SURFACE QUALITY IMPROVEMENT OF HOT-DIP GALVANIZED STEEL SHEET, USING HARD CHROME PLATED SKIN PASS MILL ROLL

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SYNOPSIS:

The chrome coating technology has been developed and applied in wide range of applications in the steel industries on the advantages of durability, wear resistance, and corrosion resistance etc.

In Continuous Hot-Dip Galvanizing Line (CGL), Skin Pass Mill (SPM) is a key facility to improve mechanical properties and surface quality. Therefore SPM work roll quality is one of the most important factors that determine the surface quality of hot dip galvanized products. CGL SPM work rolls are generally thin hard chrome plated, around 10 μm thickness, in order that the rolls roughness should be retained under high rolling forces. It is difficult to obtain thin hard coating quality as it requires thin and uniform layer in whole roll surface within the short dipping time. Due to this difficulty and the high investment cost, there is only a limited number of hard chrome plating companies to achieve such coating quality and there are not many steel companies that have own chrome coating facilities.

There have been many investigations about the effect of Cr-coated work roll, but there are not many results obtained from long-term actual line operation data.

This paper investigated roll life time in comparison of Cr-coated and non Cr-coated work rolls with the controlled parameters and the effects on roll and steel surface roughness, the printed area ratio and the surface coating quality in the actual CGL operation line for long period.

Keywords: Hot-Dip Galvanizing Steel, Hard Chrome Plating, Skin Pass Mill Work Roll

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Introduction

The chrome coating technology has been applied in various industries for decades since it has been introduced, especially in the rolling mill industries for both cold rolling mill (CRM) and skin pass mill (SPM) to extend the roll service life and performance. The advantages of the hard chrome coatings are the hardness and low coefficient of friction, and also the property of the surface finish after coating. The SPM work roll surface after coating still maintain the same texture as before coating [4], therefore the surface texture relies mainly on the pre-coating texture preparation.

The most conventional texturing method is shot blast texturing (SBT). However, due to the limitations to control the surface accurately [6], the other methods have been developed such as Laser texturing (LT), Electron beam texturing (EBT), Electrolytic Chromium Deposit Texturing (ECT), and Electro discharge texturing (EDT). [1] EDT is a very suitable method for skin pass milling process in hot dip galvanizing process due to the regularity of the texture that is uniformly dispersed over the area, the possible roughness range, the peak count, and reproducibility. [3]

![SEM image of texturing by each method](image)

In continuous hot-dip galvanizing line (CGL), the SPM plays an important role to the quality of the galvanized product. Firstly, SPM improves the mechanical property for the next process by applying load and tension to the steel strip to eliminate the stretcher strain. [5] Secondly, it provides texture to the product surface which is the main key to the appearance of the product. The textured surface masks the small imperfections in the surface and provides desirable appearance for decorative painting for automotive outer panel. Not only textured surface provides good appearance but it also has advantages on the formability. The textured surface provides reservoir for lubricating oil during forming. [2] This improves the formability and reduces die wear. The surface texture of the strip is controlled by rolling force and the quality of the work roll surface. Therefore the quality of the SPM work roll surface is the main key for hot-dip galvanized product surface.

In this study, the Electro Discharge Texturing (EDT) Hard Chrome Coated Work Roll is applied to Skin Pass Mill (SPM) Work Roll in the actual Hot-dip Continuous Galvanizing Line (CGL), in order to investigate comparison lifetime between non-coated and chrome coated work roll and the effect of rolling force to the surface quality of Galvanized Steel Sheet, and the constant surface quality of hard chrome coating work roll.

The result is determined by SEM analysis, Optical Microscope analysis, 3D topography, roughness analysis by Ra, and surface property analysis by friction test.
Experimental Methods

1. Roll Preparation Method

1.1 Grinding Process
Grinding process is a process to remove the top most part of the surface that has worn out, and to prepare the roll profile for proper operation condition and to prevent crack.

1.2 Electro Discharge Texturing (EDT)
Electro Discharge Texturing is a method to remove the material from the roll surface by electric discharges between the tool electrode and the roll which act as another electrode in the dielectric medium. The electric discharge occurs where evaporation of the material of the roll occur.

