CASTEX FORCE OF AS WIRE IN BONDING ZONE[①]

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ABSTRACT The method of AS wire by Castex is an advanced technology, but the corresponding study is incomplete and rough. Dividing the whole process into two stages: Castex stage and bonding stage, the analytic formulae of Castex force of AS wire with any wrapping angle in the three deformation zones of bonding stage using slab method is developed and verified by the measured results gotten from the experiments made on the multi-function Castex machine. The comparison shows that the error is around 15%.

Key words Castex AS wire Castex force slab method zone

1 INTRODUCTION

As further development of Conform, Castex is a latest technology with the advantages of high efficiency, low-cost and high productivity, which has been applied widely in the field of processing of non-ferrous metals. Based on Castex we have developed a new bonding technology of semi-solid Al / solid steel wire. Presently the study of Castex force for this process is seldom found about this method besides some elementary experiments[1-5]. This paper studies the Castex force of AS wire systematically and establishes a set of calculating formulae.

2 PRINCIPLE

The processing mechanism of AS wire by Castex is shown in Fig. 1. The whole procedure can be divided into two stages: Castex stage and bonding stage. In the Castex stage (Ⅰ, as shown in Fig. 1), liquid Al at a high temperature is fed into the groove of revolving wheel. Molten Al begins dynamic crystallization while it is dragged by viscous frictional force from wall of the groove and moves with the groove[6]. Semi-solid Al accumulates more and more before the abutment. While the stress that Al imposes reaches what the extrusion needs, the semi-solid Al is extruded into the bonding room. So the Castex stage can be taken as the preliminary stage. In the bonding stage (Ⅱ, as shown in Fig. 1), under a high pressure and a high temperature semi-solid Al supported by Castex stage interacts with steel wire and gets metallurgical bonding. Then bonded wire goes through the finishing die to be the AS wire.

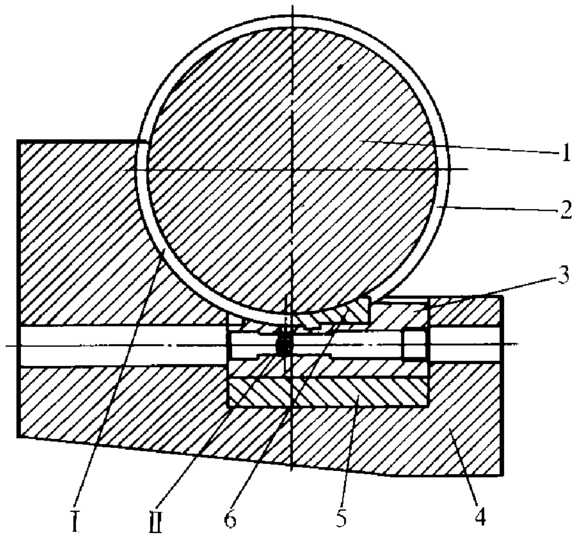

Fig. 1 Mechanism of AS wire by Castex
1 —Extrusion wheel; 2 —Extrusion wheel groove; 3 —Die container ; 4 —Shoe; 5 —Bearer; 6 —Abutment
Ⅰ —Castex stage; Ⅱ —Bonding stage

3 EXTRUSION FORCE DEVELOPMENT IN BONDING STAGE

We have known that the whole process

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comprises two stages: Castex stage and bonding stage. As the extrusion force in Castex stage have been accomplished by Cao *et al*[7], here we concentrate on the study of extrusion force in the bonding stage. As the plastic deformation velocity in bonding stage is slow, the stress field in this stage can be supposed as static stress field within allowance of error, from outlet die to feeding die the development is carried out with slab method.

There are three deformation zones during bonding stage: sizing zone, bonding zone and plastic flowing zone (Fig. 2), which are analyzed as follows[8-10].

