Range and Varieties of a single Surface Structure Technology for Sheet Steel – within and beyond the standard Roughness and Peak Count Values

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Summary

Sheet metal processors specify and order sheet metal by 2d roughness parameters like R_a and R_{pc}. Deep drawing and painting processes can be optimized through certain combinations of steel sheet topography properties. The sheet metal is textured by rolls in the skin passing mill which can be textured with a surface structure technology that forms hard calottes with a stochastic distribution but with an adjustable size and amount. However the mere 2d characteristics are not sufficient to uniquely characterize especially these advanced textures, since topographies with the same R_a and R_{pc} parameters can have vastly varying appearances and may show very different 3d topography characteristics. Therefore measurements of the 3d topography are obtained by a special confocal microscopy setup that provides mobile and automatic roughness measurements in order to get a large amount of measurement data of both cast of rolls and sheet metal. An automatic evaluation system processes the roughness measurement data, computes several roughness parameters like S_a and S_{mr} and uses an image processing method based on the Hough transform to identify each calotte in the topography with its amount and size.

These standardized and not standardized 2d and 3d roughness parameters are then used during process modeling of the work roll galvanizing process and the skin passing process with a transfer function from the roll to the sheet metal in order to independently influence the different topography characteristics and produce the desired sheet topographies according to individual customer requirements. Several possible textures with varying size and amount of the calottes with roughness parameters are shown and discussed. By combining the measurement data with coefficient of friction and paint appearance investigations functional influences of different structures are identified using data mining methods.

Keywords

steel, surface, texture, 3d roughness parameters, skin pass roll, Topocrom®, PRETEX®

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Introduction

There are different work roll texturing methods i.e. electron discharge texturing (EDT), laser and electron beam texturing (LBT, EBT), shot blast texturing (SBT) and Topocrom® [1, 2, 3]. In the analysis described here rolls textured with the galvanic Topocrom® technique (see Fig. 1) are exemplarily investigated.

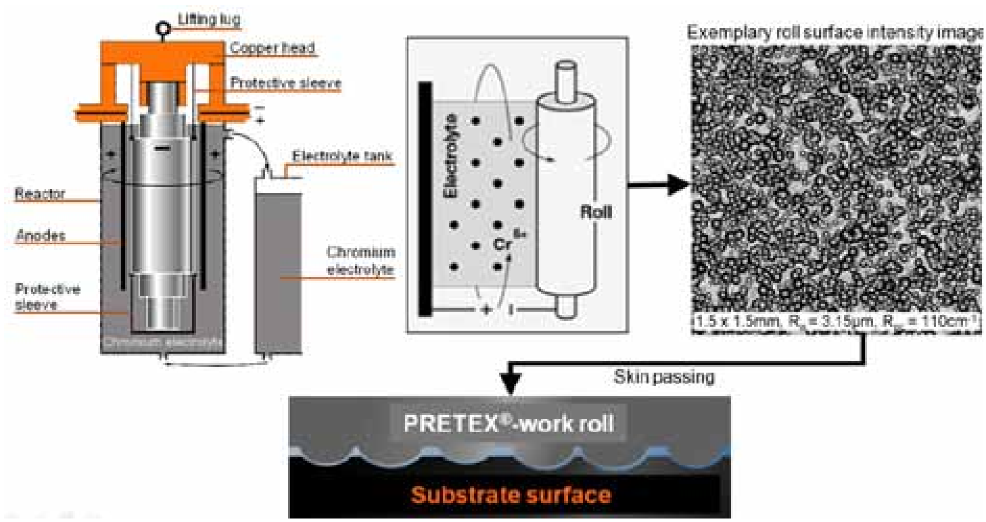


Fig. 1: Schematic sketch of the Topocrom® roll plating process and principle of texture transfer from roll to steel sheet surface during skin passing. Chromium ions are electrolytically deposited on the roll surface where they form the characteristic half dome calottes of the PRETEX® surface texture.

