# THE EFFECT OF FRICTION AT SIZING SURFACE ON DRAWING FORCE[①]

Chen, Jiamin[②]
*Northeast University of Technology*
*Shengyang 110006, China*

Bao, Junfeng[③] Chang, Fumian[③]
*Shenyang Non-ferrous Metal Works*
*Shengyang 110102, China*

**ABSTRACT**

**Regarding the sizing surface zone as a quasi-plasticity one and using yielding criterion, a new drawing force calculating formula in which the sizing surface friction was taken into account is deducted. The calculated and experimental results show that for rod drawing and tube sinking, it is permissible to neglect the effect of the friction at the sizing surface, but for tube drawing with a stationary mandrel, especially for thin-wall tube drawing this friction should not be neglected.**

**Key words:** sizing surface, Friction, effect, Drawing force

## 1 INTRODUCTION

The existing formulas for calculating drawing force generally neglect the role of the friction at the sizing surface, which fits for rod drawing and tube sinking. But for tube drawing with a stationary mandrel the effect of the sizing surface friction could not be neglected.

In order to analyze the effect of the sizing surface friction on the drawing force quantitatively, based on the existing formulas, the authors calculated a new formula in which the effect of the sizing surface friction was taken into account, and experiments were carried out to check its reliability.

## 2 THE DEDUCTION OF THE FORMULA

Fig. 1 is the scheme of the rod drawing. It seems that the metal, which is exiting from the section a—a and entering into the sizing surface, would not be deformed. But because there exists elastic recovery, normal stress will appply at the sizing surface from the die wall on the rod drawn, the value is closed to that in the vicinity of the end section a—a of defotmation zone. Regarding the sizing surface zone as quasi-plasticity zone, the relationship between the stress components could be gained by using the yielding criterion.

Taking an element from the the sizing surface the force applied on it is shown on Fig.1b. Taking the static equilibrium, it follows

$$(\sigma_x+d\sigma_x)\pi D_a^2/4-\sigma_x\pi D_a^2/4-f\sigma_n\pi D_a dx=0$$

$$D_a d\sigma_x/4=f\ \sigma_n dx$$

subsituting the approximate yielding criterion $\sigma_x+\sigma_n=\sigma_s$ into the above equation, then $D_a d\sigma_x/4=f\ (\sigma_s-\sigma_x)\ dx$

$$d\sigma_x/\sigma_s-\sigma_x=4f\,dx/D_a$$

①Manuscript received July 19, 1991

②Associate professor; ③Engineer;

by integration getting

$$\int_{\sigma_{xa}}^{\sigma_d} \frac{d\sigma_x}{\sigma_s - \sigma_x} = \frac{4f}{D_a} \int_0^l dx$$

$$\ln \frac{\sigma_s - \sigma_{xa}}{\sigma_s - \sigma_d} = \frac{4f}{D_a} l$$

we obtain

$$\frac{\sigma_d}{\sigma_s} = 1 - (1 - \sigma_{xa} / \sigma_s) / e^{\frac{4fl}{D_a}}$$

or

$$\frac{\sigma_d}{\sigma_s} = 1 - (1 - \sigma_{xa} / \sigma_s) / e^{C_1} \quad (1)$$

where $\sigma_d$—the tensile stress i. e. drawing stress

$c_1$—coefficient effecting the friction at sizing surface;

$D_a$—diameter of the sizing surface;

$f$—frictional coefficient

$l$—length of the sizing surface;

$\sigma_s$—flow stress of the drawing rod

For tube sinking (Fig.2), similar results could be obtained

$$\sigma_d / \sigma_s = 1 - (1 - \sigma_{xa} / \sigma_s) / e^{c_2} \quad (2)$$

where $c_2 = 2fl / (D_\alpha - S_a)$;

$D_\alpha$—outside diameter of the tube at sizing surface;

$S_a$—tube thickness at sizing surface

For a drawing with a stationary mandrel (Fig.3), the forces applied in the element are different from that of the previous cases, because there exist frictions caused by the mandrel and the die simultaneously.

Supposing $\sigma'_n = \sigma_n$, and $f' = f$, then

$$\sigma_d / \sigma_s = 1 - (1 - \sigma_{xa} / \sigma_s) / e^{c_3} \quad (3)$$

where $c_3 = 4fl / (D_a - d_a) = 2fl / S_a$;

$d_a$—inner diameter of the tube at sizing surface

Equations (1), (2) and (3) could be written as

$$\sigma_d / \sigma_s = 1 - (1 - \sigma_{xa} / \sigma_s) / e^c \quad (4)$$

for rod drawing: $c = 4fl / D_a$ ;

for tube sinking: $c = 2fl / (D_a - S_a)$ ;

for tube drawing with a stationary mandrel: $c = 2fl / S_a$

where c values indicate the effect of friction force of sizing surface on the drawing force.