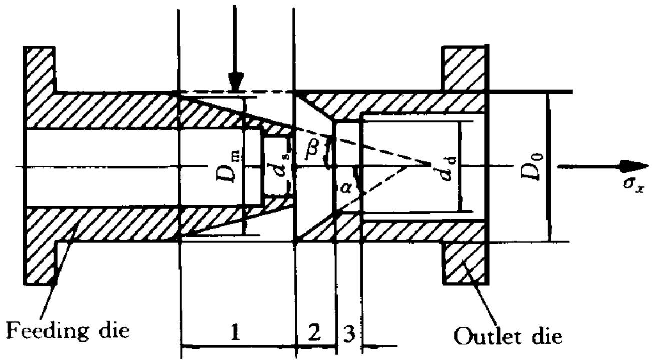

Fig. 2 Composition of bonding zone

3.1 Sizing zone

Taking the Al-coat as analyzing object, the stresses acting on mini-element of Al-coat are shown in Fig. 3. The equilibrium differential equation in x direction is

$$(\sigma_x + d\sigma_x)\frac{\pi}{4}(d_d^2 - d_s^2) - \sigma_x\frac{\pi}{4}(d_d^2 - d_s^2) - \pi d_d d_x \tau_1 - \pi d_s d_x \tau_2 = 0$$

where $\tau_1 = f\sigma_s$, $\tau_2 = f_1\sigma_s$,

then $$d\sigma_x = \frac{4\sigma_s(d_d f + d_s f_1)}{d_d^2 - d_s^2}d_x$$

After integration we get

$$\sigma_{x3} = 4\sigma_s\frac{d_d f + d_s f_1}{d_d^2 - d_s^2}x + c$$

When $x = L_d$, $\sigma_x = 0$ and $c = -4\sigma_s \cdot \frac{(d_d f + d_s f_1)}{d_d^2 - d_s^2}L_d$, the general extrusion stress

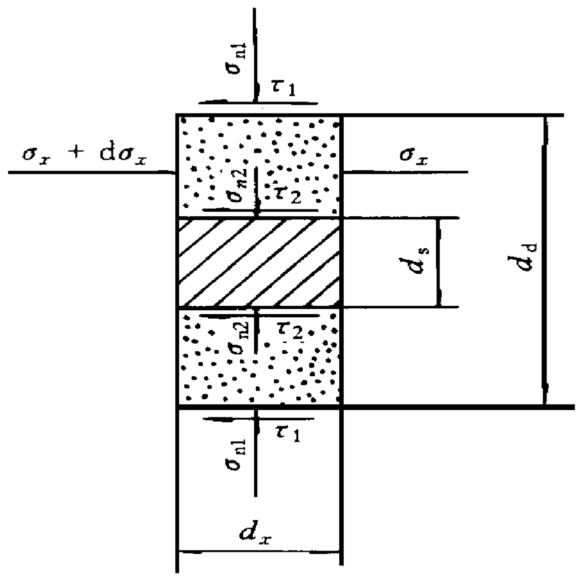

Fig. 3 Stresses acting on mini-element in sizing zone

formula in x direction in sizing zone is

$$\sigma_{x3} = 4\sigma_s\frac{d_d f + d_s f_1}{d_d^2 - d_s^2}L_d(x - L_d) \quad (1)$$

so the extrusion stress at the entry of sizing zone is

$$\sigma_3 = -4\sigma_s\frac{d_d f + d_s f_1}{d_d^2 - d_s^2}L_d \quad (2)$$

3.2 Bonding zone

The stresses acting on mini-element of Al-coat are shown in Fig. 4. The equilibrium differential equation in x direction is

$$(\sigma_x + d\sigma_x)\frac{\pi}{4}[(D + dD)^2 - d_s^2] - \sigma_x\frac{\pi}{4}(D^2 - d_s^2) - \tau_1\cos\alpha\frac{\pi D d_x}{\cos\alpha} - \tau_2\pi d_s d_x - \sigma_{n1}\sin\alpha\frac{\pi D d_x}{\cos\alpha} = 0$$

From plastic flow condition $\sigma_{n1} - \sigma_x = \sigma_s$, then $\sigma_{n1} = \sigma_x + \sigma_s$; $\tau_1 = \tau_2 = f\sigma_s$.