The transfer of the specific topographies from roll to steel sheet surface is realized through skin passing [4, 5]. Skin passing is the deformation of the steel strip with little plastic elongation between 0.1 to 1.8%. Depending on material dimensions, strength and ductility, desired final roughness and work roll diameter and topography different rolling forces have to be applied resulting in different degrees of transfer between 60…120% of the original roll texture to the steel sheet surface.

The density, number and depth of the calottes on the textured steel surface have a direct effect on the steel processor's deep drawing processes [6, 7]. This is due to the specific enclosed surface texture volume where each calotte works as a lubricant reservoir releasing the lubricant during deformation and adjusting local friction properties. Given constant lubricant distribution and deformation conditions steel sheet formability or cracking tendency during deep drawing largely depends on the material's 3d surface properties [6].

The well established 2d roughness (R_a) and peak count values (R_{pc}) are standardized [8] and can be determined with tactile or optical measurement methods. Here both techniques have been applied while the optical confocal approach is mainly used for the 3d surface parameter determination.

In Fig. 2 textures of three rolls are displayed, each has an average roughness of R_a=2.7µm and R_{pc}=107 cm^{-1} but they have a very different amount of calottes. In other words it means that the combination of R_a and R_{pc} values does not describe the surface sufficiently. A possible value to describe the density of the calottes is the S_{mr} value which is described in the next paragraph.

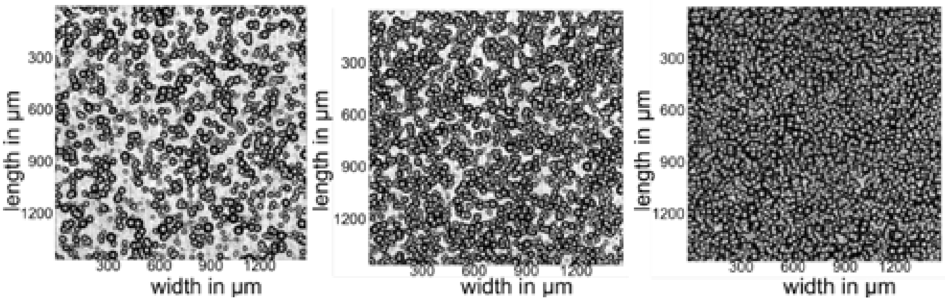


Fig. 2: intensity images (like black and white photography) of three different roll textures with the 2d roughness values R_a=2.7µm and R_{pc}=107 cm^{-1} but very different outlook that can be described with the 3d rougness value S_{mr}: 61%, 39% and 0% (from left to right).

Measurement technique and roughness characteristics

The surface of each skin pass roll is systematically measured and the measurement data and post processing results archived. Therefore, casts (inverse replica) of the rolls are taken and then inspected with an areal roughness measurement device based on confocal microscopy [9] that provides both intensity and roughness images. The casts are being taken in special stencils that can be easily inserted in a holder in the setting of the measurement device. This setup allows an automatic measurement of several casts without the need to operate all the measurements individually by hand. Not only casts of work rolls can be measured automatically but also steel sheet samples. Since the measurement device is designed to be mobile it also can be moved directly to the measurement object.

This measurement device is used only to generate the raw data that is later processed with a series of self developed analysis algorithms based on the Open Source software GNU Octave that is mostly compatible to proprietary MATLAB. This architecture allows easy modifications on the post processing side when needed without having to repeat the measurements. The raw measurement data is automatically collected from the measurement device and then processed to calculate several surface topography characteristics (see below), plotted and saved into a database. A web based front end allows filtering of characteristics and displaying the intensity and roughness images.

