# Influence of Rolling Chemicals on Temper Rolling Process and Anti-Rust Performance of Cold Rolled Steels

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**The temper rolling process is an essential step for the modification of the surface quality of cold rolled steels (CR) by applying a wet rolling chemical before further treatment with antirust oil. In this article, two newly developed temper rolling chemicals, RL1B and RL1C, are formulated by combining surfactant, wetting agent, anti-rust and anti-wear additives to improve the rolling performance. In the laboratory simulation and during actual rolling in the temper mill, the rolling lubricity by using the new rolling chemicals RL1B and RL1C were significantly improved by 20～40% and the cleanliness of the CR surface after rolling were increased by 10%. Moreover, the lubricity of the work roller was doubled and the repair frequency of work roller decreased by 20% at CSC's temper mill in 2007. Based on the use of the newly developed rolling chemicals, the anti-oil stain and anti-rust performance of CR coils during storage period were greatly enhanced, from less than 6 months to over one year.**

## 1. INTRODUCTION

The purpose of the temper rolling process is to release the yield point and to augment the stretching strain during the post forming procedures. The wet temper rolling procedure(1) is generally adopted to provide better shape, lubricity, and anti-rust and cleanliness properties on the surface quality in comparison with the dry rolling procedure. The original wet temper rolling chemical RL1A with lower anti-rust property in the temper mill was applied to provide acceptable lubricity. However, an excess of rolling chemical residues on the CR surface or water condensation during the storage stage will stimulate the white stain, oil stain or red rust defects after 6 months storage time. Therefore, a new superior formulation of rolling chemicals was necessary to improve the anti-oil stain performance for longer than a 1 year storage time. Furthermore, it was desirable that the newly-proposed rolling chemicals could improve the cleanliness on the CR surface and provide better lubrication on the roll bite. The wear rates and maintenance frequency of work roller during temper rolling could therefore be reduced significantly.

## 2. EXPERIMENTAL CONDITIONS

### *2.1 Indoor Air Exposure Corrosion Test and Anti-Oil Stain Evaluation*

The test panels were immersed in a 5% temper solution. The panels were exposed in the 60~80% relative humidity and 26 ± 4°C temperature conditions in order to compare anti-rust performance. In the center areas, the additional rust preventive oil film was applied to evaluate the anti-oil stain performance.

### *2.2 Anti-Wear Tests (ASTM2266)*

In the Falex four ball wear tester, a sample tank was filled with the temper solution. The rolling condition of four balls were loaded with 40kg force, and set in the initial temperature at 40°C and 1,200 rpm constant rolling speed.

### *2.3 Phoenix Tribology Tester (TE53)*

The instrument can be applied with different loads and temperatures as showed in Fig. 1. In this study, the lower load with 5 kg was applied, and the initial temperature was set at 40°C.

