Journal of Materials Processing Technology 216 (2015) 1–9

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

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

Influence of lubrication on roughness crushing in skin-pass rolling of steel strip

Hideo Kijima*

Rolling and Processing Research Department, JFE Steel Corporation, 1, Kokan-cho, Fukuyama, Hiroshima, Japan

ARTICLE INFO

Article history:
Received 9 May 2014
Received in revised form 11 August 2014
Accepted 18 August 2014
Available online 6 September 2014

Keywords:
Skin-pass rolling
Temper rolling
Finite element analysis
Lubrication
Roll radius
Roughness
Yield-point phenomena

ABSTRACT

Skin-pass rolling (or temper rolling) is usually the final process in the production of cold-rolled steel sheets. In operation, skin-pass rolling is performed with a lubricant with very low lubricating ability. However, relatively few studies have been reported in the literature regarding the effect of lubrication in skin-pass rolling. In this paper, the influence of lubrication on roughness crushing in skin-pass rolling is investigated by experimental rolling tests as well as numerical analysis by elastic-plastic FEM, especially focusing on differences in lubrication behavior depending on roll radius. The results with a large, operational size roll are well explained by the height characterization parameters and are considered to be reasonable from the viewpoint of classical knowledge in deep drawing tests and plane strain upsetting. It was found that some characteristics of skin-pass rolling related to lubrication are not properly simulated using small radius, laboratory size rolls due to insufficient contact length.

1. Introduction

Skin-pass rolling (or temper rolling) is usually the final operational step in the production of cold-rolled steel sheets, and is performed following the annealing process. It has a great influence on mechanical properties including Lüderband prevention, surface topography, strip flatness and so on. The parameter settings in skin-pass rolling are quite different from those in conventional sheet rolling due to the small reduction (approx. 1%), large contact length compared to the sheet thickness, large roll radius compared to the contact length and high friction.

In operation, skin-pass rolling is performed in a dry friction condition or by applying a skin-pass lubricant with very low lubricating ability in order to prevent adhesion between the roll and material and rust on the material surface after rolling, to cleanse the roll surface and so on.

Relatively few studies have been reported in the literature regarding the effect of lubrication in skin-pass rolling with bright work rolls. Imai et al. (1980) investigated a “jumping phenomena” in ultra-thin, lubricated skin-pass rolling with large, bright work rolls, and concluded that their experimental results could be explained by yield-point phenomena. Santino et al. (1994) analyzed similar conditions by the classical slab method. The calculated forward slip ratio showed good agreement with measured data. Sun et al. (2009) calculated a wider range of skin-pass rolling conditions using FEM combining elastic-plastic deformation of the workpiece and elastic deformation of the work roll without surface roughness, and reported the calculated thickness and interface stress distribution with different friction coefficients.

Dixon and Yuen (2006) considered surface roughness both on the workpiece and the work roll in their slab method analysis of skin-pass rolling. Combined roughness was simplified to a triangular profile on the workpiece surface. The calculated rolling force showed good agreement with measured data in a specific condition with a proper friction coefficient value of 0.1. Aoki et al. (2008) investigated the effect of lubrication, strip surface roughness and rolling speed on surface roughness and brightness in a lubricated skin-pass rolling condition with a very small work roll at 5% reduction, which is relatively higher than that in normal skin-pass rolling. They concluded that the viscosity of the lubricant affects surface quality when a mineral oil with high viscosity is used and the rolling speed is large. Kijima and Bay (2009) investigated the effect of lubrication in an experiment and FE analysis involving plane strain upsetting under small reduction to simulate the skin-pass rolling condition. The results revealed a significant change of elongation in the lubricated condition.

In the present paper, the effect of lubrication on elongation and roughness crushing, which are the most important parameters in operation, is investigated experimentally in skin-pass rolling of relatively soft, medium-to-heavy gauge steel strips with bright

* Tel.: +81 84 945 4162; fax: +81 84 945 3840.
E-mail address: h-kijima@jfe-steel.co.jp

http://dx.doi.org/10.1016/j.jmatprotec.2014.08.010
0924-0136/

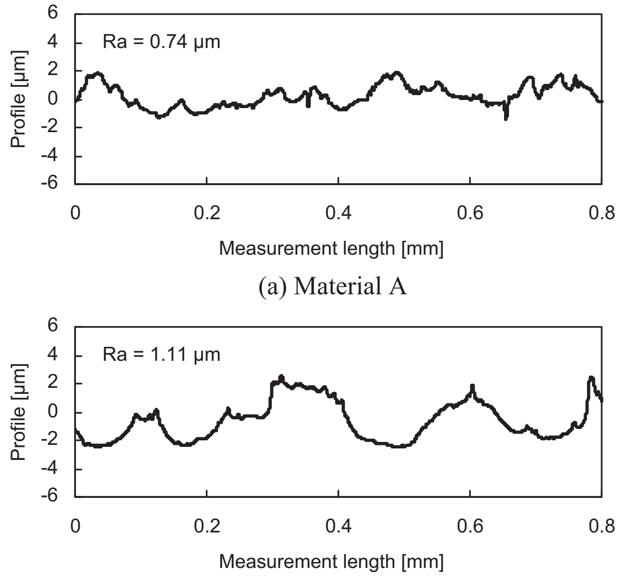

Fig. 1. Surface profiles of workpieces: (a) Material A and (b) Material B.