Table I shows the relationships between $\sigma_d / \sigma_s$ , $\sigma_{xa} / \sigma_s$ and $c$.

## 3 EXPERIMENT

In order to test the reliability of equation (4), experiments were taken for pure copper tube sinking and for drawing with a stationary

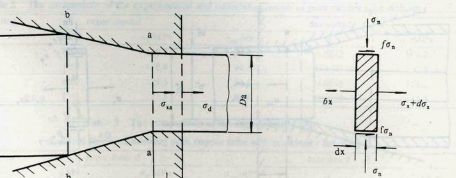


**Fig.1 the scheme of the rod drawing**

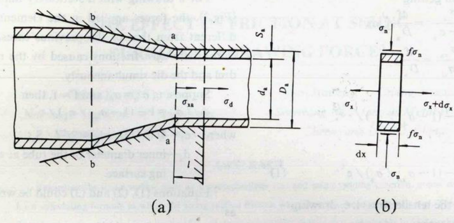

Fig.2 the scheme of tube sinking

mandrel. The tube to be drawn is $d$ 24× 1.04 mm (hard temper). The half angle of the four dies is 12°, their sizing lengths are 1, 2, 4, 6 mm respectively.

3.1 *Tube sinking*

Tube sinking was carried out without lubrication. The tube after sinking was $d$ 20× 1.11 mm. The average flow stresss of the metal is $\sigma_s$= 400 MPa. The experimental and calculated drawing forces are listed in Table 2 (taking $f$= 0.2 in calculating).

3.2 *Tube drawing with a stationary mandrel*

Tube drawing with a stationary mandrel was carried out wothout lubrication, too. The diameter of the mandrel is 18.16 mm.

The experimental and calculated drawing forces are listed in Table 3.

## 4 DISCUSSION

It is shown from equation (4) or Table I that for definite $\sigma_{xa} / \sigma'_s$ the greater the value $c$ is, the greater the ratio $\sigma_d / \sigma_s$ would be, and the effect decreases with increased $\sigma_{xa} / \sigma_s$.

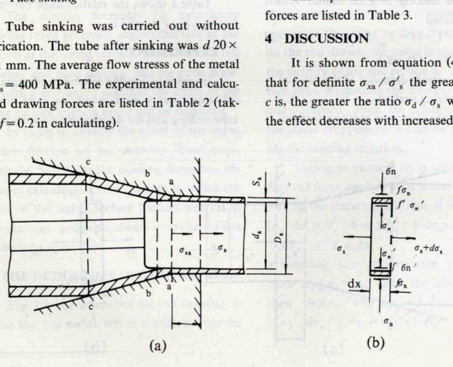

Fig.3 the scheme of tube drawing with stationary mandrel

The experimental results also show that the theoretically calculated values coincide well with experimental ones.

From production practice we know that c is generally less than 0.1 for rod drawing and less than 0.05 for tube sinking. Only in the case of tube drawing with a stationary mandrel $c$ is greater than 0.1 and even greater than 1 for thin-wall tube drawing.

Therefore, for calculating the drawing force of rod drawing and tube sinking, the error would be rather small, when the friction at sizing surface is neglected. But for calculating drawing force of tube drawing with a stationary mandrel, especially for thin wall tube, the friction is too great (which would sometimes makes the drawing process impossible) to be neglected.

For example, when a thin-wall tube is drawn with a stationary mandrel and a die of 1.5 mm in sizing length is used, the drawing force would be very high even for small reduction. Supposing $\sigma_{xa} / \sigma_s = 0.3$, and $f = 0.1$, we obtain

$$c = 2fl / S_a = 2 \times 0.1 \times 1.5 / 0.15 = 2$$

substituting c into equation (4), we have

$$\delta_d / \delta_s = 1 - (1 - 0.3) / e^2 = 0.905$$

the tube would be broken easily if drawn in such a condition.