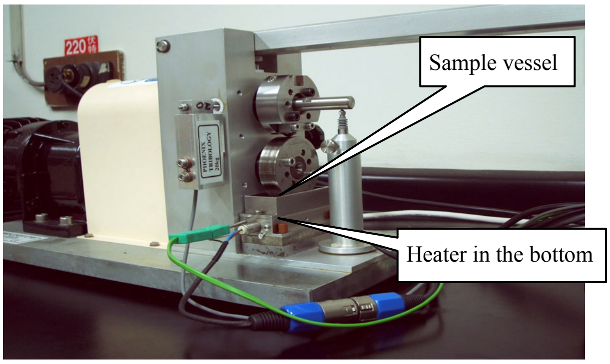


**Fig. 1.** Phoenix Tribology (TE53): Rolling friction tester with 400 rpm rolling and 5 kg load.

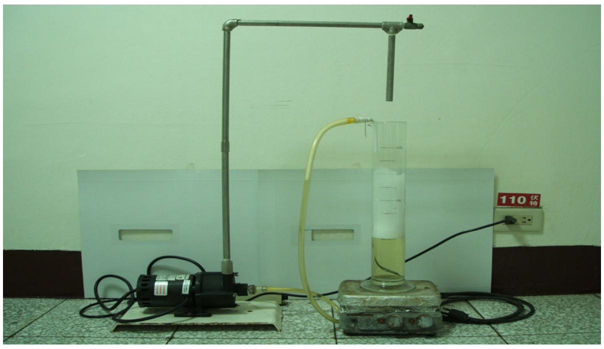

**Fig. 2.** The foaming tester with circulation flowrate: 250 ml/min.

### *2.4 Electrochemical Corrosion Tester*

EG&G 273 Electrochemical Corrosion Meter were used to evaluate the polarization impedance and the Tafel corrosion current of the CR panels versus different temper solutions.

### *2.5 Foaming Tester*

The apparatus will automatically circulate a flow rate of 250 ml/min, as shown in Fig. 2. The foaming height was recorded after 1 min pumping.

## 3. EXPERIMENTAL RESULTS AND DISCUSSION

### *3.1 The Difference of Formulation Components and Basic Properties*

The basic components of the temper rolling chemicals were formulated with anti-wear agents, anti-rust additives, surfactant, wetting agents and defoamer or other co-solvents, as shown in Table 1. The ratio and components were correlated with their rolling performance or surface quality after rolling.[2]

Four types of rolling solution have special physical properties as shown in Table 2, where SK3 solution is a commercial product. The different concentration of chemicals resulted in different refractive indices, pH values and surface tensions. The lower surface tensions of RL1B and RL1C retain a better wetting ability. The foaming heights of RL1C, developed by our own technique, and SK3 used as a second source, were greatly reduced by the addition of defoamer components, as shown in Table 1.

**Table 1 Three Different Rolling Solutions with Various Ratios of Formulated Components**

| Name | $H_2O$ | Amine solvent | Anti-rust agents | Surfactants | Wetting agent | Lubricant of organic acid | Anti-wear gradient | Defoamer Others |
|---|---|---|---|---|---|---|---|---|
| RL1A | Balance | 10～20 | <5.0 | <1.0 | | | | > 5.0 |
| RL1B | Balance | 10～20 | 5～10 | | | >1.0 | >5.0 | |
| RL1C | Balance | 10～20 | 10～15 | <1.0 | >0.1 | >1.0 | | > 0.05 |
| SK3 | Commercial | product | | | | | | > 0.05 |

**Table 2 The Basic Physical Properties of Temper Rolling Solutions**

| Character/Solution type | RL1A | RL1B | RL1C | SK3 |
|---|---|---|---|---|
| 5% PH | 9.11 | 9.74 | 8.79 | 10.5 |
| 5% refractive index | 1.6 | 1.9 | 1.8 | 1.1 |
| 10% refractive index | 3.1 | 3.7 | 3.5 | 2.2 |
| 5% surface tension (dyne/cm) | 34.6 | 28.7 | 26.3 | 30.5 |
| Foaming height of 5% Solution at 1 min pump recirculation | 8 cm | 24 cm | 3 cm | 3 cm |

### 3.2 The Evaluation of Rolling Lubrication Performance in Different Type of Temper Solutions

By four ball lubrication tester with point contact at 40 kg load, the rolling performances were measured and are summarized in Table 3. The advanced formulas of RL1B and RL1C impart lower friction coefficient, wear diameter and temperature increase. The ranking of rolling lubricity at 40 kg load is as follows RL1B > RL1C > SK3 > RL1A. When the contact load was increased to 80~100 kg, temper solutions with 5% or 10% concentration of RL1A are unable to pass the test. However, the new RL1B solution at 10% concentration possesses sufficient lubricity to pass the test with slightly expanded scar diameter (wear) as shown in Table 4.

