New Surface Finishes for Cold Rolling Mills

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Summary

The innovative technology and equipment for roll texturing developed by Pomini Tenova has opened up new possibilities for designing and engineering of surface finishes to optimize the performance of the work rolls, rolling mills and the subsequent processing of the sheet material.
The Pomini Digital Texturing™ (PDT™) system has been developed and tested by Pomini in recent years including numerous trials with users. The capability of the system to accurately control the dimensions, characteristics and placement of craters allows the production of an endless range of surface finishes. The variety of surface finishes produced and the results achieved by these surface finishes have demonstrated the high performance of the PDT™ process and the future potential for further development virtually without limitation.
Through many years of experience, Pomini has become very adept at adopting new technologies and has created very effective strategies to deliver a high quality and reliable outcome, while minimizing the lead time for development.

Key Words

Roll shop, cold rolling, work roll, rolled sheet, surface texture, forming, paint appearance, roughness.

Introduction

The characteristics of the surface texture on the work roll and the texture transferred to the rolled sheet surface have a significant effect on the performance of both the work roll and the rolled sheet. The characteristics of the surface texture for optimum performance during rolling, forming and painting are measured by a variety of parameters such as Roughness average (Ra), Peak Count (Rpc), Skewness (Rsk) and Waviness (Wa). Another very important aspect of the work roll surface texture is the ability to transfer the desired surface texture to the rolled sheet during the various rolling operations. While the current texturing processes have the ability to control some of these important parameters, they cannot always control the parameters independently of each other to create the optimum surface texture for each different application.
Most steel and automotive producers have significant differences between the manufacturing process that they use and therefore the individual process requirements, limitations and production challenges vary greatly between each facility. The use of coated and un-coated sheet material in various markets also presents different challenges during production to achieve the desired texture on the strip surface due to the different material properties and rate of texture transfer from the work roll to the rolled sheet.
Pomini has developed a new surface texturing process (1) that has the ability to individually control the surface texture parameters with great accuracy and consistency. This provides the opportunity to engineer the surface texture on the work roll to give the best combination of features for both the sheet producer and sheet user.

Previous Investigations

During the rolling process the transfer of the Ra and Rpc from the work roll to the rolled sheet are two of the two main measures of the work roll performance in addition to the useable campaign life of the work roll. Other attributes such as the generation of “mill fines” during the rolling process and the retention of the oil on the sheet, applied after rolling, during transport and storage.
The forming process considers such factors as formability, coefficient of friction, and resistance to “scoring” and “galling” as important performance measures. These factors are primarily influenced by the rolled sheet surface roughness Ra and the surface topography described by the Rpc and also the number closed voids on the sheet surface.
Previous investigations of sheet steel surface topography and the influence on the forming of automotive panels concluded that a texture comprising "many peaks and valleys" with a Ra in the range of 1.4 - 2.0 um provided good forming performance. (2) It also showed that as the surface roughness Ra is reduced below 0.8 then “scoring” is likely to occur and if the roughness is further reduced to 0.5 um then “scoring” increases significantly.
Formability is also considered to improve with increased peak density, up to a limit when the

"valleys" become too small to hold sufficient lubricant and wear debris. (3). Good anti-galling properties were found to be achieved when surface roughness Ra was in the range of 0.7 - 1.5 um and with Rpc in the range of 37 - 57 peaks/cm. Both lower Roughness Ra and higher Rpc were shown to be a disadvantage as the resulting "valleys" are too small to retain sufficient lubricant or the wear debris formed during sliding leading to wear and "galling".
Conversely higher roughness Ra and lower Rpc were found to cause high localized contact pressures due to the reduced number of contacts between the sheet and tool. Other investigations (4) found similar results for the importance of the "open roughness" with the valleys to act as oil reservoirs and evacuate the wear particles, they also found that a rolled sheet surface with negative Rsk should be used to avoid "galling".
Further investigations considered that the area of the valleys should be greater than the area of the plateau on the rolled sheet. (5) This higher ratio of valleys to plateaus resulted in a reduced bearing area and a lower potential for "galling".
The overall painting appearance is determined by such factors as; gloss, DOI and orange peel, each of which relates to a specific area of wavelength components in the surface texture on the rolled sheet as shown in Figure 1. Several studies of the effect of surface texture on the paint appearance have concluded that for stochastic textures, such as Shotblasting (SB) and Electro-discharge Texturing (EDT), there is a correlation between low Ra and high Rpc and improved paint appearance. A low roughness of approximately 0.75 um Ra in combination with high peak count, in the range of 74 peaks/cm, provided the "maximum" image clarity for a 50 um paint film. (6) While Ra and Rpc are important for good paint appearance these investigations also revealed that they alone don't always produce good paint appearance, but that the Waviness (Wa) also has a strong correlation with the paint appearance.

