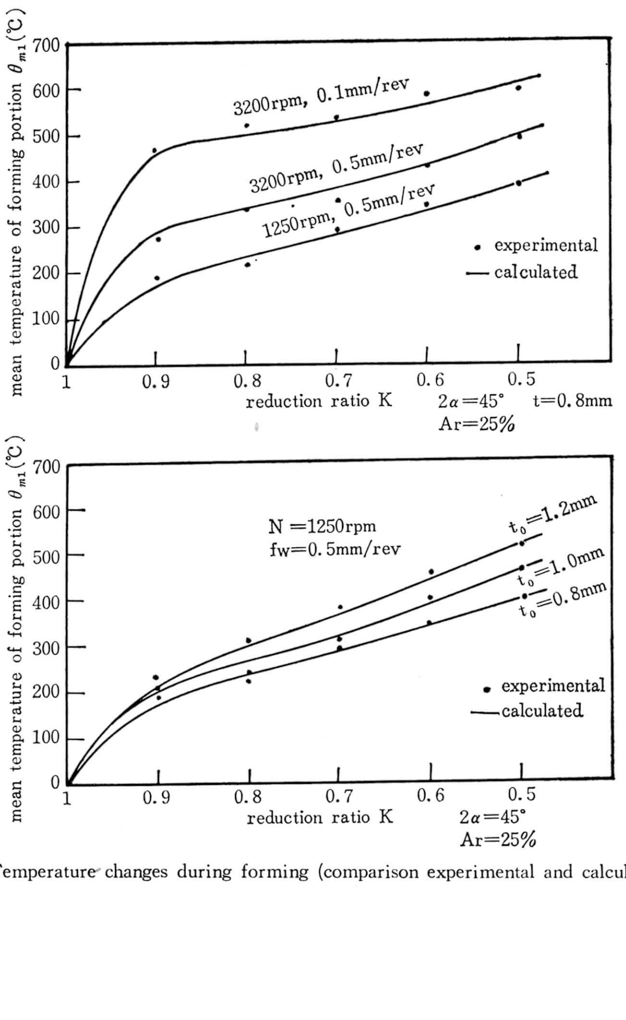

Fig. 9. Temperature changes during forming (comparison experimental and calculated)

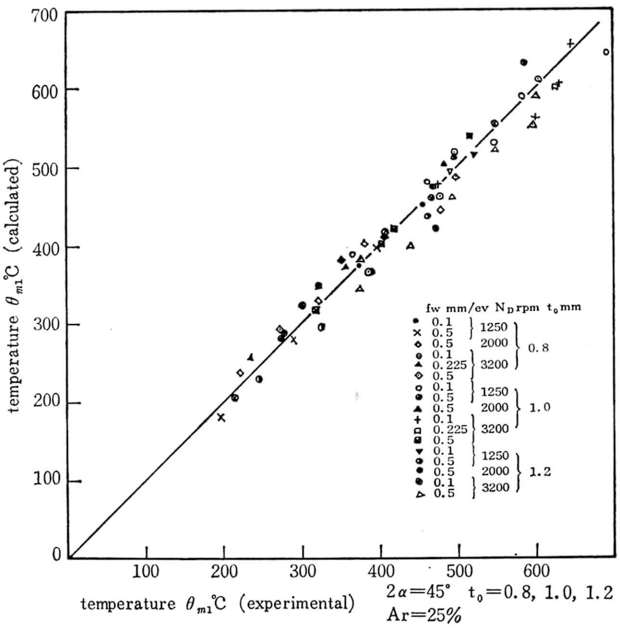

Fig. 10. Mean temperature of forming portion (comparison experimental and calculated)

$$\beta_1 = 0.583\, t_0$$
$$\lambda = -0.1467$$

Fig. 9 expresses as an example that the change of θ_{m1} during the forming compared experimental values with calculated values by expression (5). Both show fairly the tendencies of the temperature rise depend on the forming conditions. The other relation between experimental and calculated values are shown in Fig. 10, both are within 8%. So we have no difficulty in accepting (5) as the expression of the mean temperature of the forming portion.