Some of the calculated characteristics are:

- S_a (surface average) is the 2d roughness value R_a brought into 3d measurement. It is a single mean roughness value calculated from all the measurement pixels [8]. The higher S_a, the rougher the surface.
- $S_{mr}(c)$ (surface material ratio at a depth of c µm) has also its 2d counterpart $R_{mr}(c)$ [8]. The higher $S_{mr}(c)$, the higher the ratio of materials area to measurement area in this depth c. If e.g. $S_{mr}(c)$ is 40%, it means that 40% of the measured surface is bulk material within this depth c and the remaining 60% is air. The purpose of this characteristic value for the textures analyzed here is to describe how much area is taken by the calottes and how much is still original roll or steel sheet surface. If $S_{mr}(c)$ is 61% (left part in Fig. 3), it means that there is a lot of bulk material and there are few calottes and vice versa. The depth c is calculated for each measurement: it is located at the minimum between the two distribution peaks in the roughness histogram that can be found in most measurements. The thin but mostly high peak represents the roughness of the roll before the texturing and the mostly smaller but wider peak represents the roughness imposed by the roll texture (calottes). The local minimum between these two peaks is evaluated and the S_{mr} value is calculated for this depth position automatically. If this local minimum is found beyond fixed borders, it means that there is no or only a small peak on the right side and the S_{mr} value is set to zero (right part in Fig. 3). By defining c at this depth the S_{mr} value describes the areal density of the calottes for these structures (Fig. 3).

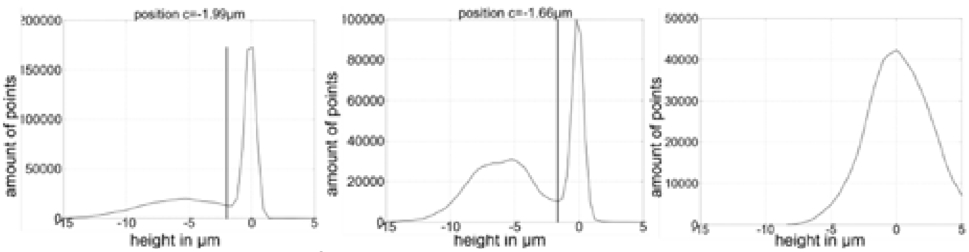


Fig. 3: Roughness histogram of the three measurements in Fig. 2 with the two roughness peaks the minimum at position c (black vertical line) in which the S_{mr} value is calculated: S_{mr}= 61%, 39% and 0% (from left to right).

- K_d (calottes density) are the number of calottes in an 1x1mm² measuring field. The higher K_d gets, the more calottes are existent. This information of the characteristic is similar the S_{mr} value but the S_{mr} value considers the area of the calottes in a special depth whereas K_d the number of calottes describes. Depending on the demands one of these values can be more significant.
- K_r (average calotte radius) is computed of each of the calottes.

The K_d and K_r characteristics are computed using the image analysis method Hough transform. This Hough transform has the ability to find similar features in images, basically simple features like lines [10]. But the Hough transform can also be modified to search more complex features; in this case this method detects the calottes that always have a circular shape. This robust method does also have the advantage that it only needs some parts of the object to be found; this is necessary since the calottes can overlap or be right next to each other with no sharp border between them.

Experiments

Several experiments have been conducted in order to produce very different roll textures. Tribological experiments of sheets of steel after the processes of skin passing and electro galvanization show lower friction coefficients if the sheets of steel have a lower R_a und higher R_{pc} values [5]. In other experiments not only roughness parameters but also different waviness are evaluated: the investigations compare waviness parameters of sheet metal from the process chain of cold rolling, hot dip and electro galvanization, skin pass rolling, deep drawing and ED-painting [11].

The vast variety of independently adjustable surface texture properties that can be realized with the Topocrom® process allow for the production of PRETEX®-type steel sheet surface textures with very specific characteristics that are optimal for all different kinds of applications, deep drawing and ideal paint appearance being two of them. The various textures introduced below and detailed characterization possibilities permit a targeted development and production of established and new surface textures meeting changing customer requirements and needs.