Referring to these conditions, we get

$$d\sigma_x(D^2 - d_s^2) - 2\sigma_s[f\,\mathrm{ctg}\,\alpha(D + d_s) + D]dD = 0$$

$$d\sigma_x = 2\sigma_s\mathrm{ctg}\,\alpha\frac{[f(D + d_s)]}{D^2 - d_s^2}dD$$

After integration, we get

$$\sigma_{x2} = 2\sigma_s[f\,\mathrm{ctg}\,\alpha\ln(D - d_s) +$$

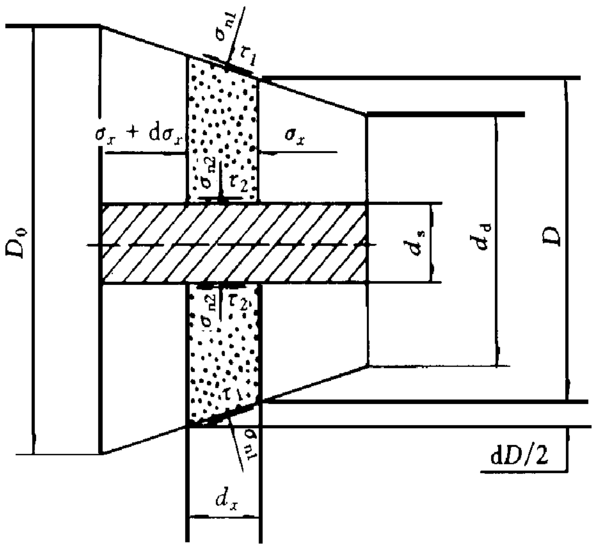

Fig. 4 Stresses acting on mini-element in bonding zone

$$\frac{1}{2}\ln(D^2 - d_s^2)] + c$$

When $D = d_d$, $\sigma_{x2} = \sigma_3$ and $c = -2\sigma_s[f \cdot \mathrm{ctg}\,\alpha \ln(d_d - d_s) + \frac{1}{2}\ln(d_d^2 - d_s^2)] + \sigma_3$, the general extrusion stress formula in x direction in bonding zone is

$$\sigma_{x2} = 2\sigma_s(f\,\mathrm{ctg}\,\alpha \ln\frac{D - d_s}{d_d - d_s}) + \frac{1}{2}\ln\frac{D^2 - d_s^2}{d_d^2 - d_s^2}) + \sigma_3 \quad (3)$$

so the extrusion stress at the entry of bonding zone is

$$\sigma_2 = 2\sigma_s(f\,\mathrm{ctg}\,\alpha \ln\frac{D_0 - d_s}{d_d - d_s}) + \frac{1}{2}\ln\frac{D_0^2 - d_s^2}{d_d^2 - d_s^2}) + \sigma_3 \quad (4)$$

3.3 Plastic flowing zone

The stresses acting on mini-element of Al-coat are shown in Fig. 5. The equilibrium differential equation in x direction is as follows:

$$\frac{\pi}{4}(\sigma_x + d\sigma_x)[D_0^2 - (D + dD)^2] - \sigma_x\frac{\pi}{4}(D_0^2 - D^2) - \tau_1\pi D_0 d\sigma_x - \tau_2\cos\beta\frac{\pi D}{\cos\beta}dx - \sigma_{n1}\pi D\,dx\,\mathrm{tg}\,\beta = 0$$

From plastic flow condition, $\sigma_{n1} = \sigma_x + \sigma_s$, $\tau_1 = \tau_2 = f\sigma_s$, we get

$$d\sigma_x = \frac{2f\sigma_s\pi\mathrm{ctg}\,\beta(D_0 + D) + 2\sigma_s\pi D}{D_0^2 - D^2}dD$$

After integration, we get

$$\sigma_x = -2f\sigma_s\pi\mathrm{ctg}\,\beta\ln(D_0 - D) - \sigma_s\pi\ln(D_0^2 - D^2) + c$$

When $D = d_j$, $\sigma_{x1} = \sigma_2$ and $c = \sigma_2 + 2f \cdot \sigma_s\pi\mathrm{ctg}\,\beta\ln(D_0 - d_j) + \sigma_s\pi\ln(D_0^2 - d_j^2)$,