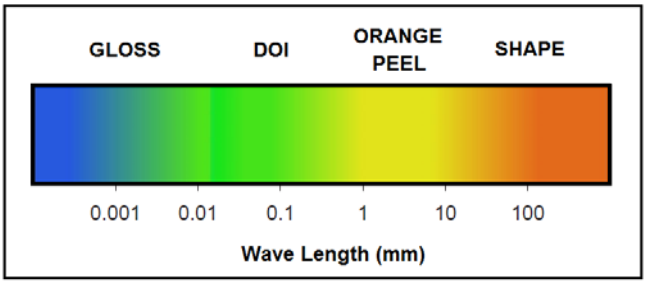

Figure 1: Surface Wave Length Components

In extensive research for CARSTEEL waviness project (7) the main influences on waviness of the galvanized steel were the rolling force during skin passing and the waviness of the work rolls. As the rolling force is generally fixed for the mill and product type the main opportunity to reduce the strip waviness is to reduce the waviness on the work roll.
It was also found that the Ra of the textured rolls has a significant influence on the waviness of the work roll. Therefore a lower amplitude of the waviness on the strip can be achieved by reducing the roughness of the work roll, while still achieving the roughness required on the rolled sheet. A reduced Wa improves paint appearance with typical values on the rolled sheet of amplitude below 0.35 μm - 0.45 μm are requested by the automotive industry.
It is also considered that deterministic texture patterns, such as Electron Beam Texturing (EBT), have improved forming and painting characteristics due to the higher level of closed voids and the more regular appearance which leads to less galling and orange peel. The EBT textured sheet has a structure with a pattern of isolated pockets, each with identical shape. The isolated pockets act as reservoirs for lubrication resulting in reduced galling without affecting the coefficient of friction. (8) Rolled sheet with a topography having low waviness and negative skewness was found to be an optimised profile to achieve a high paint appearance. Investigations have also found that the paint appearance of deterministic surfaces are less sensitive to the actual Ra and Rpc of the rolled sheet. (9)
In a study to categorise the surface of steel body panels and their effect on paint quality, it was concluded that rather than Ra or Rpc having a correlation to paint appearance it was actually the variation in peak height that was the critical parameter for paint appearance. (10)
From these multitude of investigations it can be seen that there are a number of desirable features on the work roll and sheet surface texture that improve the performance during cold rolling, forming and painting. More than 3 years of testing has proven that to achieve the required texture on the work roll it is beneficial to use a process such as Pomini Digital Texturing™ which can accurately and independently control the Ra, Rpc, Rsk, Wa, volume of closed voids and degree of deterministic /stochastic of the texture matrix.

Innovative New Texturing Process

The process is referred to as Pomini Digital Texturing™ as it relies extensively on software technology to generate the texture matrix and control the high frequency lasers that apply the texture to the roll surface. Laser technology was selected as it is a clean and efficient system, and whilst not new technology it is still being continuously developed and improved. The particular type of high frequency laser used is very suitable to software switching and control.
The Pomini Digital Texturing™ System, as shown in Figure 2, incorporates an "off the shelf" high frequency Laser which is controlled by the digital

texturing system developed by Pomini. This combination creates an accurate, flexible and efficient texturing system with the benefits of a laser source with high reliability, low maintenance and proven in a large number of industrial applications.