3-2 Effective heat Q_1 which flows into forming portion

In the Tube-end Spinning "softening" of a tube stock with frictional temperature generated between a die and a tube stock is considered as the most important fundamental principle. Accordingly, it may be considered that the torque during the forming may be changed for the heat, then the heat expands to the non-forming portion of the tube and the die. As Q_T is a total heat generated, given by

$$Q_T = (Q_1 + Q_2) + Q_3 \qquad (6)$$

where Q_1 ; effective heat used softening of forming portion
Q_2 ; heat to non-forming portion
Q_3 ; heat to the die and the other

Q_1 is effectively available to soften the forming portion though the heat (Q_1+Q_2) had actually flowed into the forming portion.

In the same way as Fig. 4, Fig. 11 shows that the relations between die revolution N_D, feeding f_w, heat relief area ratio Ar, die angle (2α) and effective heat Q_1. The effective heat Q_1 increases as N_D increases, decreases as f_w and 2α increases, and is little effected by the change of Ar.

Now the influences of those factors on Q_1 are tabled by analysis variance in Table 4. It is seen that the die angle 2α is most effective, f_w, N_D in order effective and Ar has little effect on Q_1.

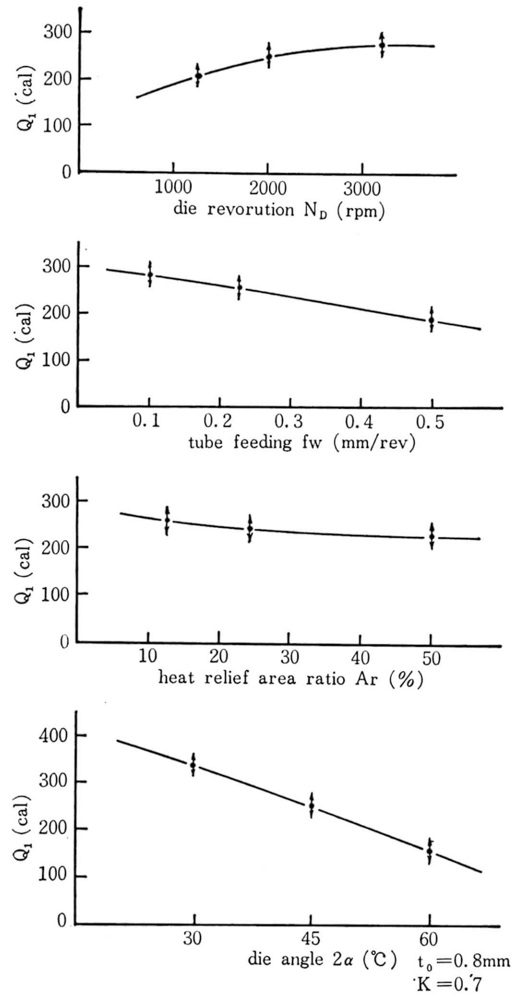

Fig. 11. Relation between forming conditions and effective heat (by arithmetical mean of levels)

Table 4 Results of analysis of variance (Q_1)

$t_0 = 0.8$ $K = 0.7$

Factors	S.	ϕ	V	F	ρ	
A(N_D)	2159006.9	2	1079503.45	8.554	7.9%	*
B(fw)	4274742.9	2	2137371.45	16.938	16.8%	**
C(Ar)	356630.9	2	178315.45	1.413	—	—
D(2α)	14711606.9	2	7355803.45	58.291	60.5%	**
A×B	127343.3	4	31835.83	0.252	—	—
A×C	792646.3	4	198161.58	1.570	—	—
B×C	702780.9	4	175695.23	1.392	—	—
e	757151.2	6	126191.87	1.00	—	—