**Table 3 Tribology Test of Various Temper Solutions with Point Contact at 40 kg Load**

| Name | Average friction coefficient | Scar diameter (mm) | Temperature increase |
|---|---|---|---|
| 5%RL1A | 0.325 | 1.92 | 30.6 |
| 5%RL1B | 0.045 | 0.63 | 0.7 |
| 5%RL1C | 0.082 | 0.76 | 1.8 |
| 5%SK3 | 0.155 | 1.39 | 26.9 |

**Table 4 Tribology Test of Two Temper Solutions with Point Contact at 80~100 kg Load**

| Name/Conditions | 40 kg Wear (mm) | 80 kg Wear (mm) | 100 kg Wear (mm) |
|---|---|---|---|
| 5%RL1A | 1.92 | Fail | Fail |
| 5%RL1B | 0.63 | Fail | Fail |
| 10%RL1A | 1.09 | Fail | Fail |
| 10%RL1B | 0.50 | 0.93 | 1.22 |

Using the Phoenix Tribology tester with area contact at lower load of 5 kg, the rolling performance was shown in Table 5. The newly-developed temper solutions RL1B and RL1C presented less wear diameter, lower friction coefficients, and better cooling effects or lubrication performance than the RL1A solution. The temperature increase is near to zero in the case of the RL1B/RL1C temper solutions. In contrast, the poor lubricities of RL1A or SK3 resulted in wider wear diameters and larger temperature increases. The ranking of rolling lubricity at 5 kg load is as follows RL1B > RL1C > RL1A > SK3. The rolling process during TE53 tribology test was monitored by friction coefficient versus time, as shown in Fig. 3. Due to strong adsorption and fast reaction of organic acid components in the particular formulation of RL1C or RL1B, the friction coefficient decreased gradually with the rolling times. However, since the property of RL1A or SK3 could not provide a sufficiently strong protection film during the rolling schedule, the friction coefficients increased with the testing time. An unstable friction coefficient or rolling force was observed in the case of SK3 rolling schedule, as shown in Fig. 3. As a result, the large amounts of scratched iron powder from the rolling disc were found in the SK3 solution during this simulation test at area contact load.

**Table 5 Tribology Test of Various Temper Solutions with Area Contact at 5 kg Load**

| Name | Friction coefficient | Wear width (mm) | Temperature increase |
|---|---|---|---|
| 5%RL1A | 0.123 | 1.31 | 14.2 |
| 5%RL1B | 0.064 | 0.53 | 0 |
| 5%RL1C | 0.084 | 0.77 | 0 |
| 5%SK3 | 0.141 | 2.06 | 18.2 |

### 3.3 The Evaluation of Rust Preventive and Anti-Oil Stain Performance on the CR Steels after Treatment with Temper Solutions and Additional Rust Preventive Oil Film

The clean test panels were initially treated with 5% or 10% temper solutions and exposed to the indoor environment for 10~17 days to examine the anti-rust performance. It was found that the panels treated with RL1A and SK3 films suffered from larger or denser spot rust. In comparison, the anti-rust performance of panels treated with the newly-developed RL1B/RL1C rolling solution was clearly augmented. After 17 days air exposure test, the RL1C treated panels showed < 3% edge spot rust. In contrast, the RL1A or SK3 treated panels demonstrated serious rust, as shown in Table 6 and Fig. 4.

In simulation of the rolling process the CR panels were initially treated with a rolling solution and further coated with anti-rust oil RP93 in the middle area to assess the compatibility of double layer treatments and anti-oil stain performance. After a 20-day air exposure test, the RL1C and SK3 treated panels showed no oil stain in the middle areas, moreover the outside area of the SK3 panels showed 90% dense rust. The compatibility and synergetic effects by new rolling solutions, RL1C and RL1B, and RP93 oil were positively endorsed. The compatibility between the RL1A solution and RP93 oil was shown to be poor. Serious rust covered the whole areas of the RL1A panel both with and without RP93 oil treatment, as shown in Fig. 5.

