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Lubrication of tube in cold pilgering

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ABSTRACT

A new method of evaluating the lubrication state of a tube in cold pilgering has been studied. A method of calculating the oil film thickness in a bite area on both the outer and inner sides of a tube using the Reynolds equation was proposed. The calculation results revealed that the effects of the tool design, rolling speed, and feed rate on the oil film thickness were significant. Cold pilgering tests were performed on zirconium alloy tubes, including measurement of the oil film thickness using laser equipment and observation of the surface characteristics of tubes. The test results proved the validity of the proposed method. The method is expected to assist the selection of appropriate operation conditions in cold pilgering.

1. Introduction

Cold pilgering is a popular cold working process for metallic tubes. Stinnertz (1988) reported that it is widely applied to the manufacture of seamless tubes, including tubes made of steels and copper, titanium, and zirconium alloys. A large cross-sectional reduction of more than 70% is possible in cold pilgering, comparable to that in cold drawing. Moreover, Ukai et al. (2000) reported that cold pilgering can be applied to low-ductility metals, such as steels strengthened with dispersed oxide.

Fig. 1 shows a schematic view of the cold pilgering process. A tube is gradually reduced in size by a pair of roll dies and a mandrel in a working zone with a length of 100 mm order. The roll dies have a decreasing caliber on the outer surface. The roll dies are rotated and simultaneously reciprocated during pilgering, and the rate of outer diameter reduction depends on the caliber. The mandrel, which is stationary inside the tube, has a tapered shape in the rolling direction. The diameter and wall thickness of the tube are gradually reduced with increasing number of forming steps while a lubricant is applied to both the outer and inner sides of the tube, and the tube is elongated in the rolling direction. In each forming step, the tube is advanced and rotated in an idle zone at a preset feed rate and turn angle, respectively. The tube is reduced in both the forward and backward strokes during the reciprocation of the roll dies, and the ratio of reduction in the forward stroke is larger than that in the backward stroke. Abe and Furugen (2012) reported appropriate cold pilgering conditions for obtaining tubes with a good surface from the viewpoint of plastic deformation because most seamless tubes made by cold pilgering must be of high quality.

Lubrication is an important factor in ensuring the surface quality of tubes and productivity in cold pilgering, as in other metal working processes such as strip rolling, forging, drawing, and extrusion. Insufficient lubrication may cause problems with the surface quality of the tube, such as scratching and galling, and result in the failure of tools. In contrast, excess lubrication may make it difficult to obtain finished tubes with a glossy surface. Thus far, the lubricant, its supply method, and usage in cold pilgering have mostly been chosen on the basis of experience and empirical knowledge. The objective of the present study is to develop a new method of evaluating the lubrication state in cold pilgering by hydrodynamic calculation of the oil film thickness of the lubricant.

Carscallen et al. (1994) reported the design of a cooling system for cold pilgering with an optimized coolant nozzle. Tripp (1988) investigated the selection of the lubricant and process controls for cold pilgering. Montmitonnet et al. (1992) reported a theoretical study on the lubrication state of the inner surface of a tube in cold pilgering. However, few basic studies on lubrication in cold pilgering have been published. In contrast, many basic studies on lubrication have been reported for cold strip rolling, and the mechanism of lubrication has been investigated by hydrodynamic calculation of the oil film thickness. Mizuno (1966) proposed an index for the oil film thickness in strip rolling by considering the hydrodynamics of the lubricant. Wilson and Murch (1976)

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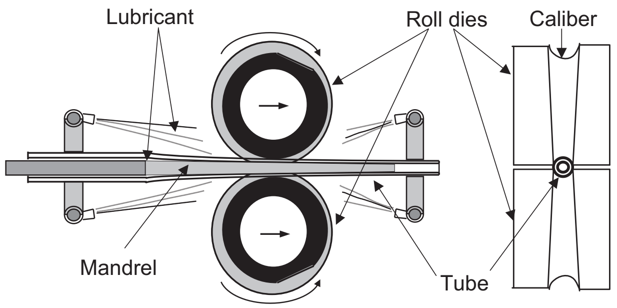

Fig. 1. Schematic view of cold pilgering.

proposed a model for the hydrodynamic lubrication in strip rolling. Dow et al. (1975) reported a hydrodynamic lubrication theory for strip rolling that included thermal effects. Azushima et al. (1978) reported detailed calculation results for the oil film thickness in strip rolling using the Reynolds and energy equations. Fujita and Kimura (2011) reported the effects of plate-out oil on the lubrication characteristics in an oil-in-water emulsion used for lubrication in cold strip rolling. Also, Wilson and Walowit (1971) reported the study of hydrodynamic lubrication using the Reynolds equation for other metal working processes such as extrusion and drawing.

