Journal of Materials Processing Technology 216 (2015) 357–368

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

journal homepage: www.elsevier.com/locate/jmatprotec

High-speed rolling by hybrid-lubrication system in tandem cold rolling mills

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ARTICLE INFO

Article history:
Received 8 September 2014
Accepted 2 October 2014
Available online 12 October 2014

Keywords:
Lubrication
Emulsion
Cold rolling
Plate-out
Hybrid-lubrication system
Chatter

ABSTRACT

Lubrication is one of the most important factors for improving the productivity of tandem cold rolling mills, as it is possible to increase the rolling speed of thin gauge steel strips and prevent chatter when rolling materials with high deformation resistance. In this study, a new hybrid lubrication system is proposed and its effectiveness is clarified. The system is based on a lubricant recirculation system combined with a system for flexible lubrication control. The key to realizing the new lubricant system is control of plate-out oil film formation on the strip surface under high-speed rolling conditions. The plate-out oil film formation of emulsions is investigated, and the conditions for achieving a sufficient plate-out oil film are clarified. The time-dependent property, oil droplet size, and emulsion concentration are found to have significant effects on plate-out behavior. In addition, the conditions for practical application of hybrid lubrication systems are discussed from the viewpoint of realizing effective plate-out control. A new hybrid lubrication system was investigated, and it successfully enabled flexible controllability of lubrication conditions and achieved the high-speed stable rolling, while maintaining an oil consumption rate equal to that of recirculation systems.

1. Introduction

High speed rolling technology for thin gauge steel strips is very important for improving the productivity of tandem cold rolling mills. As a matter of fact, production of steel strips is shifting to thinner gauges and higher strength materials with the aim of reducing the weight of steel products from the viewpoint of environmental preservation. In this situation, lubrication technology becomes more important for realizing stable and high-speed cold rolling. Oil-in-water (O/W) emulsions are generally used as lubricants in tandem cold rolling mills, as they provide good lubricity as well as cooling performance.

In conventional cold rolling mills, the emulsions are supplied by either a recirculation system or a direct application system. In direct application systems, which are applied for thinner gauge materials such as tin-mill products, a high concentration emulsion is used for lubrication, and water is used for work roll cooling. An unstable emulsion is positively used for oil film formation. This type of system is thought to be more appropriate for high speed rolling. Kaneko et al. (2000) reported that the maximum rolling speed reached over 2800 m/min with this type of lubrication system in the 1990s. At present, no other mills have exceeded that maximum rolling speed, which shows the advantage of direct application systems for high speed cold rolling. However, because the key to providing good lubricity in direct application systems is to use unstable emulsions, recycling of the emulsions is difficult, oil consumption is large, and the process generates a large volume of waste emulsions. In spite of attempts to recycle the waste lubricants, most emulsions need to be disposed of due to their unstable characteristics.

On the other hand, in recirculation systems, a low concentration steady emulsion is used for the functions of lubrication and cooling. Due to the stable characteristics of the emulsions, they maintain oil droplet dispersion in water even when used repeatedly. Recirculating use means that recirculation systems have a good oil consumption rate and generate less waste lubricants. However, since it is difficult to form an oil film on the strip surface with stable emulsions, lubricity is not comparable to than that of direct

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http://dx.doi.org/10.1016/j.jmatprotec.2014.10.002
0924-0136/

application systems, especially in high speed rolling. This is the main problem of recirculation lubrication system, and as a result, their application is mainly limited to sheet gauge products.

In the 1980s, Muramoto et al. (1982) proposed a hybrid lubrication system which simply combined a recirculation system and a direct application system. In the reported hybrid lubrication system, basically, the recirculation system is the main emulsion supply method, and a high concentration emulsion is supplied from additional nozzle headers. However, in this system, emulsions are supplied to all stands in a tandem cold rolling mill. Therefore, a large amount of highly concentrated emulsions are mixed in the recirculation system, causing large fluctuations in the emulsion concentration in the lubricants, and these fluctuations makes it difficult to realize stable high speed cold rolling. Moreover, improvement of rolling oil properties, as exemplified by the development of synthetic esters, has eliminated the superiority of the hybrid system as a lubrication system for high speed cold rolling.

In this paper, a new hybrid lubrication system is proposed in order to realize high speed cold rolling of thin gauge steel strips. The basic aims of the proposed system are high efficiency oil film formation, even when using stable emulsions, and good lubricity with a low emulsion supply rate. The lubrication property is comparable to that of direct application systems, and stable high speed rolling can be realized in spite of a low oil consumption rate equal to that of recirculation systems. The concept, basic features and production line tests of the new system are discussed in the following.