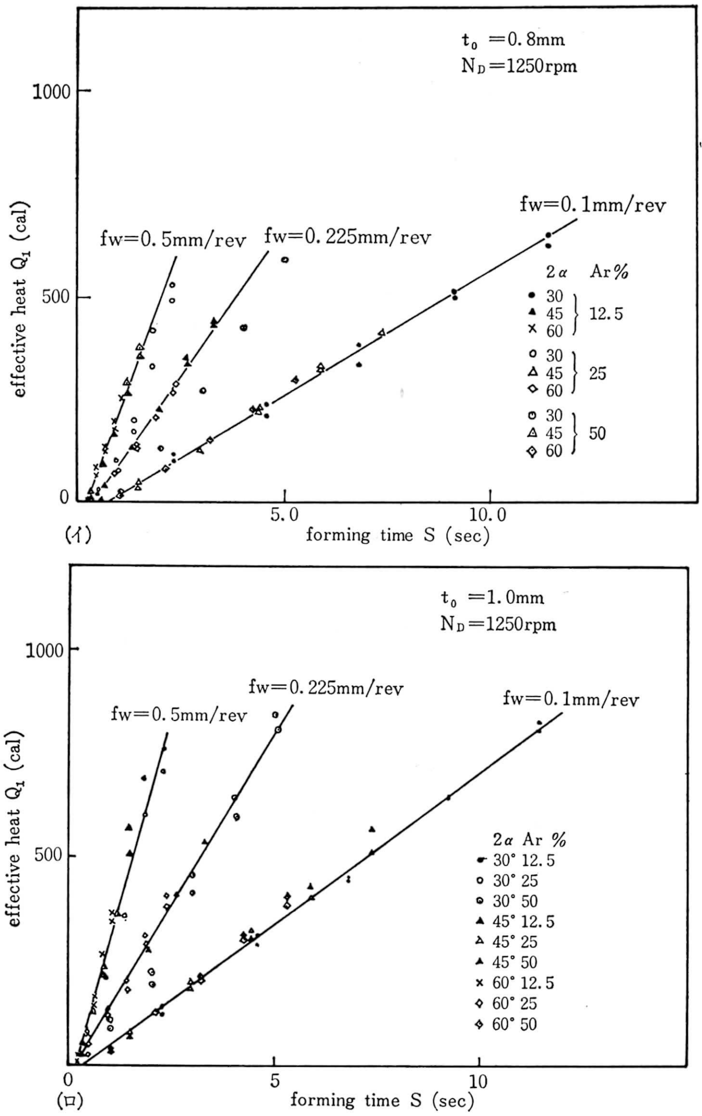

Fig. 12. Relation between effective heat and forming time

In order to examine the relations between several forming conditions and this Q_1, the correlation Q_1 and the forming time S (sec) are shown in Fig. 12. Accordingly, Q_1 may be expressed by following expression (7) from Fig. 12

$$Q_1 = A(S-S_0) \qquad (7)$$

where A ; constant

S_0 ; the value of A at $Q_1 = 0$

Fig. 13 shows the relations between this constant A and forming speed f_s (mm/sec). A is given by

$$A = a \cdot f_s^m \qquad (8)$$

where a, m ; constant (see Fig. 15, 16). On the other hand, the forming time S of Tube-end

Spinning is given by

$$S=\frac{(1-K)}{2\tan\alpha}\frac{D}{f_s} \tag{9}$$

where $f_s=\frac{N_D f_w}{60}$(mm/sec)

D: out side dia. of the tube stock

α: half die angle

therefore (7) is expressed by

$$Q_1=\frac{a\cdot f_s^{m-1}}{2\tan\alpha}\{(1-K)D-2f_sS_0\tan\alpha)\} \tag{10}$$

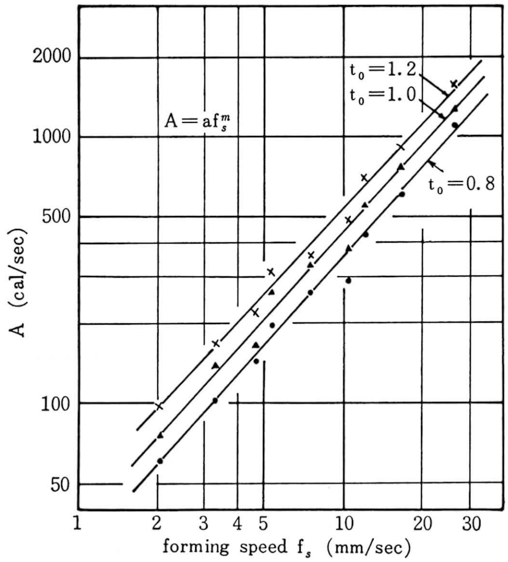

Fig. 13. Relation between A and forming speed f_s

Next, we examined the relation between (S_0) and forming speed (f_s) in Fig. 14. (S_0) becomes the function of only f_s, having no relation with tube thickness (t_0), die angle (2α) and heat relief area ratio (Ar), (S_0) is expressed as $S_0=b\cdot f_s^n$, therefore, Q_1 is expressed as (11)