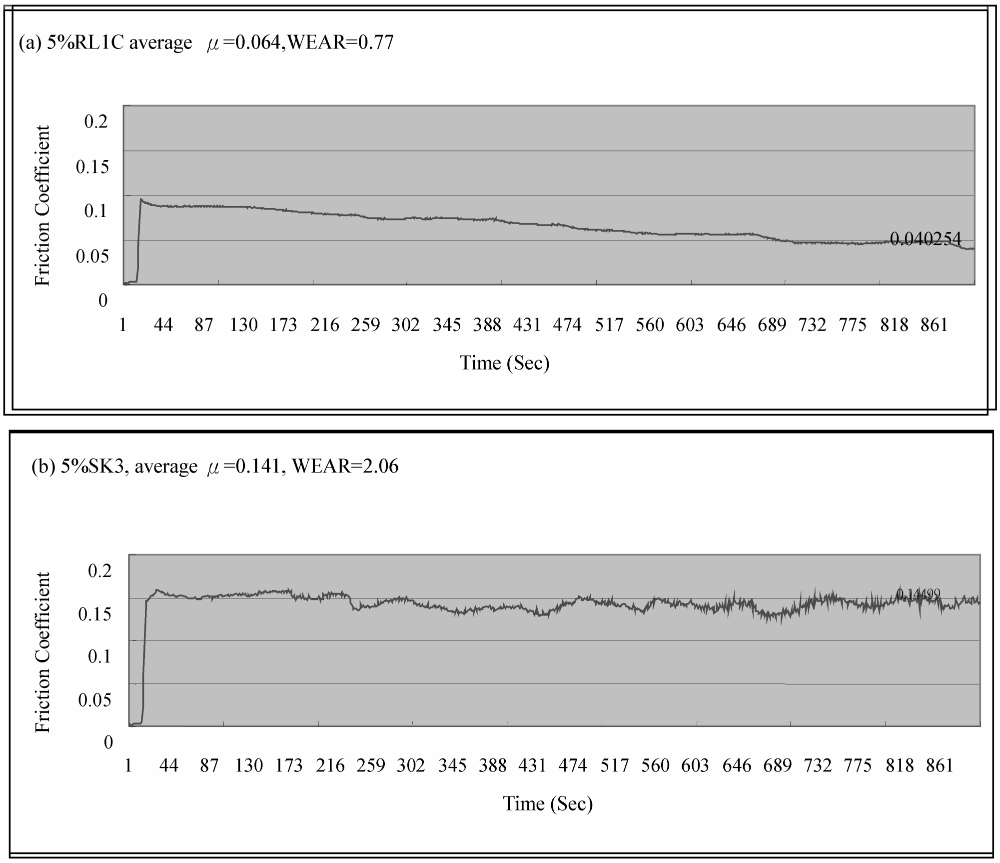


**Fig. 3.** The friction coefficient versus rolling time in different solutions (a) 5%RL14C (b) 5%SK3.

**Table 6 The Anti-Rust and Anti-Oil Stain Performance of CR Panels with Temper Solution Treatment**

| Character/Solution type | RL1C | RL1A | SK3 |
|---|---|---|---|
| 10 days exposure panels with temper solution only | <1% edge rust (0.1 mm) | 5% large edge rust (1～3 mm) | >90% dense light rust |
| 17 days exposure panels with temper solution only | <3%edge rust (0.1 mm) | 30～50% large spot rust (1～3 mm) | >90% dense deep red rust |
| 20 days exposure panels with temper solution and RP93 oiling | No oil stain in the middle areas | light oil stain to serious red rust | No oil stain in middle area Serious rust in side area |