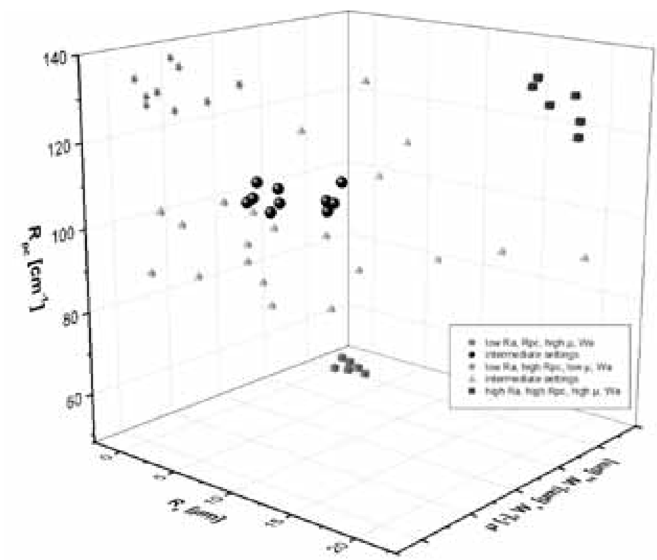


Fig. 4: Exemplary scatter plot showing a selection of possible PRETEX® steel sheet surface texture property combinations. The R_a-, R_{pc}-, waviness parameters W_a, W_{sa} and friction coefficient μ are being compared.

Range of textures

Due to the fact that the galvanizing process that forms the calottes on the rolls can be adjusted by several parameters very different textures can be produced. Some of them are displayed in Table 1:

- few and small calottes,
- several small calottes (first row in Table 1),
- calottes everywhere on the surface (second row in Table 1) and
- few but very big calottes (third row in Table 1).

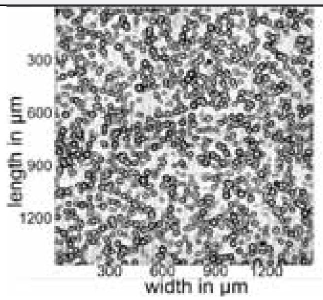
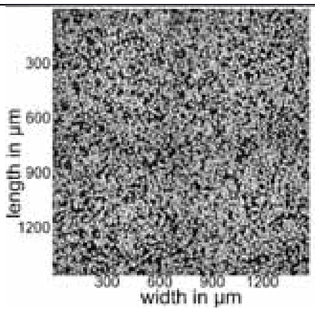
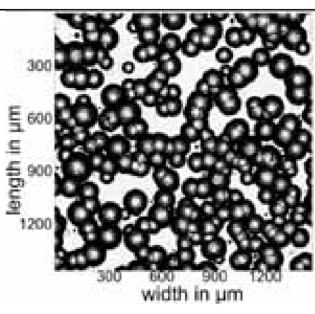
number	intensity images	R_a in μm	R_{pc} in cm^{-1}	S_a in μm	S_{mr} in %	K_d in mm^{-2}	K_r in μm
1		**1.77**	**115**	2.03	62	345	15.6
2		1.45	132	1.2	**0**	**485**	15.4
3		13.4	44	21	0	**166**	**44.5**

Table 1: Small selection of different roll textures with its roughness parameters.

Conclusion

Confocal microscopy allows for measurement of 2d- and 3d-topography properties of work roll and steel sheet surfaces, thus providing necessary quality data for advanced analytics approaches and post processing of the obtained measurement data. The calculated characteristic 2d- and 3d-topography parameters are needed to uniquely describe all possible types of work roll and steel sheet surfaces and begin a targeted specific topography development and optimization. Exemplarily single structured work rolls textured with the Topocrom® process and PRETEX®-textured steel sheet have been characterized and the possibilities and variety of independently adjustable topography properties have been shown.

Through determination of surface material ratio S_{mr}, calotte radius K_r and calotte density K_d the same as standard areal roughness S_a and peak count R_{pc} the basis for unambiguous definition of different work roll and steel surface characteristics has been created. The ability to uniquely describe the resulting surface has led to targeted extra- and interpolation of the roll texturing process and through that allows for application of various well-defined steel sheet surface textures. Different combinations of 2d- and 3d- surface properties have shown to be beneficial for deep drawing and coating results allowing for targeted development of steel sheet topographies matching those exact surface properties.

Currently, textures are being further optimized in cooperation with several car manufacturers to ensure even better deep drawing properties and paint appearance on the final product.

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