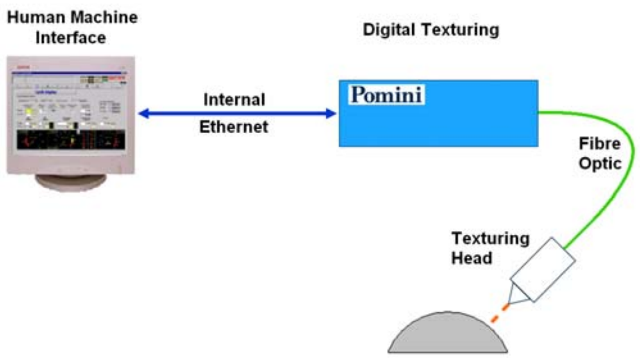

Figure 2: Pomini Digital Texturing™ System

The laser source produces a high quality, small diameter beam which is ideal for achieving the precise, consistent performance required for surface texturing. The control system and laser source allow the very high frequency operation necessary to achieve the desired surface texture and productivity. The surface texture can be designed using computer simulation to achieve the desired matrix and then the dimensions of craters, such as depth, diameter and shape and proportion of the peaks can be controlled by the software operating the laser system. By controlling these features the Ra, Rpc and Rsk can be adjusted independently from each other. Figure 3 below shows in independence of the Ra and Rpc as produced by the process whereby a range of roughness from 2.0 to 8.0 can be produced with the same crater matrix and Rpc of 80 by increasing the crater depth and rim height to increase the Ra.

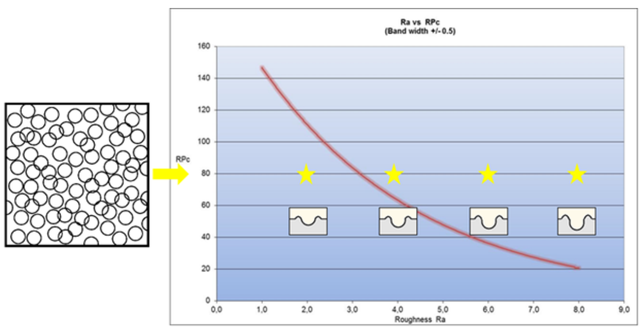

Figure 3: PDT ™ Ra controlled independent of Rpc

Because the surface texture matrix is software controlled, it allows a wide range of surfaces to be produced ranging from Deterministic to Stochastic and by altering the spacing parameters the density of the surface texture can be changed to produce "open" or "closed" surfaces as shown in Figure 4. Varying the matrix of craters textured onto the work roll allows the degree of uniformity, Wa, quantity of closed voids and ratio of valleys to plateau produced on the rolled sheet to be controlled, all parameters that previous investigations have determined as affecting both the formability and paintability of the rolled sheet.