EDT is selected for its advantages over the other texturing method such as its advantage to control the height and number of peak by controlling the EDT parameters such as voltage, current, pulse, pause, rotation speed, and cutting time. [7] Unlike conventional SB technique, EDT doesn’t have complicated controlled variable such as hardness shape and size of shots. EDT is also free from dust and loud noises. [2]

This study controlled the Ra of the rolls for different kind of product as the product has different surface properties in the beginning and it requires different final surface properties. GA work roll Ra is controlled at 1.3-1.5 µm while GI work roll Ra is higher at 2.3-2.5 µm.

1.3 Chrome Coating Process
Chrome coating process is a type of electro deposition which the roll is dipped in a solution bath as a cathode electrode. As the voltage is given the Chromium ion in the solution is deposited on the surface of the roll. The thickness of the coating layer and the coating quality is controlled by the plating time, electrolyte bath temperature, chromic concentration, current density and voltage given to the system.

1.4 Inspection Roll Surface
Thorougly visual inspection and measure Ra and hardness to confirm the surface quality before apply to CGL operation.
2. Operation Test Method

The prepared roll was applied to the CGL operation line with the control parameters. The effects of work roll were investigated in both kind of product, hot-dip galvanized product (GI) and hot-dip galvannealed product (GA), which have different surface properties. The test took place in actual CGL operation where the actual steel strip was produced with the controlled parameters. The test can be separated in mainly 3 subjects;

2.1 Comparison of lifetime between non-chrome coated and chrome coated work roll

This study is investigated the relation of strip roughness and the printed area ratio with roll life time of non-chrome coated and chrome coated work roll. To analyze and compare the non-chrome coated and chrome coated SPM work roll condition, both strip roughness and the printed area are investigated every 50~100km work roll used length.

2.2 The effect of SPM roll force to the surface properties

This study is investigated that surface appearance and formability on various SPM Roll force condition with chrome coated rolls. SPM Rolling force is varied from 0 to 500 Ton and the other parameters such as SPM tension and line speed are controlled as same condition. The sample are selected to be the same steel grade at the same steel thickness to avoid the effect of other operation conditions.

2.3 The constant surface quality of hard chrome coating work roll

The actual product is collected throughout the roll life of a work roll after using hard chrome coated work roll and investigated how long the strip texture and surface roughness properties remain the same in GI and GA product until the work roll is changed.

The results were analyzed by SEM analysis, Optical Microscope, Roughness, 3D Roughness, and friction test by rotational friction test. The result is also analyzed by the printed area ratio which is measuring the ratio of the pressed area to the total area from the strip SEM analysis.
Results and Discussions

1. Comparison lifetime between non-coated and chrome coated work roll

1.1 Lifetime of non-chrome coated work roll

The SEM images of the strip surface, that was skin passed by non-chrome coated work roll (Fig. 2), showed that printed area is not sharp and has low depth of print mark on the strip. The worn-down roll mark or the flat surface started to be printed on the strip surface at 69 km (Fig. 2 (b)) and it is increased with the increased rolling length 200km (Fig. 2 (c)). The quality of the strip texture is gradually changed as the roll life increased.

The sample texture properties are measured by the surface roughness in Ra and printed area ratio which is measuring the pressed area to the total area from the strip SEM analysis. The result showed that the strip roughness (Ra) and the printed area dramatically decreased within 50 km, the strip roughness (Ra) decreased from 1.0µm to lower than 0.8 µm and the printed area ratio is decreased to 44% and continuously decreasing while the work roll life increased. At SPM used length 200km, the Ra is decreased to 0.73 um and the printed area is decreased to the lowest at 37%. (Fig. 4)

![Fig.2: SEM analysis of GI strip surface produced by non-chrome coated work roll](image1)

- (a) 8.5 km
- (b) 69km
- (c) 200 km

![Fig.3: SEM analysis of GI strip surface produced by chrome coated work roll](image2)

