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Skin Pass Rolling of High Manganese Steels

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Abstract. Applying a specific roughness on steel sheets, to ensure paintability and sufficient lubrication, is a crucial point for the metal forming processes. Due to the strength of high manganese HSD® steels (X70MnAlSi 15-2.5-2.5), special actions are necessary to obtain the required roughness. At Salzgitter Mannesmann Forschung GmbH skin pass rolling experiments on high manganese HSD® steels with different PRETEX® textured work-rolls were performed to investigate the influence of roll-surface-texture and skin pass rolling force on the roughness transfer. The roughness and texture parameters of the steel sheets and roll surfaces were determined using optical confocal microscopy measurements. It is clearly shown that the work-roll surface texture has a major influence on the roughness transfer from work-rolls to steel sheet surfaces.

Introduction

Different work-roll surface texturing methods are industrially used i.e. electron discharge texturing (EDT), laser and electron beam texturing (LBT, EBT), shot blast texturing (SBT) and Topocrom® (also called electro-chrome deposition (ECD)) [1-3]. The work-rolls used in the present investigations were textured using the galvanic Topocrom® technique (see Fig. 1).

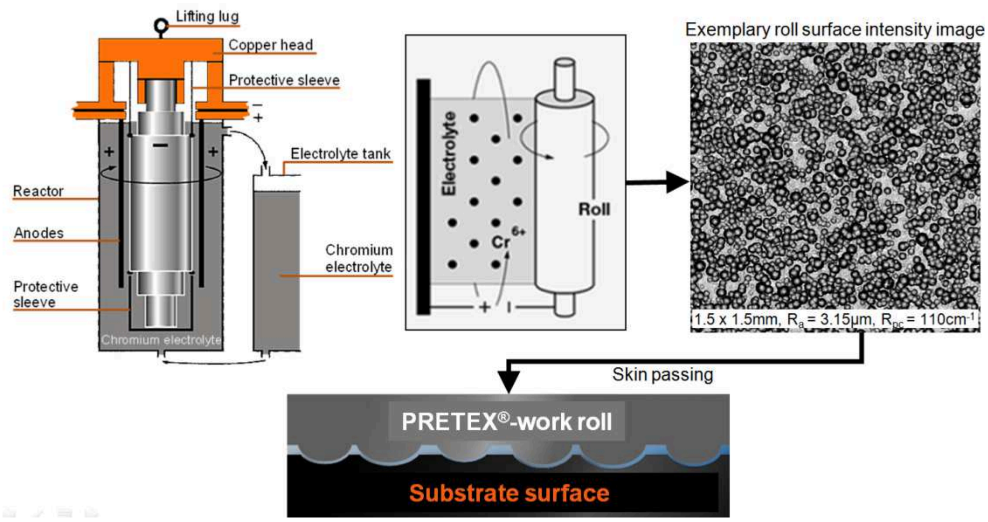

Fig. 1: Schematic sketch of the Topocrom® roll plating process and the principle of texture transfer from roll to steel sheet surface during skin passing. Chromium is electrolytically deposited on roll surfaces where it forms the characteristic half dome calottes of the PRETEX® roll surface.

The transfer of the specific topographies from roll to steel sheet surfaces is realized through skin passing [4]. Skin passing or temper rolling is the deformation of steel strips with small plastic deformations between approximately 0.1 to 2 %. The actual sheet roughness depends on a variety of parameters, e.g. the material dimensions, strength and strain hardening coefficients, the work-roll diameter and surface texture and especially the rolling forces. Recent literature on roughness transfer in skin pass rolling mainly deals with electron discharge textured rolls and carbon steel as sample material [5-11]. In contrast, the present investigation uses a Topocrom® textured roll set to transfer roughness to HSD® steel, a high manganese second generation advanced high strength steel.

Roughness Characteristics

To characterize the surface roughness well-established and standardized parameters such as average roughness (R_a, S_a) and peak count (R_{Pc}) as well as the self-developed and not standardized characteristic calotte density (C_d) were used [12]. R_a and R_{Pc} were determined with tactile measurements, S_a and C_d by means of optical confocal microscopy measurements.

In Fig. 2 textures of three roll surfaces are shown, each having an average roughness (R_a) of 2.7 µm and a peak count (R_{pc}) of 107 cm^{-1}. As it is clearly visible, the surfaces differ significantly in the number of calottes per unit area, which can be expressed with the calotte density C_d (calottes per mm^2). This means that the same set of work-roll roughness parameters R_a and R_{pc} can be achieved while having different calotte densities. Surfaces bearing low densities of calottes (Fig. 2 a)) are denoted as "*open structure*", whereas surfaces with high densities of calottes (Fig. 2 b)) are denoted as *"closed structure"*.