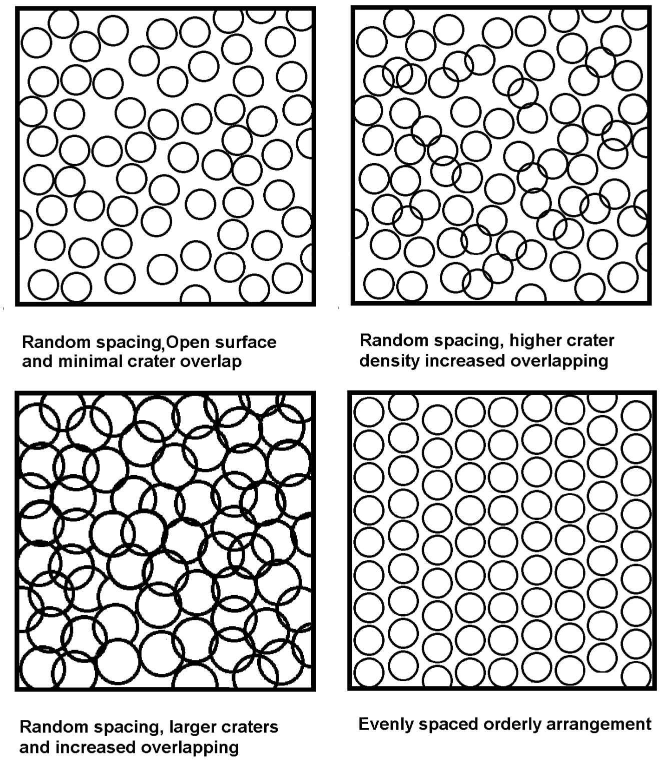

Figure 4: PDT™ Crater Matrix

In addition the broad peaks produced by the PDT™ process are highly desirable to provide very good texture transfer to the rolled sheet and wear characteristics of the work rolls without the need for any form of "post processing" to modify the surface after the initial texturing, as is a common practice by many sheet producers using the EDT process.
The Pomini Digital Texturing™ process has the ability to produce a wide range of surface texture and after testing in user's rolling mills the performance of the surface textures was sufficiently verified to design and manufacture the first production machine. This machine has been in operation for 18 months texturing both production and trial rolls for rolling mills.

Investigations

Various types of PDT™ surface textures have been developed for specific applications, primarily with the aim of producing the requested surface on the rolled sheet while improving the work roll performance. Initially, PDT™ surface textures replicating the overlapping matrix craters of EDT have been produced while also improving specific attributes such as Ra consistency, transfer of Rpc and work roll life. A typical PDT™ surface is magnified in figure 5, where the random and isotropic arrangement of uniform craters can be seen. A roll after texturing can be seen in Figure 6. to be uniform and consistent in appearance. This particular surface has a degree of crater overlap to simulate a typical EDT arrangement but with much better crater and rim definition resulting in discrete craters and broad peaks, due to the raised nature of the crater rim this surface also has a “positive” skew value on the roll.

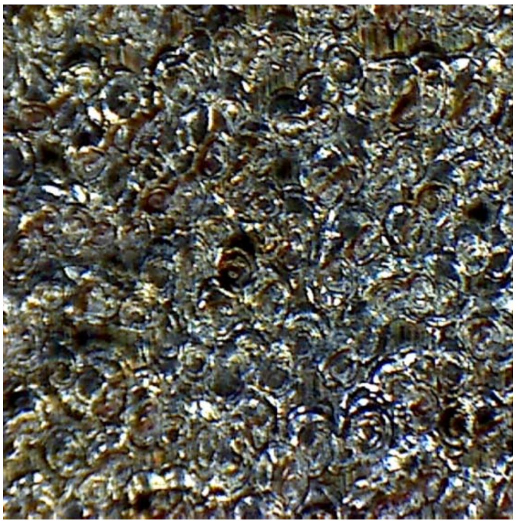

Figure 5: PDT™ Surface Texture

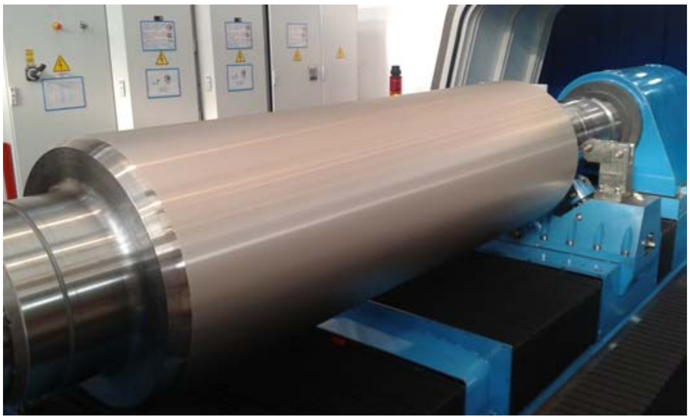

Figure 6: PDT™ Textured Roll

The transfer rate for PDT™ textures, of both the Ra and Rpc, has been found to be particularly good and an improvement over current texturing methods. In Particular the transfer of the Rpc has been very good and is almost 1:1 even in difficult applications such as the 5th stand of the Tandem Mill and during Temper Rolling. A direct comparison with post processed EDT can be seen in the results for uncoated material rolled in a 4 High temper mill in figure 7. The improved transfer rate in addition to a reduced initial Ra drop allows rolls with typically 20% lower Ra than EDT rolls used to achieve the same strip Ra. The initial Ra drop for PDT™ rolls occurs during the first few meters of rolling and the Ra is then very stable throughout the first coil as shown in figure 8 which compares the Head end, middle and tail end roughness Ra values of the first coil on new work rolls.

