Abstract

In order to improve surface glossiness of stainless steel strips in cold rolling, an experiment on roughness and glossiness of SUS 430 ferrite stainless steel was carried out in laboratory. The relation between roughness and glossiness with reduction in height, roll surface roughness, emulsion parameters was investigated. Roughness and micro defects were analyzed. The effects of micro defects on lubrication oil in deformation zone and reduction were discussed. With the increasing of reduction ratio strip surface roughness $R_a(s)$, $R_p(s)$ and $R_v(s)$ were decreasing along rolling and width direction, the drop value in rolling direction was faster than that in width direction. The roughness and glossiness were obtained under emulsion concentration $C_e = 3\%$ and $6\%$, temperature $T_e = 55$ and $63^\circ C$, roll surface roughness $R_a(r) = 0.5, 0.7$ and $1.0 \mu m$. The glossiness was declined rapidly when the micro defects ratio was above $23\%$. When lubrication oil in micro pit of deformation zone was decreased, micro defects were decreased, and glossiness value on the surface of strip was increased.

1. Introduction

Cold rolled stainless steel strips had been widely used in various fields due to their excellent corrosion resistance, heat resistance, moderate strength and ductility, long life and recycling. Cold rolled stainless steel strips were generally rolled by reverse rolling mills which had small diameter work rolls. Producing the stainless steel strips...
more efficiently had been attempted recently by tandem cold mill which had large diameter and high speed work rolls. The technology of stainless steel strips tandem cold rolling had become a hot spot because of high efficiency. It was reported the technology of stainless steel strips tandem cold rolling had been used by AK-Rockport steel factory, JFE Chiba steel factory, Nippon steel, and Sumitomo metal Ludao factory in recent years.

Surface quality of stainless steel strips in cold rolling process became the most concern. Kenmochi et al. (1997) investigated the effects of micro pit defects on glossiness of stainless steel strip. Effects of micro pit defects on work roll diameter, reduction in height, roughness of mother strip and viscosity of rolling oil were analyzed between a reversing mill and tandem mill. Sun et al. (2000) investigated the roughness of SUS 304 stainless strip and viscosity of rolling oil, and found that oil film thickness in deformation zone was related to roughness of work rolls, excessive oil film thickness generated by high viscosity would result in coarse plasticity on the surface of steel strips. The surface quality could be improved by high reduction in height and lower viscosity of rolling oil. Ma et al. (2002) carried out an experimental investigation of surface transfer in cold rolling of carbon steel strip and the influence of rolling parameters. The roughness analysis indicates that low reduction rolling could improve strip surface quality. But their results of reduction and roughness had disagreement with the work of stainless steel strip by authors in this paper. It was concerned with initial roughness of the carbon steel strip, because the strip was finished by skin-pass mill before cold rolling, and the roughness of the carbon steel strip was lower.

Lu et al. (2003) developed the modeling of the lubrication in the mixed lubrication situation of cold strip rolling. The mixed film lubrication model was adopted to describe the behavior of the lubricant and asperity deformation. Jiang and Tieu (2007) simulated the contact mechanics and work roll wear in cold rolling of thin strip using a developed modified influence function method. Surface roughness of the rolled strip on a cold rolling mill was characterized by a surface profile meter. Jin and Ren (2011) investigated the heat scratch on strip surface in a 6-high tandem cold rolling mill. Wang et al. (2011) reported the friction behavior of SUS 304 austenitic stainless steel sheet under the condition of friction coupling plastic deformation.

It was well known that the surface condition of the strips after cold rolling affects the surface brightness of cold rolled products. Rolling conditions such as the roll surface roughness, emulsion concentration and temperature, reduction in height affected the surface roughness and glossiness of the strip. The surface brightness and glossiness was evaluated by visual evaluation and a surface gloss meter. How surface brightness depends on surface roughness had not been researched in previous studies. In this paper, experimental investigation on roughness and glossiness of SUS 430 ferrite stainless steel was carried out in laboratory. The surface morphology of micro defects was observed by optical microscope. The effects of roughness and glossiness on rolling reduction, roll surface roughness and emulsion parameters were analyzed.

