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A generic model for surface texture development, wear and roughness transfer in skin pass rolling

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ABSTRACT

This paper describes the development and validation of a model describing the contribution of individual processing steps on the surface aspect of a skin passed steel strip surface validated by including microscopic analysis of the texturing process, the roll wear and roughness transfer during strip finishing. The presented work couples a fundamental model of the topology of a work roll surface based on literature and experimental observations alike for electro-discharge texturing. Simplified wear and imprint models, based on bearing area, are also discussed to replicate roll wear and roughness transfer during temper rolling. The model can provide topological quantification of roughness, peak counts and waviness for various fresh roll surface textures, and worn roll surfaces as well as the resultant imprinted strip surface.

1. Introduction

Within the steel-making industry, the surface aspect of galvanised steel for outer body parts for the automotive industry is currently one of the most demanding and quality-critical development areas. The surface finish of a galvanised steel sheet has a direct relationship with end-user paint usage [1,2], paint appearance [3,4] and product formability [5,6,7]. It is common practice that the surface finish is transferred in the skin pass, or temper rolling section of the galvanising process from a textured roll to the galvanised strip [8,9,10]. There are several methods available to the steelmaker in order to apply texture to a roll such as electro-discharge texturing (EDT) [11], electron-beam texturing (EBT) [6,12], laser texturing (LT) [13] or electro-chrome deposition (ECD) [14]. While the needs of the end product and aims of the skin pass process are well understood, the understanding of the processes involved to produce the desired surface aspect on the product is less evolved. Processes involved are texturing of the rolls, the wear of these rolls upon use and the temper rolling process that transfers the roll texture to the strip. Additional processes that affect the galvanised steel surface finish are the hot dip galvanising process that delivers the virgin surface to be textured and auxiliary processes such as chrome plating of rolls. The lack of understanding is in part caused by the complexity of the individual processes and their interactions. In addition, the vast majority of information is obtained from empirical and process-specific examples not suited for the generalisation of concepts. Steinhoff et al. [15] focus on EBT to assess roughness transfer characteristics by FE simulation. Their simulations indicate that the degree of roughness transfer was about 92% at an elongation of 1.06%. At the higher elongations the roughness transfer is characterised by the reverse extrusion of the rolled substrate into the individual EBT rings. The other process that results in roughness transfer is penetration of the work roll texture into the strip. These processes can act in parallel; however, due to the nature of EDT texture, with far less closed voids on the roll surface, the reverse extrusion process is significantly less likely to occur. Thus the roughness transfer is almost entirely the result of penetration of the work roll texture.

Representative texturing and roughness transfer trials are hampered by reproducibility and process stability issues and are generally costly and time-intensive. Typically, industrial texturing apparatus are only found in working factories, full-size work rolls are required as a base substrate for sample preparation and plant time for temper rolling are all required to administer a full trial. To overcome such empirical limitations a generic model has been developed aimed at optimisation of strip surface finish including roll texturing, roll wear and roughness transfer models. The aim of presented research is thus to develop a model that is both generic and modular such that the model is not only relevant to processing of galvanised steel strip but can be simply modified for other flat rolling or imprinting procedures. For this reason, an approach

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considering wear and roughness transfer by bearing area is thus chosen [16,17]. This method also describes well the concept of roughness transfer and wear without being material or process specific.

In this paper, first the experimental results are provided on which sub-models for roll texturing, roll wear and roughness transfer are based. Then the sub-models used for this study are detailed. Eventually, results obtained by applying these sub-models in a generic model are presented and discussed.

2. Material and methods

2.1. Texturing experiments

The roll surface used in this work is inspired by EDT surface textures. This texturing method is chosen as it is available both for industrial scale rolls as well as for laboratory scale specimens. The roll surface texture is calculated from a number of basic assumptions of the EDT process itself in combination with some experimental observations. In order to validate the model, a series of experiments and characterisations have been undertaken. These experiments incorporate electro-discharge texturing and have been designed to fabricate “standard” and “enlarged” craters. The texturing equipment used in these trials is manufactured by Waldrich-Siegen in which the work piece is submerged in a bath of commercially available dielectric fluid [18]. During the texturing procedure, the work-piece is rotated about its axis together with an axial oscillation. Using this equipment pilot mill work rolls are textured. Prior to texturing experiments, the rolls were finished to a ground Ra of 0.3 ± 0.05 μm. No chrome plating of the rolls has been undertaken post-texturing.