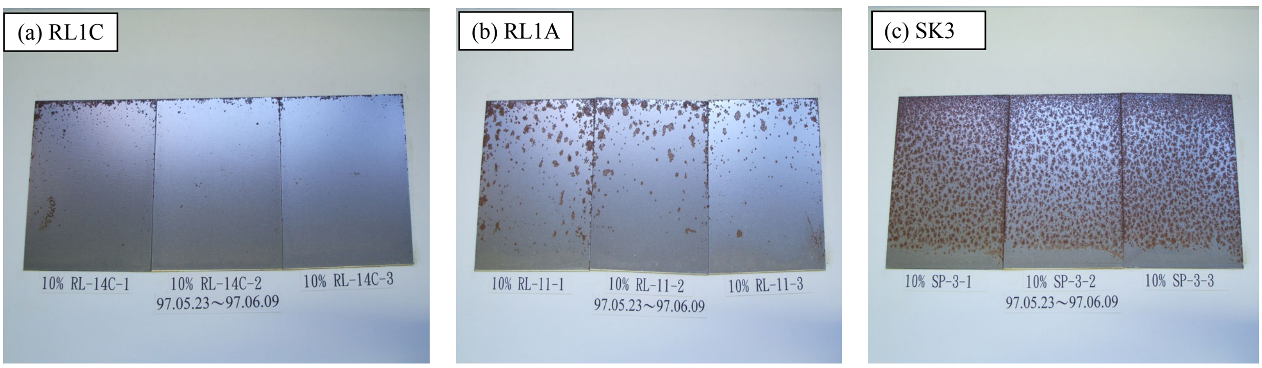


**Fig. 4.** The anti-rust performance after 17 days exposure of CR panels with 10% different temper solution treatment, (a)10%RL1C (b)10%RL1A (c)10%SK3.

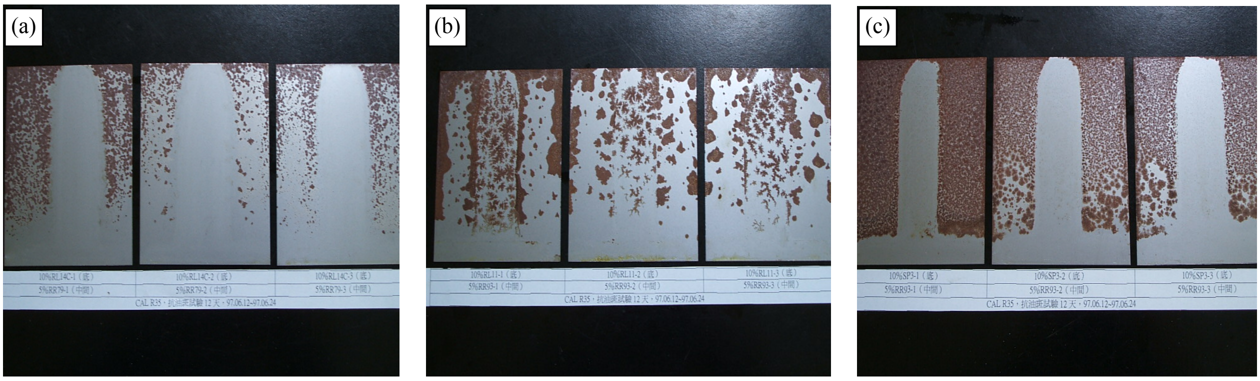


**Fig. 5.** The anti-rust and anti-oil stain performance after 20 days exposure test of panels with 10% different solutions and additional RP93 oil in the middle area (a)RL1C (b)RL1A (c)SK3.

### *3.4 The Evaluation of Corrosion Current and Polarization Resistance of CR Test Panels Immersed in the Temper Solution by Electrochemical Cells*

It was shown that the anti-rust resistance of panels was measured by an electrochemical corrosion test. When the voltage with ± 10 mv or ± 250 mv near to an open circuit potential was applied, the polarization resistance and corrosion current were measured by Tafel polarization techniques. The lower corrosion current and higher polarization resistance of RL1B or RL1C with reference to RL1A and SK3 are shown in Table 7. The corrosion current induced by electrochemical methods and the atmospheric rust presented the same tendency, as shown in Table 7 and Fig. 4. Although the rust area of panels with RL1A was smaller than the rust coverage on SK3, the largest and deeper rust on RL1A related with highest corrosion current was detected in the above evaluation tests.