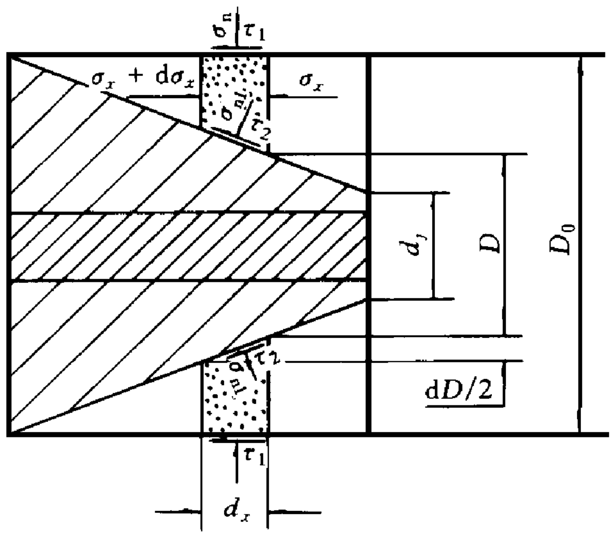

Fig. 5 Stresses acting on mini-element in plastic flowing zone

the general extrusion stress in x direction in bonding zone is

$$\sigma_{x1} = \sigma_2 + 2f\sigma_s\pi\mathrm{ctg}\,\beta\ln\frac{D_0 - d_j}{D - D} + \sigma_s\pi\ln\frac{D_0^2 - d_j^2}{D_0^2 - D^2} \quad (5)$$

Then the extrusion stress at the entry of plastic flowing zone is

$$\sigma_1 = \sigma_2 + 2f\sigma_s\pi\mathrm{ctg}\,\beta\ln\frac{D_0 - d_j}{D_0 - D_m} + \sigma_s\pi\ln\frac{D_0^2 - d_j^2}{D_0^2 - D_m^2} \quad (6)$$

where σ_s—the yielding stress of aluminium; d_d—the inner diameter of finishing die; L_d—the length of sizing zone; f, f_1—frictional ratio; d_s—the diameter of steel wire; D_0—the inner diameter of bonding zone; D_m—the maximum effective outer diameter of feeding die; d_j—the outer diameter on minimum end of the feeding die; α, β—cone angles of outlet and feeding die.

4 EXPERIMENTAL VERIFICATION

The main equipment in the experiment is Castex Machine made by our own, which not only can produce figured products and wire of Al or Al-alloys, but also can produce bonding composites. The diameter of the groove wheel is 300 mm, the rotating speed is 10 r/min. The assistant equipments: two heating stoves (capacity: 60 kW and 20 kW), one coil (diameter: 400 mm) and corollary kinetic devices (capacity : 60 kW). The materials used are Al and steel wire; the composition of Al is Al-0.013Cu-0.145Fe-0.104Si in mass fraction, and the steel wire is d5.9 mm annealed T8 steel. The values of experimental parameters are listed in Table 1.

Table 1 Values of experimental parameters

Parameter	Value
Gap/mm	0.7~1.5
Casting temperature/ ℃	750~800
Heating temperature of shoe/ ℃	400~500
Rotating speed of groove wheel/ $(r\cdot min^{-1})$	10
Coiling speed of steel wire/ $(mm\cdot s^{-1})$	3~5

The twisting moment of the shifting axle is measured with the twisting moment apparatus made by our own in order to be compared with the calculated. With the results of this paper and Ref. [7], we can get the tangential force imposed on the groove wheel, F_t. The twisting moment M and the driving capacity W of the wheel needed can be obtained by tangential force of the groove wheel F_t and the rotating speed n of the wheel ω:

$$M = \frac{1}{2}D_w F_t, \quad W = M\omega = \frac{\pi n}{30}\cdot M$$

The measured twisting moment and the calculated are compared in Table 2, from which we can see that the twisting moment measured accords with the calculated perfectly. So the formulae of Castex force of AS wire in the bonding zone are reliable.

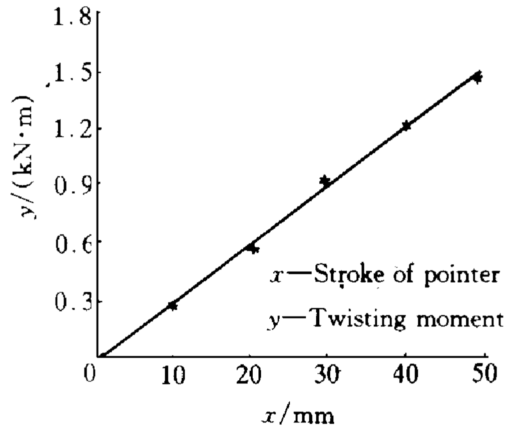

Fig. 6 Relationship between twisting moment and output signal of twisting moment apparatus

Table 2 Comparison of measured twisting moments and calculated

Experiment	Twisting moment/(N·m)		Relative error/ %
	Calculated	Measured	
No. 1	16014	18704	14.38
No. 2	16360	18827	13.83
No. 3	16148	18998	15.36

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