2. Lubrication systems in tandem cold rolling mills

2.1. Recirculation system and direct application system

Lubrication systems for tandem cold rolling mills are mainly classified as either recirculation systems or direct application systems, as shown in Fig. 1. The differences were described by Semoto and Okamoto (1992) with the historical background. Recirculation systems are mainly applied to sheet gauge products, while direct application systems are mainly used in high speed rolling mills for thin gauge steel strips. In both types of systems, oil-in-water (O/W) emulsions are generally used as the lubricant, which in an idiomatic manner is referred to as a coolant.

In recirculation systems for cold rolling of steel strips, low concentration emulsions, typically with a concentration of 1–3%, are used. These emulsions are supplied to the roll bites for lubrication and to the work rolls and back-up rolls for cooling. One feature of this system is use of the same emulsions for both lubrication and cooling. The main advantage of this system is reduction of oil consumption. The waste lubricants treatment processes can also be simplified. Furthermore, the choices of base oil are more flexible than in direct applications systems, because synthetic esters specifically designed for each tandem cold rolling mill can be selected as base oils. Iwado et al. (1996) reported an example of the design of synthetic esters as cold rolling mill lubricants and explained that the selection of base oils and emulsifiers is flexible and design of lubricity is possible by using synthetic esters.

In direct application systems, emulsions with a concentration of 5–15% are supplied to the strip surface for lubrication before the strip enters the roll gap. Cooling spray systems, which supply water to the roll surfaces, are provided separately. The direct application system has the advantage of a good lubrication property because oil film on the strip surface is easily formed, enabling formation of a large amount of oil film. Its disadvantages are high oil consumption and the need for an additional waste lubricants treatment process because the fundamentally unstable property of the emulsions prevents reuse in the circulation system. The choice of the base oil is also limited by economical reasons, as high oil consumption inevitably necessitates the use of less expensive oils like natural fats and oils, which are usually more prone to deterioration than synthetic esters.

In spite of the differences in these two types of lubrication systems, emulsions are supplied for roll bite lubrication in both systems. The interesting point of emulsion lubrication is that lubrication in the roll bite is achieved only by an oil film, even if a mixture of oil and water is supplied to the roll bite or the strip surface. Two representative theories are well known as explanations of the mechanism of oil film formation, one being the dynamic concentration theory and the other the plate-out theory.

The dynamic concentration theory has been widely reported since the 1980s. The basic idea is that an oil droplet in an emulsion may be trapped at the geometrically wedge-shaped region between the work roll and the strip with a certain probability, and the oil concentration increases to 100% while water is excluded before entering roll bite. Wilson et al. (1993) explained the inlet oil film thickness was much smaller than the oil droplet size of emulsion due to the dynamic concentration of emulsions. Kimura and Okada (1989) also proposed a dynamic concentration model and they investigated the influence of surfactant on oil film formation behavior. This theory is widely accepted as an emulsion lubrication mechanism. Recently, Reich and Urbanski (2004) investigated the dynamic concentration behaviors of emulsions in experimental high speed rolling, and Lo et al. (2010) adopted an analytical approach, in which a CFD (Computational Fluid Dynamics) analysis was applied to numerically simulate the dynamic concentration behavior.

The plate-out theory is based on the idea that the oil phase transformation from an O/W emulsion spontaneously progresses on the strip surface. Because the surfaces of steel strips show lipophilic and hydrophobic properties, the oil droplets in an emulsion preferentially spread on the strip surface. The theory was mainly reported in the 1970s. Roberts (1966) proposed the basic concept, and it has large influence on lubrication properties in cold rolling. Mase et al. (1977) investigated the properties with some different experimental methods, showing the spraying conditions have large influence on plate-out oil film thickness. Recently, Kimura et al. (2009) reported that plate-out oil film formation has a clear time-dependent property, and this time-dependency may have a large effect on roll bite lubrication in high speed cold rolling. Analytical approaches based on the plate-out theory have also been proposed. For example, Azushima et al. (2011) proposed an oil film thickness estimation model using a new starvation model which considers the plate-out film on the roll and strip surfaces. Guillaument et al. (2011) analyzed plate-out oil film formation after emulsion supply on the strip surface using CFD, and Laugier et al. (2011) reported that the rolling force can be controlled to a suitable level under high speed cold rolling conditions by controlling the plate-out oil film at the entry section on the roll bite.

The different lubrication mechanisms described above can be considered to correspond to the two representative lubrication systems. That is, in recirculation systems, dynamic concentration may be the dominant mechanism of oil film formation because stable, low concentration emulsions are used, and they are usually supplied directly to the geometrically wedge-shaped region formed by the work roll and the strip. On the other hand, in direct application systems, plate-out plays a more important role in oil film formation because unstable, high concentration emulsions easily form an oil film by plate-out and are usually supplied to the strip surface before the strip enters the roll bite.

The properties of emulsions for tandem cold rolling mills are also different in recirculation systems and direct application systems, as shown in Fig. 2. Emulsions for direct application systems usually contain no emulsifiers in order to secure an unstable emulsion and