### Nomenclature

- \( Ra(r) \): rolls roughness of arithmetic average deviation
- \( r \): rolls of rolling mill
- \( Ce \): concentration of the emulsion in cold rolling
- \( Te \): temperature of the emulsion in cold rolling
- \( Ra(s) \): strip surface roughness of arithmetic average deviation
- \( Rp(s) \): strip surface roughness of maximum height of profile peak
- \( Rv(s) \): strip surface roughness of maximum profile deep valley
- \( H \): entrance thickness of rolling steel strip
- \( h \): outlet thickness of rolling steel strip
- \( eps \): reduction in height of the rolled strip
- \( v \): velocity of the rolls in rolling mill

### 2. Experimental materials and methods

The experimental materials were SUS430 ferrite stainless steel strips which were treated by hot rolling, annealing in Bell type furnace, and continuous pickling in sequence. Chemical composition of the material was
shown in Table 1. The rolling oil was supplied by a chemical company. Viscosity value of the oil at 40 °C was 61 mm²/s, saponification value was 181 mgKOH/g, and acid value was 10.0 mgKOH/g. The emulsion used as lubricant in rolling was composed of rolling oil (3%-7%) and deionized water (93%-97%). According to the requirements of rolling process, the concentration and temperature of the emulsion could be adjusted.

Table 1. Chemical composition of the tested steel (wt, %).

<table>
<thead>
<tr>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>S</th>
<th>P</th>
<th>Cr</th>
<th>Ti</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.039</td>
<td>0.35</td>
<td>0.25</td>
<td>0.002</td>
<td>0.014</td>
<td>16.01</td>
<td>0.230</td>
<td>0.0427</td>
</tr>
</tbody>
</table>

SUS430 ferrite stainless steel strips were prepared with 3.0 mm in thickness, 120 mm in width before cold rolling, the target thickness of rolled strips was 0.6 mm, and total reduction ratio in height was 80 %. Entrance thickness and outlet thickness of the tested strips, reduction distribution at rolling passes, rolling speed, roll surface roughness and conditions of the emulsion were shown in Table 2.

Table 2. Reduction distribution at rolling passes and emulsion parameters.

<table>
<thead>
<tr>
<th>Pass No</th>
<th>Entrance thickness H (mm)</th>
<th>Outlet thickness h (mm)</th>
<th>Reduction εp(%)</th>
<th>Rolling speed v (m/s)</th>
<th>Rolls roughness Ra(r) (μm)</th>
<th>Concentration of emulsion Ce (%)</th>
<th>Temperature of emulsion Te (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.0</td>
<td>2.26</td>
<td>24.7</td>
<td>0.2</td>
<td>0.5, 0.7, 1.0</td>
<td>3, 6</td>
<td>55, 63</td>
</tr>
<tr>
<td>2</td>
<td>2.26</td>
<td>1.53</td>
<td>32.3</td>
<td>0.5</td>
<td>0.5, 0.7, 1.0</td>
<td>3, 6</td>
<td>55, 63</td>
</tr>
<tr>
<td>3</td>
<td>1.53</td>
<td>1.08</td>
<td>29.4</td>
<td>0.6</td>
<td>0.5, 0.7, 1.0</td>
<td>3, 6</td>
<td>55, 63</td>
</tr>
<tr>
<td>4</td>
<td>1.08</td>
<td>0.76</td>
<td>29.6</td>
<td>0.8</td>
<td>0.5, 0.7, 1.0</td>
<td>3, 6</td>
<td>55, 63</td>
</tr>
<tr>
<td>5</td>
<td>0.76</td>
<td>0.60</td>
<td>21.0</td>
<td>1.0</td>
<td>0.5, 0.7, 1.0</td>
<td>3, 6</td>
<td>55, 63</td>
</tr>
</tbody>
</table>

A 4 high cold rolling mill (diameter of work rolls was 110 mm, diameter of backup rolls was 300 mm, length of work rolls and backup rolls was 300 mm, maximum rolling force was 1000 kN, rolling velocity was 0~7 m/s, main motor power was 400 kW) was employed in the experiment. The rolling mill was equipped with Automatic Gauge Control (AGC) system, the emulsion system which had function of temperature control, flow control, mixing and iron power filter. The material of work rolls was 9Cr2Mo steel. The roll roughness of arithmetic average deviation was 0.5, 0.7 and 1.0 μm.