If the drawing process is substituted by "center-type mandrel" method (see Fig. 4), the drawing stress $\sigma$ would be greatly reduced, because the tensile stress at the interface between deformation zone and sizing surface (plane a—a) $\sigma_{xa} / \sigma_s$ is very close to that of a tube drawing with a stationary mandrel. The

**Table 1 the relationships between $\sigma_d / \sigma_s$ and $\sigma_{xa} / \sigma_s$ , C**

| $\sigma_{xa} / \sigma_s$ | c | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.05 | 0.10 | 0.15 | 0.20 | 0.25 | 0.30 | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 | 3.00 | 3.50 | 4.00 |
| 0.30 | 0.334 | 0.367 | 0.398 | 0.427 | 0.455 | 0.481 | 0.575 | 0.742 | 0.844 | 0.905 | 0.942 | 0.965 | 0.979 | 0.987 |
| 0.40 | 0.429 | 0.457 | 0.484 | 0.509 | 0.533 | 0.556 | 0.636 | 0.779 | 0.866 | 0.919 | 0.951 | 0.970 | 0.982 | 0.989 |
| 0.50 | 0.524 | 0.548 | 0.570 | 0.591 | 0.611 | 0.630 | 0.697 | 0.816 | 0.888 | 0.932 | 0.959 | 0.975 | 0.985 | 0.991 |
| 0.60 | 0.620 | 0.638 | 0.656 | 0.673 | 0.689 | 0.704 | 0.757 | 0.853 | 0.911 | 0.946 | 0.967 | 0.980 | 0.988 | 0.993 |
| 0.70 | 0.715 | 0.729 | 0.742 | 0.754 | 0.766 | 0.778 | 0.818 | 0.890 | 0.933 | 0.959 | 0.975 | 0.985 | 0.991 | 0.994 |
| 0.80 | 0.810 | 0.819 | 0.828 | 0.836 | 0.844 | 0.852 | 0.879 | 0.926 | 0.955 | 0.973 | 0.984 | 0.990 | 0.994 | 0.996 |
| 0.90 | 0.905 | 0.910 | 0.914 | 0.918 | 0.922 | 0.926 | 0.939 | 0.963 | 0.978 | 0.986 | 0.992 | 0.995 | 0.997 | 0.998 |
| 1.00 | 1.00 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |

**Table 2 The comparison of the experimental and calculated forces of pure copper tube sinking**

| length of bearing *l* | experimental | | calculated | | |
|---|---|---|---|---|---|
| (mm) | *p*,kN | $\sigma_d$,MPa | $\sigma_{xa}$,MPa | c | $\sigma_d$,MPa |
| 1 | 7.30 | 110.8 | 94.8 | 0.0212 | 101.2 |
| 2 | 7.80 | 118.4 | 94.8 | 0.0424 | 107.5 |
| 4 | 8.20 | 124.5 | 94.8 | 0.0848 | 119.6 |
| 6 | 8.40 | 127.5 | 94.8 | 0.1272 | 131.3 |

**Table 3 The comparison of the experimental and calculated forces of drawing pure copper tube with stationary mandrel**

| length of bearing *l* | experimental | | calculated | | |
|---|---|---|---|---|---|
| (mm) | *p*,kN | $\sigma_d$,MPa | $\sigma_{xa}$,MPa | c | $\sigma_d$,MPa |
| 1 | 15.50 | 296.4 | 244.7 | 0.460 | 302 |
| 2 | 17.30 | 330.8 | 244.7 | 0.920 | 338 |
| 4 | 19.60 | 374.8 | 244.7 | 1.840 | 375.2 |
| 6 | 20.50 | 392.0 | 244.7 | 2.760 | 390 |

difference is only the features of the sizing surface; in the case of drawing with the conventional stationary mandrel, the friction acts on the inner and outer surface simultaneously; while drawing with a "center-type mandrel", friction acts only in the outer surface, just the same as the tube sinking, thus resulting in smaller c value.

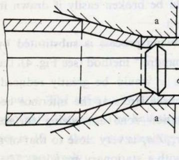


**Fig.4 The scheme of drawing with "center–tube mandrel"**

Using the same data as the above example and the length of sizing surface of the die (3 mm) to draw a tube of $d$ 10× 0.15 mm with "center–type mandrel", we have

$$c = 2fl/(D_a - S_a) 2\times 0.1\times 3/(10-0.15) = 0.061.$$

$$\delta_d/\delta_s = 1-(1-0.3)/e = 0.341$$

this indicates that by using "center-type mandrel" the feature of the friction acting at sizing surface is altered, and the ratio of drawing stresses $\sigma_d/\sigma_s$ decreased from 0.905 to 0.341. the effect is remarkable, thus making it possible to increase the reduction per drawing pass and reduce the total passes, and also making the thin-wall tube drawing process applicable. This could also be used as a real example to show the importance of the sizing surface friction in tube drawing.

## 5 CONCLUSION

(1) The values of the drawing force calculated by formula (4) match the experimental ones, which mean that this formula can be adopted to calculate the drawing force for the sizing surface friction taken into account;

(2) For rod drawing and tube sinking the bearing surface friction may be neglected;

(3) For the tube drawing of conventional stationary mandrel the calculated drawing force would be much lower than the actual one if the sizing surface friction is neglected. Therefore, the friction must be taken into account in the calculation especially for thin wall tube drawing.