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# Development on Technique of Tube Reducing in Double 3-Roll Dies

*Baolong Zheng*[1], *Li Sun*[2], *Ruichen An*[2], *Lianshi Li*[1]

1) Material Science and Engineering School, University of Science and Technology Beijing, Beijing 100083, China
2) No.1 Steel Rolling Factory, Tangshan Iron and Steel Corporation, Tangshan 063000, China
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**Abstract:** Based on the experiments, a new technique of reducing tube with two linked 3-roll roller dies was developed. The external friction conditions, velocity and the non-uniform deformation of metal were distinctly improved, and the friction between metal and tool was decreased. Corrosion strip layers and photo-elastic coatings methods were adopted in the experiment for measuring residual stress, and the residual stresses in the drawn tube with 3-roll dies are reduced.

**Key words:** reducing tube; roller dies; drawing; deformation

Reducing tube is one of the procedures of seamless tube production, and an important method for changing tube dimensions. It is divided roughly into hot rolling; cold Pilger rolling, and cold drawing in reducing seamless tube [1].The two former methods are sink rolling in continuous mills, the latter is cold drawing through conventional dies. Cold drawing is relatively simple, but its high friction between metal and die and non-uniform deformation will cause many quality problems. More residual stresses exist in drawn tube, especially surface hoop stress, cracks appear more easily in drawing thick walled tube [1, 2].

To overcome the problems, authors developed a new technique of tube reducing in double 3-roll dies. The external friction and the non-uniform deformation of metal were distinctly improved and the residual stresses in the drawn tube are reduced. This process requires less investment and will bring more profits.

## 1 Experiment and Theory Analysis

### 1.1 Deformation of tube reducing in roller dies

It is important to analyze the law of tube wall thickness changes when reducing tube in roller dies. Influencing factors mainly include the ratio of diameter to thickness (*D*/*S*) before drawing and the forces acting in the process of deformation. The influence of the drawing method on the changes in thickness is shown in **figure 1**.

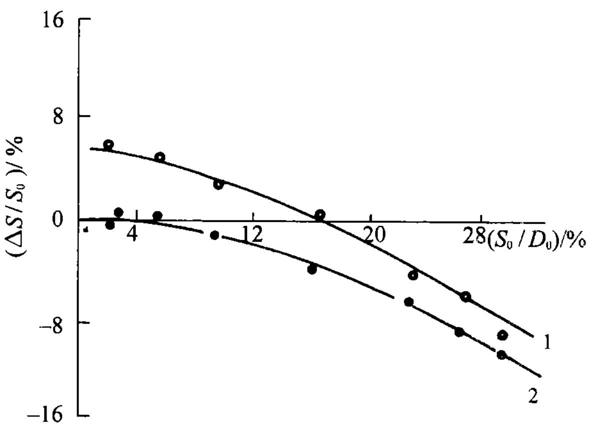


**Figure 1 Effect of drawing method on changes in tube wall thickness, 1—conventional dies; 2—roll roller dies (outside diameter of the tube is 25 mm).**

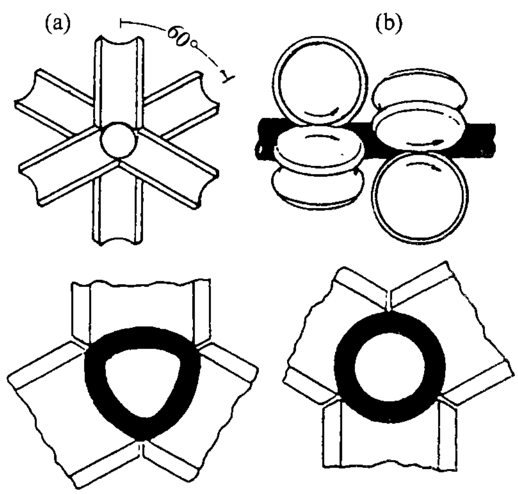


**Figure 2 Schematic diagram of reducing tube with a 3-roll roller die, (a) oval groove; (b) round groove.**

The roller die for experiment is shown in **figure 2**. The double 3-roll dies have two sets of rollers, the first set rollers have an oval groove and the second set rollers have a round groove. The drawing force of the oval groove pass is the backward tension of the round groove pass [3]. The considerable reduction of diameter can be obtained in drawing tube with double 3-roll dies. The existence of backward tension may increase the stability of the deformation process. Meanwhile, elongation can decrease the breadth flow, radial flow and non-uniform deformation. The effect of the backward drawing force also decreases the normal pressure and friction force, therefore, service life of the tools is prolonged [4].