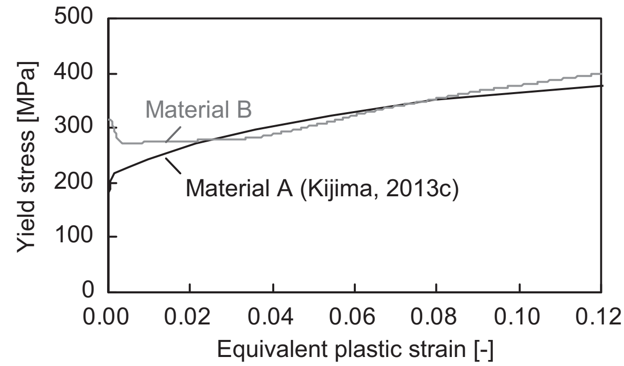

Fig. 2. Work hardening model of materials.

Table 1
Height characterization parameters of linear material ratio curve on workpiece surface before rolling (average of 5 measurements).

Material		Rpk	Rk	Rvk
A	[μm]	0.963	2.388	0.779
	[%]	23.3	57.8	18.9
B	[μm]	0.793	3.776	0.932
	[%]	14.4	68.7	16.9

rolls, following the previous investigations with the dry friction condition (Kijima, 2013c, 2014b). Two types of lubricants having different viscosity are used. In addition, this investigation focuses on the influence of the roll radius, which is discussed using FEM analysis. Here, two low carbon steel strip materials with different yielding behavior, one of which is the same material as in the previous reports, are rolled using two laboratory mills with bright work rolls of different radii. A numerical analysis, combining elastic-plastic deformation of the material and elastic deformation of the roll, which is modeled as having a smooth surface, is performed with commercial FE software under different friction conditions to investigate the experimental results. The rolling behavior is discussed in relation to crushing of surface roughness. In addition to average roughness, the height characterization parameters of the linear material ratio curve, which are some of the roughness parameters used in the ISO standard to express the lubricating property of the surface roughness profile, are also evaluated in this research.

2. Experimental apparatus and FEM analysis

2.1. Experimental conditions

The basic experimental conditions were the same as in the previous papers (Kijima, 2013c, 2014b), including two laboratory mills with roll radii of 250 mm (hereinafter referred to as "large roll" as an example of the operational size) and 50 mm (hereinafter referred to as "small roll" as an example of the laboratory size) and a roll surface condition in which the roll surface was ground in the longitudinal direction to a roughness Ra ≈ 0.2 μm.

Adding to the dry condition in the previous papers (Kijima, 2013c, 2014b), two types of lubricants were supplied: (a) soluble organic acid amine skin-pass lubricant with viscosity of 1 mm^2/s at 50 °C, and (b) synthetic ester cold-rolling lubricant with viscosity of 19 mm^2/s at 50 °C for comparison of a higher viscosity condition. The lubricants were warmed to 50 °C and applied sufficiently on the workpiece and the work roll surfaces with a brush as the neat condition before rolling.

Two types of workpieces hereinafter referred to as "Material A" and "Material B" were used. Both materials were annealed low carbon steel strips. Material A, with a thickness of 0.69 mm, was the same as in the previous papers (Kijima, 2013c, 2014b) and displayed practically negligible discontinuous yielding behavior. In Material B, the thickness of which was 0.99 mm, yielding behavior was obvious. Their mechanical properties were modeled as described in the next section, and typical surface profiles are shown in Fig. 1. The surface roughness of the workpieces before rolling was Ra = 0.74 μm and Ra = 1.11 μm for the cut-off length of 0.8 mm, respectively.

In the case of the large roll, a simple vertical compression test (Pawelski et al., 1993) was also conducted as in the previous study in the dull and dry condition (Kijima, 2014b).

After rolling and compression, the surface roughness of the workpiece was measured by a mechanical profilometer in the axial (transverse) direction in the same manner as in the previous paper (Kijima, 2014b). The cut-off lengths were chosen to be 0.8 mm. The roughness crushing ratio was then calculated from the measured roughness. The roughness crushing ratio is defined as follows:

$$\gamma \quad [\%] = \frac{Ra_{\text{-}S0} - Ra_{\text{-}S1}}{Ra_{\text{-}S0} - Ra_{\text{-}R}} \cdot 100, \qquad (1)$$

where $Ra_{\text{-}S0}$ is the workpiece roughness before rolling, $Ra_{\text{-}S1}$ the workpiece roughness after rolling and $Ra_{\text{-}R}$ is the roll roughness. In addition, the height characterization parameters of the linear material ratio curve of ISO 13565, i.e., core roughness profile (Rk), which expresses the depth of the roughness core profile, reduced peak height (Rpk), which expresses the average height of protruding peaks above the roughness core profile and reduced valley depth (Rvk), which expresses the average depth of valleys projecting through the roughness core profile, were evaluated for the large roll. The values of the parameters on the workpiece surface before rolling are shown in Table 1. The data for the surface roughness and height characterization parameters was the average values of 5 repeated measurements.

2.2. Conditions of FEM analysis

An FEM analysis simulating the experiments of skin-pass rolling described above was carried out to discuss the effect of the friction coefficient and, especially, roll radius. As mentioned in Section 3, the FEM results supported the reasonable effect of lubrication on rolling force in the case of the large roll and showed the