### *3.5 The Actual Performance of the Newly-Developed Rolling Chemicals in the Temper Mill*

It was shown that the rolling force remained stable after the 6th rolled coil under the application of a 5% temper solution and at 1.0~1.25% reduction rates, whereas the amount of rolling force is also dependent on steel thickness, width and its materials.[3,4] In Table 8 it is demonstrated that the 5% RL1B solution contributed better lubricity at 16~40% than the 5% RL1A solution during the temper rolling process. Those results are similar to the conclusions observed from Table 4 and Table 5, where the friction tests were carried out at the point of contact and the area of contact. In addition, the cleanliness of the CR surface was detected by a reflection meter and showed a >10% improvement in the case of the RL1B temper solution compared with the RL1A solution, as shown in Table 9. Therefore the surface cleanliness and surface quality image have been greatly improved at CSC's temper mill by using the RL1B solution.[5] Meanwhile the lubricity of the work roller was doubled and the repair frequency of the work roller decreased 20% in 2007.

**Table 7 The Comparative Evaluation of Polarization Resistance and Corrosion Currents of Panels in 4 Different Temper Solutions (Panels Treated with #1000 Sand Paper)**

| Name | Polarization Resistance Rp (Ω/cm$^2$) | Corrosion current (amp/cm$^2$) |
|---|---|---|
| 10%RL1A | 6913 | $3.79\times10^{-6}$ |
| 10%RL1B | 13149 | $1.99\times10^{-6}$ |
| 10%SK3 | 8063 | $3.25\times10^{-6}$ |
| 10%RL1C | 12539 | $2.09\times10^{-6}$ |

**Table 8 The Assessment of Rolling Lubricity of RL1B and RL1A in the Temper Mill**

| Name/rolling conditions | Thinner coil 0.4×1222 mm | Thin coil 0.6×1222 mm | Note (stable rolling after 6th coil) |
|---|---|---|---|
| 5% RL1B | 408-421 MT<br>Avg:415 MT | 284-339 MT<br>Avg:300 MT | The rolling force of RL1B decrease 40 % at 0.4 mm CR |
| 5% RL1A | 594-890 MT<br>Avg:687 MT | 333-382<br>Avg:358 MT | and decrease 16 % at 0.6 mm CR |

**Table 9 Surface Cleanliness of CR Coils after Temper Rolling by Reflection Meter**

| Name/rolling conditions | Sampling number | Average detergency (%) |
|---|---|---|
| 5% RL1A | 5 | 60-80 |
| 5% RL1B at first test | 4 | 92.6 |
| 5% RL1B at second test | 2 | 92 |

It was also demonstrated that the rolling force was mutually affected by the RL1A and RL1C solutions under the application of two types of temper solution and 0.98% steel reduction ratio, whereas the amount of rolling force is dependent on lubricity of temper solution at the same condition of entry coils. Table 10 shows that for the initial 5 coils with an application of the RL1A solution the average rolling force showed 339 tons and that for the 6th to 20th subsequent coils, by changing to RL1C, the force was reduced down to 247 tons, which indicated 20% decrease. From the 21st coil the RL1A solution, partially mixed with RL1C in pipe line, was spraying onto the mill and the rolling force increased gradually. The same trend of rolling performance with higher lubricity of RL1B and RL1C has been verified in two different mills. The reason why both of the RL1B and the RL1C solutions could present higher lubricity than the RL1A solution is due to strong chemical adsorption films contributed by the organic acid lubricants in the formulation, as shown in Table 1.