### 1.2 Analysis of the force parameters and acting forces when reducing tube in a roller die

According to the measured data in production, the drawing force in a roller die is much less than that with a conventional die, generally it decreases about 22%. The parameters influencing the drawing force are mainly $D/S$ and diameter reduction $\Delta D$, as shown in **figures 3** and **4**.

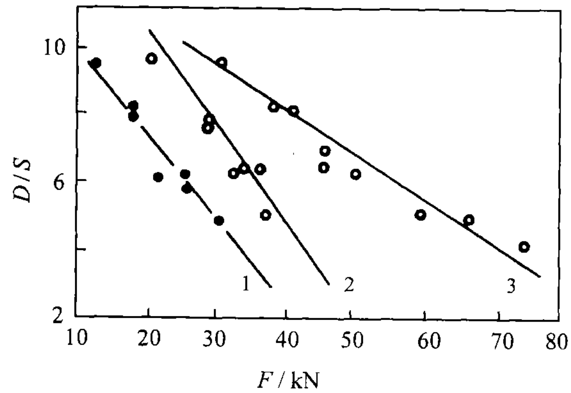


**Figure 3 Relation between $D/S$ and drawing force, 1—first pass of single drawing; 2—second pass of single drawing; 3—continuous drawing**

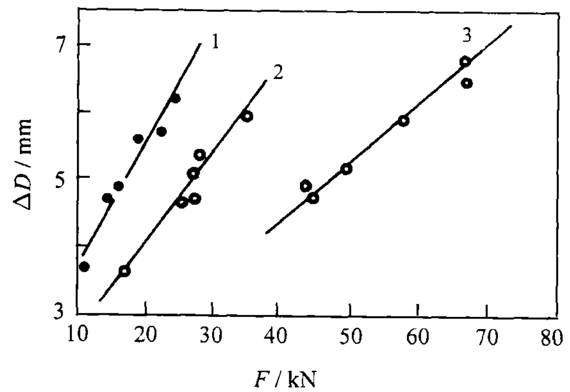


**Figure 4 Relation between overall diameter reduction and drawing force, 1—first pass of single drawing; 2—second pass of single drawing; 3—continuous drawing.**

The acting forces on the roll when reducing tube with a roller die are shown in **figure 5**. $P_S$ is the resultant forces which act on the roll, and the direction of $P_S$ is towards the center of the roll because the roll is not driven. $P_r'$ and $1/3 \cdot P_0'$ are respectively the vertical and horizontal components of $P_S$. The latter equals to the drawing force of metal deformation. If bearing friction is taken into account, the resultant force on the roll will be $P$, the vertical and horizontal components of which are respectively $P_r$ and $1/3 \cdot P_0$, ($P_0 \geqslant P_0'$), $P_\Sigma$ can also be resolved into $P_s$ and $T$, where $T$ is the resultant friction force between roll and metal.Assuming the friction factor to be $f$, so $T = P_S \cdot f$. The moment of this frictional force is $T \cdot D_m/2$, which equals to the frictional moment on the bearing:

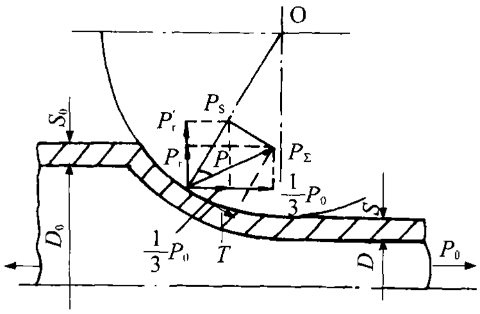


**Figure 5 The forces acting on the roll**

$$T \cdot D_m/2 = P_S \cdot f_c \cdot d_r/2;$$

$$P_S \cdot f \cdot D_m/2 = P_S \cdot f_c \cdot d_r/2;$$

$$f = d_m/D_1 \cdot f_c;$$

$$D_m > d_r;$$

$$f < f_c,$$

where $D_m$ is the mean diameter of the roll, mm; $f_c$ the friction factor on the bearing; $d_r$ the diameter of the roll neck, mm; $f$ the friction factor between the roll and metal.It shows that the drawing force can be obtained from the analysis of forces, which are composed of the horizontal component of normal pressure on the roll and frictional force. Either frictional force or normal pressure can be reduced by using 3-roll dies to reduce tubes [5].

### 1.3 Resultants of measuring residual stress and analysis

The main advantage of reducing tube in 3-roll dies is the decrease of internal residual stress, as shown in **figure 6**. From the figure, it can be seen that the residual stress of reducing tube with a 3-roll roller die is much less than that in a conventional die. Thus, cracks are effectively eliminated, which easily emerge in the process of cold sinking of heavy wall tube.