As Wa is a function of texturing process and also proportional to Ra, a lower roll Ra has been previously found to produce a lower rolled sheet waviness, which is significant for paint appearance. The improved transfer rate is possibly due to a combination on the work roll surfaces, textured with PDT™, of positive skew and a greater uniformity of the peaks.

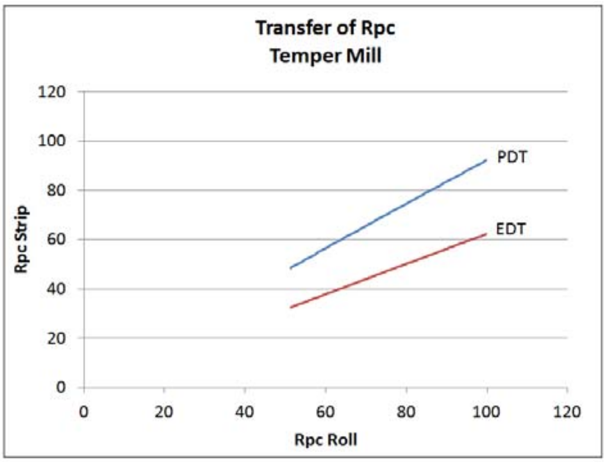

Figure 7: PDT™ Rpc Transfer

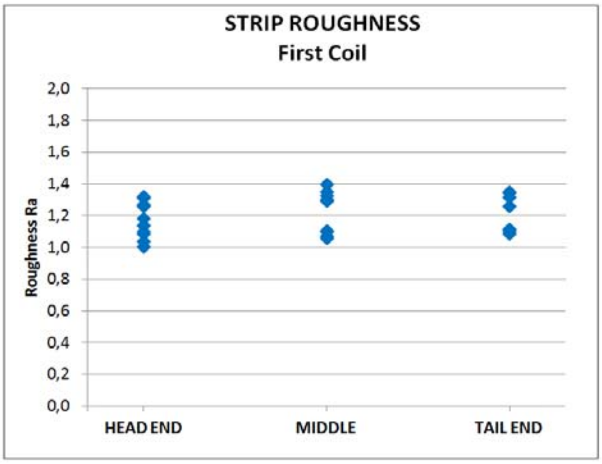

Figure 8: PDT™ Ra of first coil

In one application the aim was to improve Ra consistency, produce negative skew on strip surface and prolong the work roll useable life. The results from this application can be seen in figure 9 and figure 10. The useable roll was almost double that of the current textured work rolls and the negative skew was maintained on the rolled sheet throughout the roll life, whereas the current process with EDT textured work rolls always produced a positively skewed strip surface. The appearance of the rolled sheet produced from PDT™ work rolls is considered by experienced quality inspectors as being noticeably "brighter" than the rolled sheet that was produced the current practice using EDT textured work rolls. An increased number of isolated pockets on the rolled sheet surface were expected to improve oil retention and reduce oil migration from the coils and incidence quality complaints from the customer.

