Applied Mathematical Modelling 39 (2015) 7326–7337

Contents lists available at ScienceDirect

Applied Mathematical Modelling

journal homepage: www.elsevier.com/locate/apm

Simulation algorithm for automotive steel sheet texture formation in temper mill

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ARTICLE INFO

Article history:
Received 2 April 2014
Received in revised form 26 February 2015
Accepted 5 March 2015
Available online 19 March 2015

Keywords:
Surface texture (microtopography)
Roughness
Automotive steel sheet
Temper rolling
Simulation
Linear system

ABSTRACT

The article presents a simulation algorithm for surface texture formation processes during tempering of automotive steel sheet as function of the surface texture of work rolls and semi-finished rolled product (initial material). The process of temper rolling is simulated as a linear system with several inputs and one output. Description and validity of the algorithm along with simulation results in comparison with experimental data are covered.

1. Introduction

Presently, the surface quality of cold-rolled sheet and particularly its texture (microtopography) are the most critical criteria for many consumer goods' manufacturers. Over 20 quality parameters of sheet surface like formability, weldability, coating adhesion, coating material consumption, etc., are directly related to sheet surface texture [1,2]. Given these facts, manufacturers of automobiles and white goods (refrigerators, microwave ovens, etc.) impose the ever-increasing requirements on producers of cold-rolled steel sheets regarding the surface texture [3,4].

Generally, most of consumers of automotive steel sheets specify such surface texture parameters as amplitude characteristic *Ra* and frequency characteristic *RPc* [5].

Amplitude characteristic *Ra* shows a mean deviation of ordinate values of the assessed profile from a mean line, and for finite digitized profiles it can be calculated as follows [6]:

$$Ra = \frac{1}{N}\sum_{i=1}^{N}|Z_i|.$$

where N is a number of data points.

Frequency characteristic *RPc* shows a profile peak count per unit length (1 cm). Peak is a profile irregularity which consecutively intersects the preset lower and upper section lines. The section lines are drawn parallel to and equidistant from a mean line [6].

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http://dx.doi.org/10.1016/j.apm.2015.03.010

In automotive engineering, the vertical distance between the section lines and the profile mean line is set to $c_1 = +0.5$ μm and $c_2 = -0.5$ μm [5,7].

RPc is an empirical characteristic which is useful in view of its relation to performance parameters and appearance of a surface (glossy, matte, rough).

A more precise functional characteristic of surface profile irregularity is the autocorrelation function (*ACF*) and its numerical estimation, i.e. a correlation length τ.

The autocorrelation function (*ACF*) of a finite digitized profile can be calculated as follows:

$$ACF(\tau) = \frac{1}{Rq^2}\frac{1}{(N-j)}\sum_{i=1}^{N-j} Z_i Z_{i+j},$$

where $\tau = jd$ is a shift distance, d is a profile sampling interval.

Rq is a root mean square deviation of the assessed profile within a sampling length and measured from the mean line [6].

A correlation length τ is the distance where the autocorrelation function decreases to a preset value. This value is commonly assumed to be 1/e (the base of the natural logarithms), and the correlation length is usually designated as τe. Parameter τe characterizes a random component of the surface profile.

A pronounced profile irregularity corresponds to higher values of *RPc* and lower values of τ.

In iron and steel industry, finishing of steel flats (i.e. automobile-body sheet and black plate) is performed in temper mills with relatively small reductions (about 0.5–2%), at low temperatures (about 15–30 °C) and high rolling speeds (about 5–10 m/s) using rolls with previously prepared surface. The main purpose of temper rolling is not to change sheet thickness but to provide material with required mechanical properties such as mechanical hardening, etc. Temper rolling can also provide required surface texture, namely, micro- and macrotopography of sheet surface (i.e. roughness, waviness and lay) [2,8–12].

In practice, a method of imprint coefficients is widely used to predict the topography characteristics of a tempered strip [13,14]. Imprint coefficients are experimentally estimated for every rolling pattern. These make it quite easy to predict the topography characteristics of a tempered strip (Ra_{TS}) based on topography characteristics of initial strip (Ra_{IS}) and work rolls (Ra_{WR}) as follows:

$$Ra_{TS} = k_1 Ra_{WR} + k_2 Ra_{IS}$$

The issues concerning determination and calculation of imprint coefficient K_{Ra} by *Ra* parameter are well-covered in works of Mazur V.L. (e.g. [11]). Some challenging works on the subject matter were made by Garber E.A., Salganik V.M., Rumyantsev M.I. and others.

In view of new requirements to surface texture regarding *RPc* characteristic it was found that the issue of determination and calculation of imprint coefficient K_{Pc} is studied poorly [13,15–17]. Thus, the challenge is how to predict the resulting *RPc* and *Ra* characteristics of tempered strip (TS) with known surface texture of initial strip (IS) and work rolls (WR).

It is well known [2,9,10] that *ADF* and *PSD* are independent for processes with a prevailing random component. Therefore, to predict frequency characteristics of rough surfaces one should use mathematical tools that differ from those used for prediction of amplitude characteristics.

For this reason, a new complex approach to simulation algorithm for automotive steel sheet texture formation in temper mill is suggested to be taken: (1) the use of imprint coefficients to predict amplitude characteristics *Ra* or *Rq* (numerical estimates of functional characteristics like Bearing Area Curve (*BAC*) and Amplitude Density Function (*ADF*)); (2) the use of transfer functions to predict frequency characteristics *RPc* or τe (numerical estimates of functional characteristics like Power Spectral Density (*PSD*) and Autocorrelation Function (*ACF*)).

In order to determine the transfer functions, the authors suggest describing the process of transferring the frequency characteristics of WR's surface topography onto TS's surface as a system with several inputs and one output.

2. Material and methods

2.1. Sampling volume

Arrays of roughness profiles obtained in two separate experiments on Temper Mill 2500 at MMK, OJSC (Magnitogorsk, Russia) served as initial data for simulation. Profiles of ISs, WRs and TSs were measured in several areas of surfaces in each experiment after the 1st, 3rd and 5th coils tempered. The total amount of profiles and areas of measurement are presented in Tables 1 and 2.

As a result, 18 profiles of IS and 18 profiles of TS (left, middle and right parts of top and bottom surface, 3 profiles per measuring area) were obtained for each tempered coil. In the 1st experiment, 12 profiles of WR (left, middle and right parts of top and bottom rolls, 2 profiles per measuring area) were determined. In the 2nd experiment, 6 profiles of WR (left, middle and right parts of top and bottom rolls, 1 profile per measuring area) were obtained.