- (a) 15km
- (b) 306km
- (c) 1,392km

1.2 Lifetime of Chrome coated work roll

On the other hand, for the chrome coated work roll, the SEM images of the strip surface (Fig. 3) showed that it has deeper and sharper roll mark on the strip and there is no worn-down roll mark or flat mark on the strip surface like in non-chrome coated rolls. When compare to non-chrome coated roll 200km (Fig. 2 (c)) the surface produced by non-chrome coated work roll has already flatten in some area, however the texture of the strip produced by coated roll is still well dispersed and no flat area even in 306km and 1,392km(Fig. 3 (b,c)). The quality of
the strip texture is stable and does not change as the roll used length is increased. Considering the Ra and printed area ratio, the result showed that the Ra and printed area deviated within the small range of Ra average 1.1 µm and the Ra is remain above 0.87 µm. (Fig. 4(b)) When compare the printed area ratio of the coated and non-chrome coated roll results, the Ra and printed area ratio of the coated roll strip is higher than the non-coated roll. However, the long rolling distance during operation has caused the deviation of roll force. It could lead to doubt or disbelieve that the strip roughness is not only higher than the non-coated roll because the roll force is higher.

Therefore another test is taken with a closer range of roll force controlled. (Fig.5) The result showed that the printed area ratio and the Ra is much higher than the non-chrome coated roll when considering the same roll force. For example, at the rolling length are 100km and 200km, the roll force of the non-chrome coated roll are 350 and 320 Ton, the roll force of the coated roll are 320 and 364 Ton respectively. As a result, the Ra of the non-coated roll samples are 0.71 and 0.73 µm and for the coated roll samples are 1.28 and 1.19 µm. This means the Ra increased by 0.5 µm or 70%. For the printed area ratio, the non-chrome coated roll samples are 44.8% and 37% and the coated roll samples are 52% and 48%. The surface texture has been improved by the chrome coated surface of the SPM work roll.

![Fig.4: Comparison of Ra, Printed area ratio by non-coated & chrome coated work roll](image)

![Fig.5: Comparison of Ra, Printed area ratio by non-coated & chrome coated work roll](image)
2. The effect of SPM roll force to the surface properties

2.1 The effect of SPM roll force to Hot-Dip Galvanized Product (GI)

The different rolling force gives different appearance to the naked eye. The increasing of rolling force gives more desirable appearance due to the roughness given from the SPM work roll has buried some of the appearance flaws such as coating pattern. The optical microscopic image showed the comparison of each sample appearance with different roll force. (Fig. 6) The coating pattern can be seen clearly from the strip that is SPM by the roll force 100 Ton (Fig. 6 (a)) and improved by 200 Ton (Fig. 6 (b)). The roll force 500 Ton (Fig. 6 (c)) has masked all the small imperfections, and provided better appearance to the naked eye and Optical microscope (OM).

![Fig. 6: Optical Microscope (OM) analysis of GI strip surface that varied the roll force
(a) 100 Ton (b) 200 Ton (c) 500 Ton](image)

![Fig. 7: SEM analysis of GI strip surface that varied the roll force
(a) 100 Ton (b) 200 Ton (c) 500 Ton](image)

![Fig. 8: 3D roughness analysis of GI strip surface that varied the roll force
(a) 100 Ton (b) 200 Ton (c) 500 Ton](image)

The SEM and the 3D roughness analysis showed that the roll printed mark on strip is increased as the rolling force increased. (Fig. 7, 8)
The 3D roughness showed that the higher peaks and lower valleys occurred when increased the roll force. When measuring the surface properties, the roll force has direct effect to the Ra and printed area ratio. *(Fig. 9, 11)*

As the friction property is investigated, the friction coefficient is affected by roll force and strip roughness. To satisfy the customer request, strip roughness need to be controlled by roll force and optimized by customer’s press die condition. Based on this friction information, further investigations will be taken including customer’s press condition.

All above means the paintability and formability can be controlled by optimizing the SPM roll force and strip roughness. To supply same quality of products for each, constant SPM roll force and roughness condition is important. Hard chrome coating roll give to maintain same strip roughness quality without wear-down.