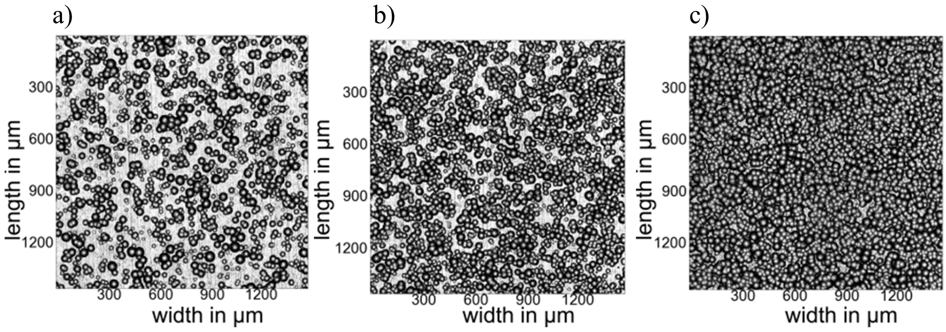

Fig. 2: Intensity images of white light microscopy of three different roll textures with the same 2d roughness values R_a=2.7µm and R_{pc}=107 cm^{-1} but different calotte densities. a) C_d = 241 mm^{-2}, b) C_d = 297 mm^{-2}, c) C_d = 370 mm^{-2}

Measurement Technique

The surfaces of the skin pass rolls and steel sheet samples were measured automatically. Therefore, roll surface replicas were taken and then inspected with the 3-dimensional roughness measurement device *µsurf mobile* from the company *Nanofocus*, which is based on confocal microscope [13]. The confocal microscope is used only to generate the intensity and roughness image raw data that are later processed with a series of self developed analysis algorithms based on the open source software GNU Octave. This architecture allows easy modifications on the post processing side, when needed, without having to repeat the measurements. The raw data are automatically collected from the measurement device and then processed to calculate several surface topography characteristics (see below), plotted and saved into a database. A selection of the calculated roughness parameters is given in the following list:

- $\mathbf{S_a}$ (surface average) is the 2d roughness value R_a brought into 3d measurement. It is the mean roughness calculated from all the measurement pixels. The higher S_a, the rougher the surface.
- $\mathbf{C_d}$ (calottes density) is the number of calottes in a 1x1mm² measuring field. The higher C_d gets, the more calottes exist.

The C_d characteristic is computed using the Hough transform image analysis method. The Hough transform has the ability to find similar features in images, basically simple features like lines. However the Hough transform can also be modified to search for more complex features [14]; in this case, the method detects the calottes that always have a circular shape. This robust method also has the advantage that it only needs some parts of the object to be found, which is necessary since the calottes can overlap or be right next to each other with no sharp border between them.

Material

The sample materials used in this investigation and their mechanical properties are given in Table 1. The micro-alloyed steel HC340LA was supplied as a well deformable, lower strength reference material.

Table 1: Sample materials used in this investigation. $R_{p0,2}$ /R_{el} = yield strength, R_m = tensile strength, A_{80} = elongation at fracture, n-value = strain hardening coefficient

	HSD®600	**HSD®900**	**HSD®1100**	**HC340LA 1.0548**
$R_{p0,2}$ [MPa]	620	920	1100	-
R_{el} [MPa]	-	-	-	360
R_m [MPa]	1000	1150	1250	423
A_{80} [%]	50	30	17	30
n-value	0.36	0.19	-	0.19
thickness [mm]	1.3	1.3	1.3	1.4
Sheet roughness S_a [µm]	0.18	0.15	0.24	0.14

In all experiments sheet material with a width of 250 mm and a length of 1000 mm was used and no lubricants were applied.

Laboratory Rolling Mill

All experiments were carried out on the laboratory cold rolling mill at Salzgitter Mannesmann Forschung GmbH in Salzgitter. The rolling forces of the 250 mm wide HSD® sheets were between 300 kN and 2400 kN and were kept constant during each skin pass rolling trial. However, in further discussions the normalized specific rolling force (force per meter sheet width) will be used. Technical details of the laboratory cold rolling mill are given in Table 2.

Table 2: Technical details of the laboratory cold rolling mill

roll diameter [mm]	sheet width [mm]	sheet speed [m/min]	max. rolling force [kN]
330 - 360	100 - 300	used: 6 max: 60	5500

The PRETEX® texturing of the work-roll pair was carried out at the company TOPOCROM® (see Fig. 1). Both rolls were coated with the same average roughness S_a but with different calotte densities, which resulted in one roll having an open and one roll having a closed PRETEX® surface structure (see Fig. 2). The roughness parameters of both rolls are given in Table 3.