In the present study, hydrodynamic theory is applied to lubrication in the cold pilgering process. A method of calculating the oil film thickness in a bite area on both the outer and inner sides of a tube using the Reynolds equation is proposed. From the calculation results, the effects of operation conditions on the lubrication state in cold pilgering are discussed. Cold pilgering tests were performed on zirconium alloy tubes, including measurement of the oil film thickness, surface observation of the tube, and measurement of the surface roughness. The test results proved the validity of the proposed method of calculating the oil film thickness.

2. Description of cold pilgering process

2.1. Working section

Fig. 2 shows an illustration of the working section. In cold pilgering, the area in which the roll dies move is divided into three zones: an idle zone, a working zone, and a sizing zone. In the idle zone, the tube is fed and rotated, and it is not reduced. In the working zone, the diameter and wall thickness of the tube are reduced. In the sizing zone, the tube is finished in terms of its dimensions and surface. The axial position in the working zone is called the working section X, which is defined by Eq. (1). It is a dimensionless value and varies from 0 to 1. The working section can also be used in the sizing zone, where it has a negative value.

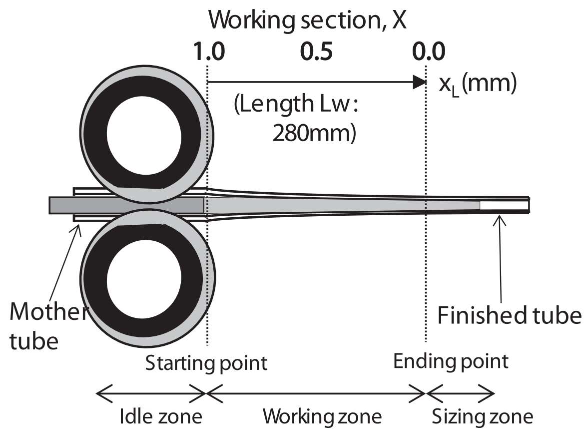

Fig. 2. Working section in cold pilgering.

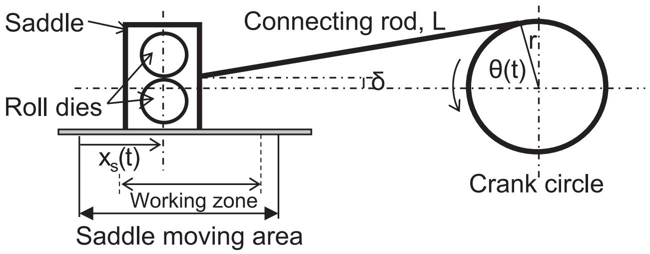

Fig. 3. Crank mechanism of cold pilger mill.

$$X = 1 - \frac{x_L}{L_w} \tag{1}$$

Here, x_L is the distance from the starting point of the working zone and L_w is the length of the working zone.

2.2. Crank mechanism of cold pilger mill and saddle speed

Fig. 3 shows a schematic view of the crank mechanism of a cold pilger mill. The pair of roll dies is installed in the saddle housing. The rotation of the drive motor is transmitted to induce the reciprocating motion of the saddle via the connecting rod by a crank shaft mechanism. The motion of the saddle makes the roll dies rotate via the combination of a pinion comprising the roll shaft and a rack fixed in the mill. The zone around the upper dead point of the crank corresponds to the idle zone. The other zone around the lower dead point is the sizing zone. The working-zone length is about 60% of the total length of saddle motion.

The crank angle $\theta(t)$ at the time from the upper dead point (original point) is defined as

$$\theta(t) = \omega t - \theta_\delta, \tag{2}$$

where ω is the angular velocity of the crank, t is the time from the upper dead point, and θ_δ is the offset crank angle.

The saddle position $x_s(t)$ and saddle velocity $v_s(t)$ are given by Eqs. (3) and (4), respectively,

$$x_s(t) = x_z - \left\{ r \cdot \cos\theta(t) + L - \frac{L}{2}\left(\frac{r \cdot \sin\theta(t) + \delta}{L}\right)^2 \right\}, \tag{3}$$

$$v_s(t) = r \cdot \omega \cdot \left\{ \sin\theta(t) + \frac{r \cdot \sin\theta(t) \cdot \cos\theta(t) + \delta \cdot \cos\theta(t)}{L} \right\}, \tag{4}$$

$$x_z = \sqrt{(L+r)^2 - \delta^2}, \tag{5}$$

where r is the radius of the crank circle, L is the length of the connecting rod, δ is the offset of the crank, and x_z is the distance between the saddle position at the upper dead point and the center of the crank circle.

2.3. Design of roll-die caliber and mandrel diameter

The basic curves of the roll-die caliber and the mandrel shape generally follow power-law functions with coefficient M. Also, the designed inner diameter $d(X)$ and outer diameter $D(X)$ of the tube in the working zone are expressed by Eqs. (6) and (7), respectively,

$$d(X) = d_1 + C_i \cdot X^{M1}, \tag{6}$$

$$D(X) = D_1 + C_o \cdot X^{M2}, \tag{7}$$

$$C_i = d_0 - d_1, \tag{8}$$

$$C_o = D_0 - D_1, \tag{9}$$