FUNDAMENTAL STUDY OF LUBRICATION CHARACTERISTICS OF HIGH STRENGTH STEEL IN COLD ROLLING *

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Abstract

When advanced high strength steel (AHSS) is rolled at a high reduction ratio, the forward slip ratio in cold rolling tends to be lower than that of the other softer strips such as low-carbon steels, and the work roll sometimes skids the strip. To identify why forward slip ratio of AHSS at a high reduction ratio becomes smaller than that of low-carbon steel, the relationship between the reduction ratio and forward slip ratio was investigated by a rolling experiment. For this trial, a 4Hi laboratory cold mill was used. AHSS and low-carbon steel coils were rolled by two different rolls that were set to 0.3 and 0.6 μmRa to create two types of friction conditions. Furthermore, the rolling conditions were numerically analyzed to determine the influence of friction coefficient and flow stress on the relationship between forward slip ratio and reduction ratio. The experimental investigation and numerical analysis revealed that the forward slip ratio reduced with increasing rolling reduction ratio in a low friction state; contrarily, it increased with increasing rolling reduction ratio in a high friction state. This feature was clearly visible when harder materials were rolled.

Keywords: Cold rolling, Lubrication, Friction, Forward slip ratio.

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1 INTRODUCTION

Owing to the increasing demand for fuel efficiency and collision safety, advanced high strength steel (AHSS) has been applied to vehicles. When AHSS is rolled at a high reduction ratio, the forward slip ratio in cold rolling tends to be lower than that of other softer strips such as low-carbon steels, and the work roll sometimes skids the strip [1]. This skid causes defects on the strip surface. However, when the reduction ratio increases, the bite angle also becomes larger. This increase in the bite angle leads to a decrease in the inlet oil film thickness, and the friction coefficient increases with an increase in the forward slip ratio. In this presentation, the effects of reduction ratio in cold rolling on the forward slip and friction coefficient are determined by the rolling experiment and rolling theory.

2 MATERIAL AND METHODS

For this trial, a lab 4HI cold reversing mill was used. The rolling speed and backward and forward tension were constant. The reduction rate was set in the range of 10-40%, and 10 vol% emulsion was used as a lubricant. The experimental conditions are summarized in Table 1. SPCC and JSC980YL were used as the rolling test coils. SPCC was used as low-carbon steels and JSC980YL was used as AHSS.

The forward slip ratio was obtained, and the torque meter was set up on work roll spindles measured rolling torque.

Table 1. Experimental conditions

Material	SPCC, JSC980YL
Thickness	SPCC:1.0 mm, JSC980YL: 1.4 mm
Width	100 mm
Reduction (r)	5, 10, 15, 20, 25, 30, 35, 40%
Front tension (σ_f)	98 MPa
Back tension (σ_b)	98 MPa
Rolling speed	5 mpm
Roll roughness	0.2 μmRa
Work roll	φ165 mm×400 mm
Back up roll	φ480 mm×400 mm
Concentration	10 vol%

3 RESULTS AND DISCUSSION

The relationship between the reduction rate and the forward slip ratio is shown in Figure 1. In each coil, SPCC and JSC980DP, forward slip ratio reduced with an increase in the rolling reduction ratio, and the forward slip ratio of JSC980DP became negative and lower than that of SPCC. By using rolling load (P) ,torques obtained from torque meters (TQ) and work roll radius(R), friction coefficient was calculated from the Equation 1.

$$\mu = TQ/(R \times P) \qquad (1)$$

Relationship between the reduction rate and the friction coefficient is shown in Figure 2. Two interesting results were obtained. First, the friction coefficients were almost equal in SPCC and JSC980DP, although their forward slip ratio differed. Second, the friction coefficient increased with an increase in the rolling reduction ratio, although the forward slip ratio decreased.

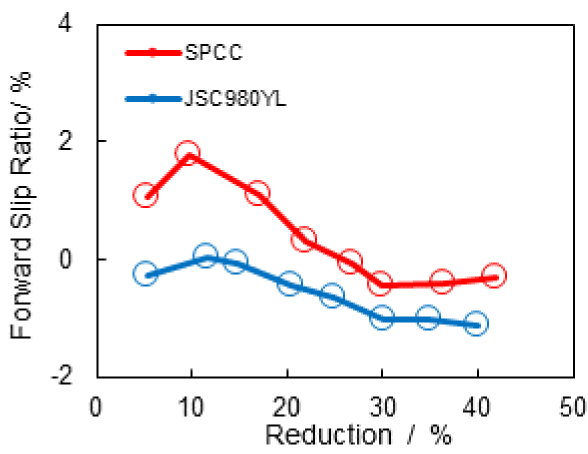

Figure 1. Effect of reduction on forward slip ratio.

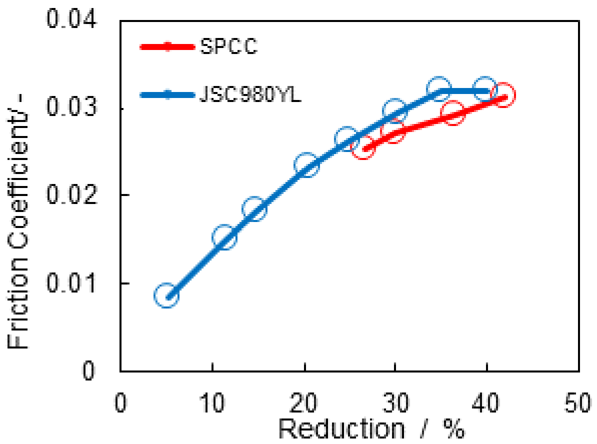

Figure 2. Effect of reduction on friction coefficient.