The anti-rust and anti-oil stain performance of the temper rolled coils with and without RP93 oil treatment was monitored over a long period. It is demonstrated in Table 11 that CR coils treated only with temper solutions have a different level of anti-rust property. Coils treated with the RL1A rolling solution were initially found with rust defects after 3.5 months storage time. In addition, larger areas of spot rust gradually developed with time. However, coils treated with RL1B rolling solution showed better anti-rust characteristics with only a few areas of spot rust (0.01%) occurring after 6 months storage time. Furthermore, the coils process with RL1A solution and RP93 oiling treatment showed edge spot rust due to the evaporation of the oil film, and oil stain in the center areas due to the over-residue of rolling solution when the coils were stored above 6 months, as shown in Table 12. However, using the RL1B solution and RP93 treatment, neither oil stain nor rust was observed after 5.5 months and 1 year storage stages.

**Table 10 The Assessment of Rolling Lubricity of RL1C and RL1A in the Skin Pass Rolling at CAL Process**

| Solution type | Size (mm) | Materials | Rolling force (Ton) | Reduction rate % |
|---|---|---|---|---|
| RL1A (at initial 5 coils) | 0.6*1209 | CQS | 339 | 0.98 |
| RL1C ($6^{th}$ to $20^{th}$ coil) | 0.6*1209 | CQS | 247 | 0.98 |
| RL1A (after $21^{st}$ coil) | 0.6*1209 | CQS | 279 | 0.98 |

**Table 11 Anti-Rust Performances of CR Coils after Temper Rolling and Wrapping with VCI Paper**

| Name of solution/ coil number | 3.5 months storage time | 4.5 months storage time | 6 months storage time |
|---|---|---|---|
| RL1A/102814 | 0.05% spot rust | 3% spot rust | 5% spot rust |
| RL1B/436276 | Pass, No rust | Pass, No rust | 0.01% spot rust |

**Table 12 Anti-Oil Stain and Anti-Rust Properties after Rolling Solution and RP93 Oiling Treatment**

| Name of solution/ coil number | 1st assessment 5.5 months storage time | 2nd assessment 6～12 months storage time |
|---|---|---|
| RL1A+RP93 /015158,587263 | Edge rust, Oil stain in the center area (5%) | Edge rust, Oil stain Fail |
| RL1B+RP93 435815,436276 | No rust, No oil stain Pass | No rust, No oil stain Pass |

## 4. CONCLUSION AND SUGGESTION

From the formulation development and laboratory simulation, it was found that lubricity evaluation can effectively predict rolling performance. The surface quality was also improved by the rolling chemicals. The significant conclusions obtained were as follows.

(1) The new rolling chemicals of RL1B and RL1C contain unique gradients of lubricants, antirust agents, wetting agents and other additives. Different physical properties, such as lower surface tension, lower friction, and higher refractive index, were obtained in this study. The RL1C chemical possesses lower foaming, and slightly less lubricity than the RL1B chemical to meet the different rolling processes.

(2) By four ball tester and TE53 tribology tester it was observed that the new rolling chemicals offered a tremendous improvement in rolling lubricity. The formulation with organic acid additives can contribute to the protection film which can reduce the friction coefficient and decrease the rolling force by 20-40% in the rolling mill. Moreover, the lubricity of the work rollers was doubled and the repair frequency of the work rollers decreased by 20% at CSC's temper mill.

(3) By electrochemical corrosion study with polarization and Tafel techniques, RL1B and RL1C temper solutions can provide 1.8 times higher polarization resistance and one half less corrosion current than RL1A or SK3 solutions. The trend of anticorrosion performance from the electrochemical test is consistent with the results from the air exposure test for CR steel panels.

(4) The anti-oil stain properties of CR panels treated with RL1B and RL1C rolling solutions and RP93 oiling film showed a higher performance than CR panels treated with RL1A rolling solutions and RP93 because of the compatibility of the rolling chemicals and the anti-rust oil. In actual CR steel coils, it was established that RL1B can sustain a >12 months anti-oil stain performance, whereas RL1A protects against oil stain and rust for < 6 months in storage period.

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