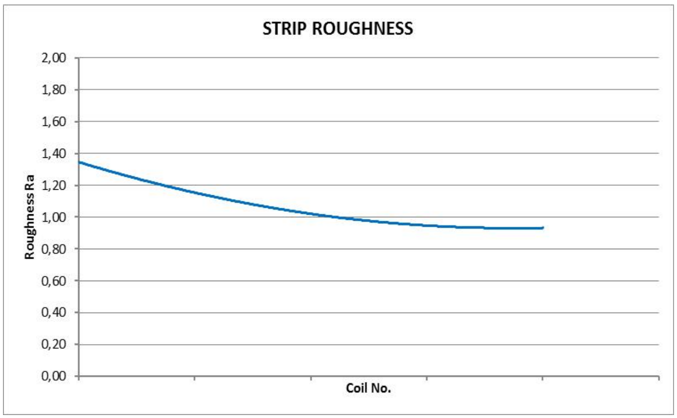

Figure 9: PDT™ Ra evolution

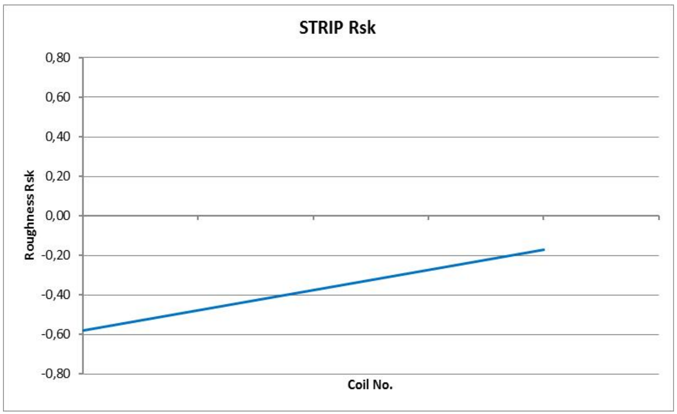

Figure 10: PDT™ Rsk evolution

It is generally considered that negative skew (less protruding peaks) and increased bearing area on the work roll texture improves work roll life, which is confirmed in figures 9 and figure 10. As the roll wears and the skew, on the roll, becomes less positive and rate of wear in figure 9 decreases. Unfortunately, producing negative skew on the work roll to improve the roll life produces positively skewed roll sheet texture which is known to be detrimental to forming and painting. PDT™ textured rolls were able to produce negatively skewed strip surface whilst significantly increasing roll life.
Similar results have also be achieved in the 5th stand of the tandem mill, where the roll Ra was reduced from typically 5.5 µm for EDT work rolls to 4.5 µm for PDT™ work rolls to achieve the same rolled sheet Ra and useable roll life was increased by a minimum of 30%. The transfer of Rpc was again 1:1 in the 5th stand of the tandem mill, whereby a work roll Rpc of 55 peaks/cm produces the equivalent on the rolled sheet.

Future Development

There has been a general trend to reduce Ra and increase Rpc on the rolled sheet surface, as this has been shown to improve paint appearance for stochastic type surfaces. On stochastic type surfaces decreasing Ra and increasing Rpc is known to reduce the waviness amplitude on the rolled sheet leading to the improved paint appearance. Equally, it has been shown that for deterministic type surfaces the paint appearance is also improved due to the more regular nature of the surface.
Until the development of PDT™ it has not been possible to accurately and independently control so many of the surface texture parameters. This high degree of control allows the ability to optimize the performance of both the work roll and the rolled sheet for each particular application and rolling process. It is known that different mill types and the different rolled sheet produced require different textures with particular combinations of parameters to optimize performance of the roll and the rolled sheet. The PDT™ process also allows new surface textures to be developed that were not possible to produce with accuracy and repeatability in the past. Such textures may have the following features that have shown to be desirable for good performance during forming and painting in previous investigations;

- Increased uniformity / Reduced Irregularity (Stochastic / Deterministic) of the texture
- Optimum size and ratio of closed voids (Valleys to Plateaus) on the rolled sheet
- Negative skew (More Valleys and less Asperities) on the rolled sheet
- Reduced Ra of the rolled sheet while maintaining formability by improved texture characteristics
- Optimum Rpc to provide sufficient valleys dimensions and good paint appearance
- Reduced Waviness on the rolled sheet for improved paint appearance

Conclusions

In the past there have been a large number of investigations looking at the various aspects of the textured surface on work rolls and its performance. Typically these investigations were limited to considering one or two aspects of the surface texture and the effect on performance of the work roll or rolled sheet for a particular application. With very limited control over the irregular, stochastic type surfaces textures their performance is very sensitive to the parameters of Ra and Rpc. Until the development of PDT™ process it has not been possible to accurately control so many of the surface textures parameters, including the degree of irregularity, to optimize the performance of both the work roll and the rolled sheet.

Abbreviations

PDT™ - Pomini Digital Texturing™
EDT - Electro-Discharge Texturing
EBT – Electron Beam Texturing
SB – Shot Blasting
Ra - Roughness Average
Rpc - Roughness Peak Count
Rsk - Roughness Skew
Wa - Waviness Average.

Acknowledgements

Authors would like to thank the following people who contributed to this paper: Giacomo Zampatti, Ermano Croci and Niraj Kumar.

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