To understand why the forward slip ratio of JSC980DP decreases at a high reduction ratio, compared with SPCC, the relationship between the reduction ratio and the forward slip ratio was investigated based on the two-dimensional rolling theory. This model considers elastic recovery in the entry and exit area of the rollbite; therefore, it can calculate the forward slip even if the result is negative [2].

The values listed in Table 1 were used for the work roll diameter and forward and backward tension. The friction was set to 0.04 and 0.08. The strip's yield stress can be written as follows:

$$\sigma_y = A(\varepsilon + \varepsilon_0)^n \qquad (2)$$

The variables A, ε_0, and n are constants provided by the user. In this calculation, A = 196, ε_0= 0.01, and n = 0.3. To compare the strip's deformation resistance, the value of A was changed to 294 and 392. As a result, when the friction coefficient was high, then the forward slip ratio decreased with increasing reduction ratio. Conversely, the friction coefficient was low then it increased. The strip's deformation resistance had an effect on the forward slip ratio. The stronger the strip deformation resistance, the more was the change in the forward slip ratio.

Considering these calculations, the result shown in Figure. 1 is reasonable because the friction coefficient of the experiment shown in Figure. 2 is under 0.04. To check whether the same results as the calculations were seen in the experiments, another rolling experiment was performed. To change the frictional condition between the work rolls and strip surfaces, the roughness was set to two experimental levels: 0.3 and 0.6 μmRa.

The effect of work roll roughness on forward slip ratio is shown in Figure 3. When the roll roughness was 0.6 μmRa, the forward slip ratio increased along with the reduction ratio.

These experiments and numerical analyses reveal that the forward slip ratio reduced with increasing rolling reduction ratio in a low friction state, whereas it increased with increasing rolling reduction ratio in a high friction state. This feature was clearly seen when harder materials were rolled.

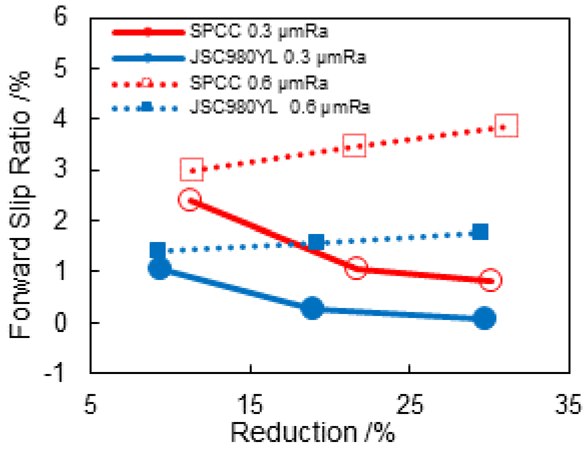

Figure 3. Effect of roll roughness on forward slip.

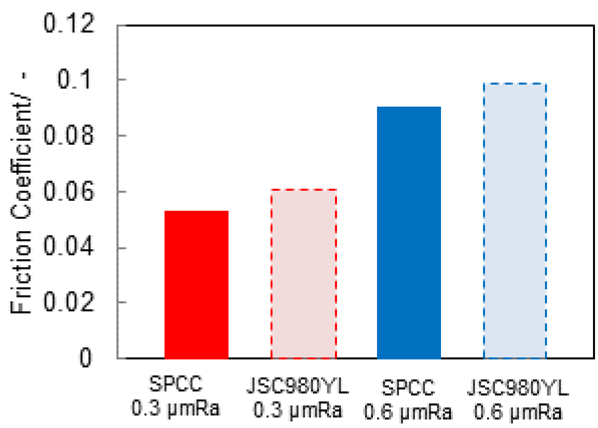

Figure 4. Effect of roll roughness on friction coefficient at r=30%.

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4 CONCLUSION

The forward slip ratio in cold rolling tends to be lower than that of other softer strips such as low-carbon steels, and the work roll sometimes skids the strip when AHSS is rolled at a high reduction ratio; to explain this behavior, some basic rolling experiments and calculations based on rolling theory were conducted. From these examinations, the following results were obtained

1) When the work roll skided the strip, the forward slip ratio decreased with an increase in rolling reduction irrespective of the material being AHSS or low-carbon steel. The forward slip ratio of AHSS was lower than that of low-carbon steel. The friction coefficient calculated from rolling load and torque was not very different between the AHSS and low-carbon steel.

2) The reason for the increase in rolling reduction ratio causing a decrease of the forward slip ratio was considered numerically. Calculations revealed that when the friction coefficient was low, the forward slip ratio decreased with increasing rolling reduction ratio. Further, this tendency was more pronounced in harder materials. This friction coefficient effect was confirmed from the rolling experiments. From these results, it can be said that if the friction coefficient is low in AHSS rolling, then the forward slip ratio decreases. This is the reason why slip between work rolls and strips tend to occur at high rolling reduction ratios more easily, especially in AHSS rolling.

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