Table 3: Work-roll roughness parameters: S_a = average roughness, C_d = calotte density

surface structure type	S_a [µm]	C_d [mm^{-1}]
open	3.3	220
closed	3.3	290

Experimental Results

In this study, skin pass rolling experiments on high manganese HSD® steels with different PRETEX® textured work-rolls were performed to investigate the texture and rolling force influence on the roughness transfer. The texture was altered so that the work-rolls had the same average roughness S_a but different calotte densities C_d. Through this, open and closed PRETEX® structures were formed on the work-roll surfaces (see Fig. 2 and Table 3). The results of the skin pass experiments are summarized in Figs. 3 and 4. In these figures the average sheet roughness S_a and the roughness transfer from work-rolls to sheet surfaces are given as a function of the applied specific roll forces (force per meter sheet width).

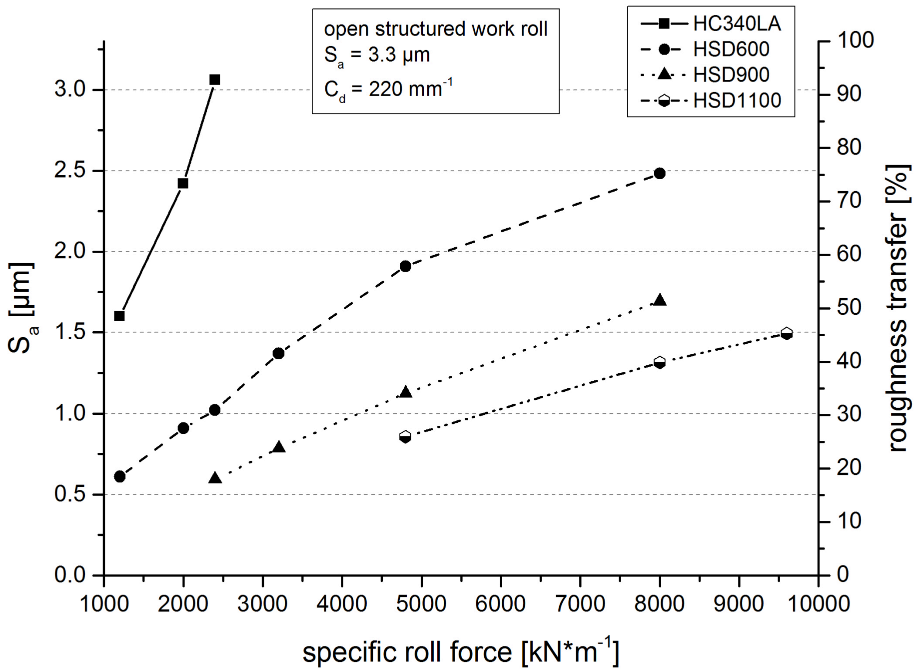

Fig. 3: Results of skin pass rolling experiments using a work-roll having an open surface structure with a calotte density C_d of 220 mm^{-1}. The average roughness S_a and the roughness transfer as a function of the specific roll forces are shown.

Figs. 3 and 4 show, particularly for the set of HSD® steels, that the roughness transfer at a given rolling force decreases with increasing yield strength. This is true for both open and closed PRETEX® textured work-rolls. As an example, the average roughness and the roughness transfer at a specific rolling force of 4800 kN/m for the open structured roll will be considered. Using this rolling force, roughness transfers of about 60 % for HSD®600, 35% for HSD®900 and 27 % for HSD®1100 were achieved, resulting in an average roughness of 1.9 µm, 1.1 µm and 0.9 µm, respectively. Depending on the specific roll force, the overall applied average roughness S_a for HSD steels varied between 0.6 µm and 2.5 µm for the open structured work-roll and between 0.4 µm and 1.9 µm for the closed structured work-roll.

The major goal of the present skin pass rolling trials was to investigate the influence of the work-roll PRETEX® texture on the roughness transfer to high manganese steels. A comparison of the roughness transfer values in Figs. 3 and 4 show that the open structured work-roll does in all cases transfer a higher ratio of its roughness to steel sheet surfaces.

A numerical comparison is listed in Table 4, where the ratios of roughness transfer values for the open and closed structured work-rolls were calculated as a function of the specific rolling forces. For example transfers the open structured work roll 35.6 % of its roughness to a HSD®900 steel sheet at a specific rolling force of 4800 kN/m, whereas the closed structured roll transfers 19.6 % (see Figs. 3 and 4). The ratio of these roughness transfer values is 35.6 % / 19.6 % = 1.82 which is equivalent to an increased roughness transfer of 82% for the open structured work roll (assuming that the transfer value for the closed structured roll corresponds to 100 %).