$$Q_1=\frac{a\cdot f_s^{m-1}}{2\tan\alpha}\{(1-K)D-2\cdot b\cdot f_s^{n+1}\tan\alpha\} \tag{11}$$

where b, n; constant (see Fig. 15, 16). Fig. 15 and 16 show these constants a, b, m, n. From the expression (11) we can see that Q_1 decreases as α_1, K increase, while Q_1 increases as D increases.

Fig. 17 is an example of the comparison between Q_1 calculated with (11) and experimental values. Fig. 18 shows other forming conditions, it is seen that experimental expression (11) is adaptable and it will be possible to adopt (11) as the expression of Q_1.

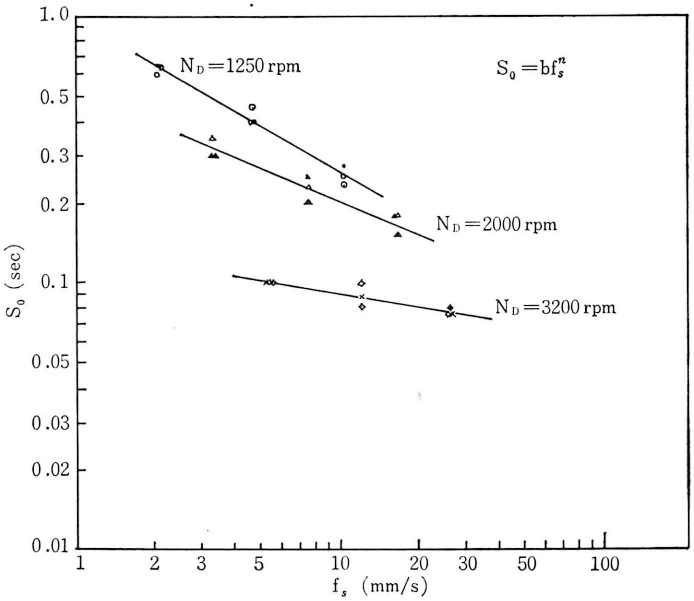

Fig. 14. Relation between S_0 and forming speed

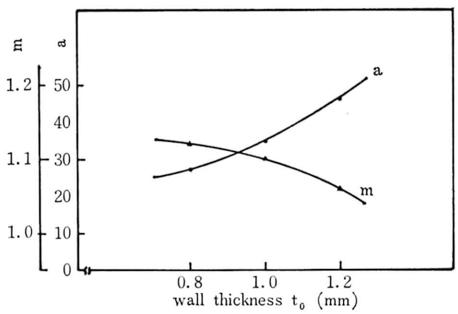

Fig. 15. Relation between constants (a, m) and wall thickness (t_0)

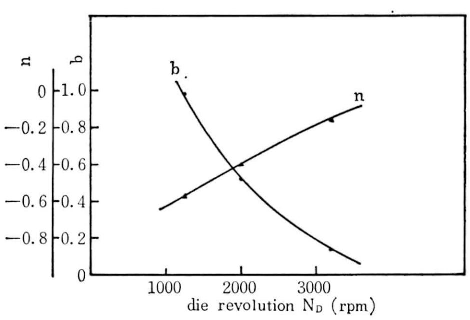

Fig. 16. Relation between die revolution N_D and constants b, n

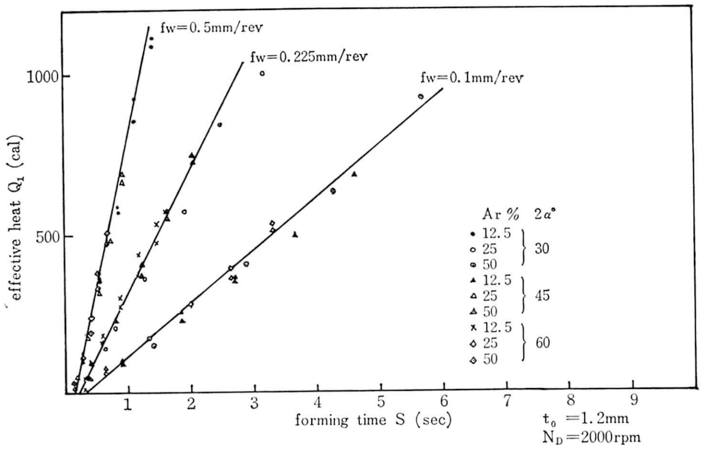

Fig. 17. Relation between forming time S and effective heat Q_1 (comparison experimental and calculated)