The surface roughness was measured by TR300 desktop roughness meter. Surface glossiness was measured by Picogloss503 meter. Temperature was measured by portable MXM1310 digital thermometer. In order to observe and analyze surface morphology, the strip samples were also scanned by LEICA-DM2500M microscopy. The micro defects ratio was calculated by measuring the ratio of the defect area observed through microcopy to the whole observed area of the strips.

3. Results and discussion

3.1. Strip surface roughness with reduction in height

Strip surface roughness along rolling and width direction was measured at different reduction in height, including arithmetic average deviation $Ra(s)$, maximum height of profile peak $Rp(s)$, maximum profile deep valley $Rv(s)$, which was shown in Fig. 1(a)–(c).

It can be seen from the figures, with the increasing of reduction the roughness value $Ra(s)$, $Rp(s)$ and $Rv(s)$ of the strip was decreased along rolling and width direction. The drop of $Ra(s)$ value in rolling direction was faster than that in width direction. The critical value of reduction was 30 %. When the reduction was less than or equal to critical value, $Ra(s)$ value in width direction was less than or equal to $Ra(s)$ value in rolling direction. When the reduction was greater than critical value, $Ra(s)$ value in width direction was great than $Ra(s)$ value in rolling
direction. While \( R_p(s) \) and \( R_v(s) \) value in width direction was throughout greater than that in rolling direction during deformation zone.

With the increasing of the reduction, the rolling force and flatten roll diameter increased, deformation resistance in rolling and width direction would be varied. In the present research, when reduction ratio was greater than 30%, slope curve of \( Ra(s) \) value varied in rolling and width direction. As a result of reduction of rolling oil in grooves of roll and strip surface, deformation resistance was increased in rolling direction, the drop of \( Ra(s) \) value in rolling direction was faster than that in width direction.

### 3.2. Strip surface roughness with roll surface roughness and emulsion parameters

The roughness value \( Ra(s) \) of the sample was measured under different rolling pass with the concentration \( Ce=3 \% \) and 6%, temperature of emulsion \( Te=55 \) and 63 °C, roll surface roughness \( Ra(r)=0.5, 0.7 \) and 1.0 μm. The effects of strip roughness on roll surface roughness and emulsion parameters were shown in Fig. 2.

With the growing of pass number, roughness of strip \( Ra(s) \) was decreased under roll surface roughness \( Ra(r)=0.5, 0.7 \) and 1.0 μm. At different rolling pass roughness of the strip \( Ra(s) \) was increased with the increasing of roll surface roughness \( Ra(r) \). In the same concentration of emulsion, roughness of strip \( Ra(s) \) was decreased.

![Fig. 1. Strip surface roughness of (a) arithmetic average deviation \( Ra(s) \), (b) maximum height of profile peak \( R_p(s) \) and (c) maximum profile deep valley \( R_v(s) \) along rolling and width direction at different reduction in height of rolling.](image)

![Fig. 2. Roughness value \( Ra(s) \) of sample under condition of emulsion parameters (a) \( Ce=3 \% \), \( Te=55 \) °C; (b) \( Ce=3 \% \), \( Te=63 \) °C; (c) \( Ce=6 \% \), \( Te=55 \) °C and (d) \( Ce=6 \% \), \( Te=63 \) °C with roll roughness \( Ra(r)=0.5 \) μm, \( Ra(r)=0.7 \) μm and \( Ra(r)=1.0 \) μm.](image)
when temperature of emulsion varied from 55 to 63 °C. In the same temperature of emulsion, roughness of strip \(Ra(s)\) was decreased when concentration of emulsion varied from 3 % to 6 %.