![Graphs showing relation between SPM Roll force and strip roughness & printed area ratio for GI and GA products.](image)

**Fig. 9:** Relation between SPM Roll force and of Strip roughness & Printed area ratio on GI/GA product

### 2.2 The effect of SPM roll force to Hot-Dip Galvannealed Product (GA)

On the other hand, GA product has a different surface texture from GI product. The GA product goes through a galvannealing process that makes diffusion of Fe alloying between steel surface and the zinc layer. The alloying process makes the zinc layer has higher roughness and hardness. The SPM work roll did not press down deeply and make print mark at the same way of GI product. The SEM analysis *(Fig.10)* showed that the higher the roll force, it showed some small peaks roll printed marks. When there is no rolling on the surface (0 Ton), the roughness of GA is higher that of GI from 0.87 to 0.37 µm. *(Fig.9)* After the SPM roll force is applied the influence of the roll force effects to the surface of the strip by decreasing the roughness because the roll mark pressed down the small peaks on GA strip surface and then the roughness increased by the increasing roll force.
When compare the relation between the roll force and friction properties GI product has direct relation to the roll force while GA product does not have such relation. *(Fig.11)* The surface of GA product is harder than of GI product, due to the alloying of Fe on the surface of Zinc layer, therefore the friction of the GA product is determined by mainly the alloying process. However, GA product can also be controlled the same surface quality by SPM roll force and roughness.
3. The constant surface quality of hard chrome coating work roll

The actual product is collected throughout the roll life of a work roll after using hard chrome coated work roll. It is showed that the strip texture and surface roughness properties remain the same in GI and GA product until the work roll is changed by work schedule 630 km for GI work roll and 360 km for GA work roll. Although, it has been tested that the chrome coated work roll can be used until longer than 1,000km, the roll has to be changed due to the production scheduling to prevent other defect from occurring after long operation. The SEM analysis showed sharp deep and well dispersed roll mark on the strip from first rolling strip to last rolling strip. (Fig. 12, 13) The measured Ra value and printed area ratio is showed in (Fig. 14), the Ra value and printed area ratio remain constant value throughout the roll life.

Fig.12: SEM analysis of GI strip surface produced by chrome coated work roll
(a) 5 km (b) 214 km (c) 630 km

Fig.13: SEM analysis of GA strip surface produced by chrome coated work roll
(a) 107 km (b) 263 km (c) 360 km

Fig.14: GI and GA sample Roughness and print area ratio measurement according to the rolling distance with hard chrome coating roll
Conclusion

The surface appearance and formability of hot-dip galvanized steel sheet can be controlled by optimizing the SPM roll force and strip roughness with SPM work roll texture and coating method. To supply same quality products for each customer, constant SPM roll force and roughness condition is important parameter in CGL operation. Hard chrome coating rolls effects to maintain same strip roughness quality without roll texture wear-down. The chrome coated work roll provides a sharper, deeper texture to the steel surface when comparing to non-chrome coated work roll. This is due to the hardness of the chrome protects the weak peaks and make the work roll more durable, while non-coated work roll worn down within the first 50 km. Chrome coated technology has increased the work roll life in this study. In this test, work roll life time is longer than the non-chrome coated work roll and it also reduces the number of work roll change time.

The quality of the surface texture is determined by the work roll surface and roll force on hot-dip galvanized steel sheet. The higher roll force has been proved to provide better appearance and higher strip roughness quality. Comparing the relation between the roll force and friction properties, GI product has direct relation to the roll force while GA product does not have such relation. The surface of GA product is harder than of GI product, due to the alloying of Fe on the surface of Zinc layer, therefore the friction of the GA product is determined by mainly the alloying process. However, GA product can also be controlled the same surface quality by SPM roll force and roughness. Both products quality required to be controlled through the roll life from the first rolling product until the last of the roll life.

Reference

[1] D.J. Wentink et al., 2015, A generic model for surface texture development, wear and roughness transfer in skin pass rolling, wear, 328-329, 167-176