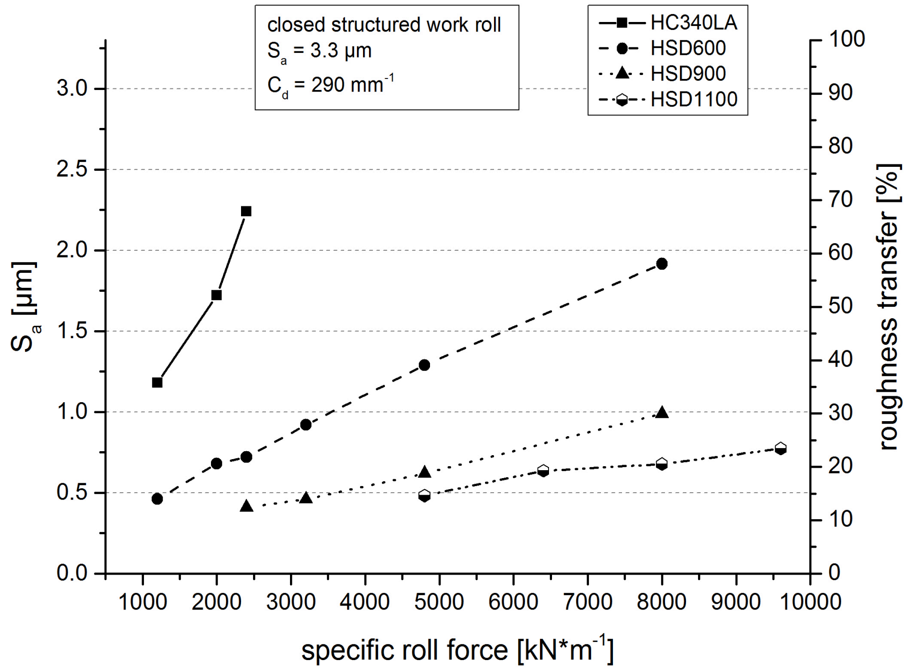

Fig. 4: Results of skin pass rolling experiments using a work-roll having a closed surface structure with a calotte density C_d of 290 mm^{-1}. The average roughness S_a and the roughness transfer as a function of the specific roll forces are shown.

The calculations show that increases in roughness transfer up to 94 % were achieved when shifting from a closed structured work-roll to an opened structured one. The higher transfer values can be attributed to the fact that open structured rolls have fewer calottes on their surfaces which leads to higher specific forces per calotte during skin passing compared to closed structured rolls.

Table 4: Ratios of roughness transfer values of open and closed structured work-rolls as a function of the specific roll forces (see Figs. 3 and 4). In all cases, open structured rolls transfer more of their roughness to steel sheets surfaces. See text for explanation.

	ratios of roughness transfer values for (open /closed) work-roll structures			
specific roll force [kN*m^{-1}]	**HC340LA**	**HSD®600**	**HSD®900**	**HSD®1100**
1200	1.36 (47.8% / 35.1%)	1.33 (18.3% / 13.8%)		
2000	1.42 (72.6% / 51.3%)	1.35 (27.3% / 20.2%)		
2400	1.38 (91.7% / 66.6%)	1.42 (30.6% / 21.5%)	1.46 (18.8% / 12.9%)	
3200		1.49 (41.0% / 27.5%)	1.70 (24.8% / 14.6%)	
4800		1.58 (60.5% / 38.4%)	1.82 (35.6% / 19.6%)	1.77 (27.1% / 15.3%)
8000		1.29 (78.6% / 60.7%)	1.71 (53.6% / 31.3%)	1.94 (41.6% / 21.5%)
9600				1.93 (47.3% / 24.5%)

Summary

Using the PRETEX® process roughness parameters of skin pass rolls can be alter within wide limits (see Fig. 1 and 2). Roll surfaces can be adjusted so that they have the same average roughness (R_a/S_a) and peak count (R_{Pc}) values but different coverage of PRETEX® chromium calottes. Through this open and closed work-roll structures are accessible (see Fig. 2).
Roughness values of steel sheets and roll surfaces can be optically determined using confocal microscopy measurements. In the series of high manganese HSD® steels the roughness transfer from work-roll to steel sheet surfaces decreases with increasing material yield strength. The roughness transfer is significantly influenced by the work-roll texture. Open structured work-rolls transfer a higher ratio of their roughness to steel sheet surfaces compared to closed structured work-rolls. Increases of roughness transfers up to 94% could be achieved.

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