Moreover, the residual stress of the tube reduced in a double 3-roll die is a bit less than that in a double 2-roll die, and more uniform deformation existes in the tube reducing with a 3-roll die. It is suited for reducing low plasticity materials.

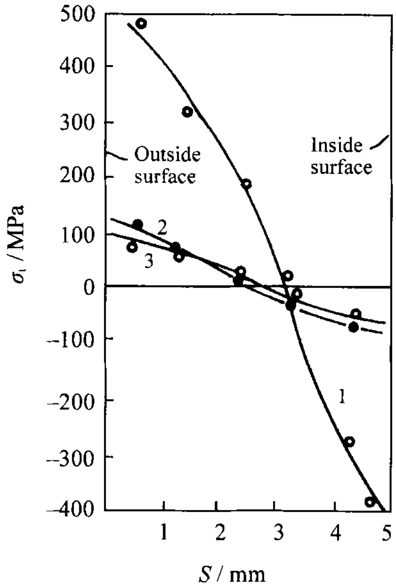


**Figure 6 Changes in residual stress along the tube wall, 1—the measured residual stress of sink drawing in a conventional die; 2—the measured residual stress of reducing tube with a double 2-roll die; 3—the measured residual stress of reducing tube with a double 3-roll die. Dimensions of the workpiece, $D_0$ = 25 mm, $S_0$ = 5.0mm, diameter reduction, $\Delta D / D$ = 22%.**

Corrosion strip layers and photo-elastic coatings were adopted in the experiments for measuring residual stress [6]. The comparative error of the measured data was within 10%, as shown in **table 1**.

## 2 Conclusions

In the production of cold working seamless tube, reducing in a 3-roll die instead of in a conventional die thoroughly changes the friction, velocity and deformation conditions. The problem of cracks emerging in the process of cold reducing heavy wall tubes is resolved. A 3-roll die has a rolling feature, in that the relative position of the rolls can be adjusted to change the dimensions of the tube. Thus, it increases the flexibility to control dimensions of products. It not only improves the surface quality of tube, enhances the die service life, decreases power consumption, but also simplifies the process. However, the dimensional precision of tubes drawn in 3-roll dies is less than that drawn in conventional dies. Therefore, it is not suitable for the finished pass drawing.

**Table 1 Measured residual stress**

| Method of drawing | Measured data No. | Outside diameter $D_0$ / mm | Wall thickness $S_0$ / mm | Overall reduction $\Delta D$ / mm | Hoop residual stress $\sigma_t$ / MPa | Axial residual stress $\sigma_l$ / MPa | Method of measurement |
|---|---|---|---|---|---|---|---|
| Conventional dies | 1 | 25.08 | 5.00 | 5.24 | 500.0 | 476.0 | Corrosion strip layers |
| | 2 | 25.12 | 4.08 | 5.26 | 316.0 | 425.0 | |
| | 3 | 25.00 | 2.50 | 5.16 | 203.0 | 273.0 | |
| 2-roll dies | 1 | 25.08 | 5.00 | 5.28 | 131.0 | 93.1 | |
| | 2 | 25.10 | 4.08 | 5.50 | 68.0 | 81.6 | |
| | 3 | 25.00 | 2.50 | 5.00 | 40.1 | 46.7 | |
| 3-roll dies | 1 | 25.05 | 5.00 | 5.30 | 102.0 | 86.0 | |
| | 2 | 25.07 | 4.10 | 5.44 | 51.2 | 74.7 | |
| | 3 | 25.00 | 2.52 | 5.02 | 36.8 | 40.0 | |
| Conventional dies | 4 | 25.10 | 5.04 | 5.30 | 469.0 | 488.0 | Photoelastic coatings |
| | 5 | 25.06 | 4.04 | 5.32 | 298.0 | 391.0 | |
| | 6 | 25.00 | 2.54 | 5.10 | 214.0 | 255.0 | |
| 2-roll dies | 4 | 25.10 | 5.04 | 5.30 | 115.0 | 125.0 | |
| | 5 | 25.06 | 4.04 | 5.34 | 71.4 | 79.1 | |
| | 6 | 25.00 | 2.54 | 5.08 | 44.3 | 52.9 | |
| 3-roll dies | 4 | 25.08 | 5.04 | 5.32 | 93.8 | 110.9 | |
| | 5 | 25.04 | 4.06 | 5.38 | 52.6 | 70.2 | |
| | 6 | 25.02 | 2.56 | 5.04 | 39.7 | 49.8 | |

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