3.3. Strip surface glossiness with roll surface roughness and emulsion parameters

The glossiness \(GS20^\circ\), \(GS60^\circ\) and \(GS85^\circ\) value of strip surface was measured under the concentration of emulsion \(Ce=3\%\) and 6 %, temperature of emulsion \(Te=55\, ^\circ\text{C}\) and 63 °C, roll surface roughness \(Ra(r)=0.5\) and 0.7 \(\mu\text{m}\). Because the regular variation of \(GS20^\circ\), \(GS60^\circ\) and \(GS85^\circ\) were the same, effects of only glossiness value \(GS20^\circ\) on roll surface roughness and emulsion parameters was shown in Fig. 3.

![Fig. 3. Effects of strip glossiness value \(GS20^\circ\) on roll surface roughness \(Ra(r)=0.5\) \(\mu\text{m}\), 0.7 \(\mu\text{m}\) with emulsion parameters (a) \(Ce=3\%\), \(Te=55\, ^\circ\text{C}\), (b) \(Ce=3\%\), \(Te=63\, ^\circ\text{C}\), (c) \(Ce=6\%\), \(Te=55\, ^\circ\text{C}\) and (d) \(Ce=6\%\), \(Te=63\, ^\circ\text{C}\).](image)

As it can be seen from Fig. 3, under the experimental conditions strip glossiness value \(GS20^\circ\) was increased with the increasing of roll surface roughness at different rolling pass numbers. In the same concentration of emulsion, when temperature of emulsion varied from 55 °C to 63 °C glossiness of strip value \(GS20^\circ\) was increased. In the same temperature of emulsion, when concentration of emulsion varied from 3 % to 6 %, glossiness of strip value \(GS20^\circ\) was increased.

3.4. Strip surface glossiness with micro defects

The glossiness of the strip was affected by micro defects. The micro defects of the strip were observed by microscopy at different pass numbers, as shown in Fig. 4. It was seen from the figure that the micro defects was decreased with pass number increasing. When the rolling oil was less in micro pit lower micro defects and higher glossiness were happened on the surface of the strip. Quantity of oil in entrance zone was affected by mechanical entrapment intensively, because the roughness of the mother strip was larger than oil film thickness in entrance. Roughness of the mother strip had more intensive effects on micro defects of strip than that of roll surface roughness, concentration and temperature of emulsion.

Micro defects ratio was decreased after bite point in deformation zone. If the rolling force was increased from bite point to neutral point, squeezing oil was increasing so that oil film thickness was thin. With the increased reduction in height, micro defects were less, and glossiness value of the strip was increased.
3.5. Modeling of the strip surface roughness

Modeling of strip surface roughness with reduction in height, roll surface roughness and emulsion parameters had been built by authors. Due to space limitations the results and discussion could be seen in reference [8].

4. Conclusions

With the increasing of reduction in height, roughness value $Ra(s)$, $Rp(s)$ and $Rv(s)$ was decreased along rolling and width direction, the drop of $Ra(s)$ value in rolling direction was faster than that in width direction.

With the growing of pass number, surface roughness of strip $Ra(s)$ was decreased under roll surface roughness $Ra(r) = 0.5 \mu m$, $0.7 \mu m$ and $1.0 \mu m$. In the same concentration of emulsion, roughness of strip $Ra(s)$ was decreased when temperature of emulsion varied from 55 to 63 °C. In the same temperature of emulsion, roughness of strip $Ra(s)$ was decreased when concentration of emulsion varied from 3 % to 6 %.

In the same concentration of emulsion, when temperature of emulsion varied from 55 to 63 °C glossiness of strip value GS20° was increased. In the same temperature of emulsion, when concentration of emulsion varied from 3 % to 6 %, glossiness of strip value GS20° was increased.

Glossiness and micro defects on surface of steel strip was investigated. Effects of micro defects on lubrication oil nearby deformation zone were analyzed.

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References