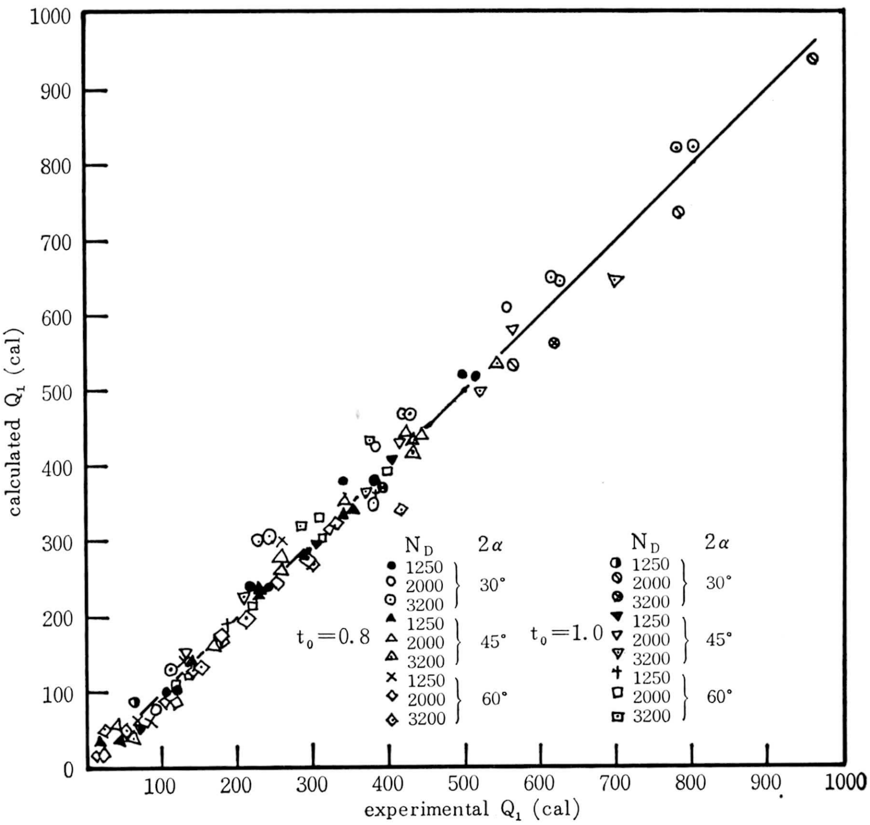

Fig. 18. Relation betweon experimental values and calculated values for effective heat Q_1

4. Conclusion

About the forming temperature and the heat flowing effectively into the forming portion which have influence on the formabilities of Tube-end Spinning, we know that

1) When the heat relief area ratio Ar, and die angle 2α are settled, the mean temperature θ_{m1} of the forming portion is given by

$$\theta_{m1} = \theta_M - \gamma(N_D/f_w)^{\lambda}$$

where $\gamma = \alpha_1 K^{\beta_1}$

$\alpha_1 = -207.14\,t_0 + 3150.0$

$\beta_1 = 0.583\,t_0$

$\lambda = -0.1467$

θ_M : melting point of copper

N_D : die revolution (rpm)

f_w : feeding of tube stock (mm/rev)

t_o : wall thickness (mm)

2) The effective heat Q_1 to the forming portion is given by

$$Q_1 = a \cdot f_s^{m-1}\{(1-K)D - 2bf_s^{n+1}\tan\alpha\}$$

where f_s : forming speed (mm/s)

D : out side dia. of tube stock (mm)

α : die half angle (degree)

a, m, b, n ; constants.

Reference

1) K, Takazawa: Journal of JSPE 3-11 (1964) 852.