2.2. Rolling experiments

A series of laboratory skin pass rolling trials were then performed on a Fröhling rolling mill which can be used for (cold) rolling of steel and aluminium. The main processing limits of the mill are: speed: 0.1–20 m/s, strip thickness range: 0.02–3.0 mm, rolling force < 1800 kN, strip tension force 0.5–50 kN, strip width: 50–250 mm and coil weight up to 1250 kg. The rolling stand is of either 2-high or 4-high configuration and the rolling process can be lubricated by virtue of a re-circulating emulsion system, or in combination with a (single use) direct application system.

Trials were performed using the 2-high configuration, utilising 400 mm diameter 3% Cr steel work rolls of 63 Rockwell C nominal hardness. The rolling trials were performed under equivalent lubrication conditions (roll cooling by water only with a flow rate of 20 l/min) and the rolling speed was 2 m/s, being typically representative of skin pass rolling speeds in continuous hot dip galvanising lines. The strip being rolled was 0.7 mm thick, annealed and hot dip galvanised (HDG) interstitial free (IF) TiSULC steel (DX54) and was of 220 mm width. Each coil was 1.25 km in length. The zinc coating weight was 55 g/m^2 per side. Rolling conditions were a constant rolling force (specific rolling force see Table 1) and nominal strip entry and exit tension forces of 7.5 kN. The rolling process was elongation controlled and when needed the exit tension force was used to maintain constant elongation (elongations see Table 1). Rolling conditions were such that the neutral point remains inside the arc of contact, which is representative for industrial skin pass rolling of this material.

In order to validate the numerically derived observations in roughness transfer by bearing area, skin pass rolling experiments were performed where a work roll surface was indented to create a surface identification marker. Post-rolling, the strip was cut and analysed around the indentation marks such that the original roll surface could be correlated precisely with the strip surface.

2.3. Surface characterisation methods

Roughness parameterisation and measurement (Simulated and Empirical)

- In simulated surface texture parameterisation, values have been determined from tracks of 48 mm length. The longest wavelength included within this study is 8.0 mm. For this reason, after Gaussian filtering, the central $(48-8)=40$ mm of the tracks can be used for analysis of texture parameters.
- All simulated surface texture parameters reported are averages of 9 tracks (except for Fig. 12, which is only calculated for 1 track/point). Representative standard deviations are shown in Fig. 15.
- Ra and RPc are calculated with a long cut off wavelength of 2.5 mm and for RPc slice levels of ± 0.5 μm have been used (according to the EN 10049:2005 norm for measurement of Ra and RPc on metallic flat products).
- Wa is calculated with short cut off wavelength 0.8 mm and long cut off wavelength 8.0 mm.
- Track- and cut off lengths used in roughness and waviness experiments and in simulations are identical unless specifically mentioned.

Where actual roughness and peak count values are provided, the Ra and RPc values are calculated as average of 5 tracks. Strip roughness measurements are made using a BMT (Breitmeier Messtechnik GmbH) skidless stylus device with a measurable height range of ± 200 μm. A track length of 56 mm is used for Wa measurements. After filtering, the central 40 mm is used for waviness evaluation. In addition, confocal microscopy (Nanofocus μsurf mobile) has been undertaken in-situ on roll bodies and in laboratory environments on strip materials and work roll replicas. The work roll replicas were prepared using Kulzer Technovit 3040. Software μsurf version 6.1 and MountainsMap version 4.1 have been used to analyse the resultant confocal images.

Table 1
Process and roughness parameters of the freshly textured roll, worn roll and rolled strip. Note that the waviness is measured with a cut off of 2.5–8.0 mm, rather than 0.8–8.0 mm elsewhere in this study.

	Length rolled (m)	Specific rolling force (kN/mm)	Elongation (%)	Ra (μm)	RPc (cm^{-1})	Wa (2.5–8 mm) (μm)	Reference in text
Strip (before rolling)	–	–	–	0.48	16	0.32	–
Roll (fresh)	0	–		2.90	74	0.64	Figs 5–7
Roll (worn)	2500	–		2.47	72	0.61	Figs 6 and 7
Roll (worn)	4000	–		2.41	71	0.59	Figs. 6–8 and 14
Strip	4500	0.80	1.3	0.85	30	0.18	Figs. 9 and 14
Strip	5000	1.45	2.5	1.36	56	0.35	Figs. 9 and 14
Roll (worn)	5000	–		2.22	66	0.58	–