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**Abstract**

This paper introduces a new assessment technique to monitor the quality of coated steel sheet surfaces, mainly used in the construction industry, e.g. as cladding for commercial buildings, external surface composite panels or even domestic applications, so clearly the visual appearance is critical. Normally, these types of steel sheets are coil coated onto steel strips. After curing the coating is soft, when it has cooled to approximated 60 °C it can be embossed with a pattern by application of pressure by a roller with the appropriately pattered surface. After embossing and further cooling the coated strip can be coiled and stored. However during the storing process the weight of the coil (of the order of several tonnes), can damage the soft surface by creating visible pressure marks. Sometimes the surface will relax back to the original embossed shape some time after the pressure has been relieved or with the help of heat treatment. On occasion however the surface does not recover and a visual defect remains, which leads to customer rejection.

In this paper, a new way to characterize coated surface of steel sheets, which combines wavelet filtering [1] with decomposed numerical analysis techniques [2] is presented. The wavelet filtering is based on complex wavelet, and it has very good metrological characteristics in the scale domain and provides shift-invariance and directions sensitive properties. In this research, this wavelet model is used to extract the information of structured texture of coated steel surfaces within the original emboss. The decomposed numerical description is used to qualify the variation phenomena of surface texture during storage and transportation. The results can be feedback to steel industry to significantly improve their coating techniques, storage and transportation.

**Keywords:** Wavelet filtering, decomposed numerical analysis, surface texture

## 1. Introduction

Coated steel products are used widely in the construction industry due to their decorative appearance and the fact that the coating protects the underlying steel from the effects of environmental corrosion. The manufacturing process involves coating steel sheet with a polymeric material. During processing the polymer is well above its glass transition temperature however, when the temperature reaches approximately 60 °C a texture can be roll embossed on the surface of the coating using a suitably textured roller. The coating form is defined by the roller texture and is usually of a visually appealing form. See Fig. 1. During storage and transportation of the sheet "flat spots" can appear in the coated surface due to high spot loading caused by the weight of the coils which is of the order of several tones and these flattens zones are easily detectable to the human eye and can thus lead to the rejection of large batches of coated rolled coil.

This paper seek to develop a measurement technique which can detect he first signs of flat spotting and can shed more light on the origin of the problem. Following initial areal surface metrology and analysis a hypothesis concerning the development of the damaged surface was developed.

• The back (or rear) side of the sheet metal is pressing the polymer coated surface, reducing the depth of the large embossed pits.

• Additionally the back (or rear) side of the sheet metal is imparting its own roughness into the existing roughness of the polymer coating surface hence increasing the "plateau" roughness.

To prove the hypothesis, there was a need to effectively separate the long wavelength features of the surface (the large pits) from the small wavelength features of the surface roughness.

## 2. Wavelet analysis

Discrete wavelet transform (DWT) can provide multi-scalar analysis, which has been used for filtering engineering surface data. The orthogonal wavelets used for the extraction of roughness of engineering surfaces are not linear phase filters (asymmetric filter) and lead to phase distortion in filtering. Biorthogonal wavelet filtering for engineering surface analysis is capable of obtaining linear phase characteristics. To reduce the complexity of the algorithm for biorthogonal wavelet transformation and overcome boundary distortions, the second-generation biorthogonal wavelet transforms using the 'lifting scheme' were proposed and applied to engineering surface analysis. The lifting scheme of the cubic spline wavelet have been standardised by ISO/TC213 as the standard wavelet filter for profile analysis. However, the DWT is still hampered for use in many applications, especially for the areal surface analysis, due to the lack of shift invariance, which means small shifts in the input signal can cause major variations in the distribution of the energy between DWT coefficients at different scales. Hence, it the characterization results are dependent on the measurement frame [1, 2].

A novel Dual-Tree Complex Wavelet Transform (DT-CWT) representation was thereby previously proposed for the separation and extraction of different components of engineering surfaces. The DT-CWT can provide approximate shift-invariance property and improved directional selectivity. Zero/linear phase property of DT-CWT ensures that the filtering results have no distortion and good feature localization ability. The 'steep transmission curve' property of the amplitude transmission characteristic enables the DT-CWT to separate and extract different frequency components of surfaces more accurately [1, 3].

By using two parallel fully-decimated trees, which are subsampled differently and are both real wavelet transform respectively, the DT-CWT can achieve perfect reconstruction and very nearly shift invariant. The main approach of DT-CWT operation is to use two-channel filter banks in the real and imaginary parts The scale coefficients and wavelet coefficients (or approximations and details) for the two trees are denoted respectively ($a^a, d^a$) and ($a^b, d^b$).

The filters are the same in the two trees for level one and different for other levels. For levels above one, a Q-shift filter design technique based on the Z-transform theory of linear time invariant sampled systems is used to construct the lowpass FIR filter to satisfy a linear-phase and perfect reconstruction condition.

For one dimensional discrete surface profile data $f(x)$, the DT-CWT can replace it with two series: $a_J^a, d_J^a \cdots, d_1^a$ and $a_J^b, d_J^b \cdots, d_1^b$, which can be interpreted as the real and imaginary parts of the complex process: $a^C = a^a + ia^b$, $d^C = d^a + id^b$ (where $i = \sqrt{-1}$) After $J$ levels decomposition, it can be expressed by:

$$W_J[f(x)] = \left(a_1^C, d_1^C\right) = \left(a_2^C, d_2^C, d_1^C\right) = \left(a_J^C, d_J^C, d_{J-1}^C, \cdots, d_1^C\right)$$

where $J$ denotes the coarsest scale, $a_J^C$ and $d_j^C$ refer to the complex smooth coefficients at level $J$ and the complex detail components of coefficients at the level $j$, respectively.

For two dimensions, the surface areal data $f(x, y)$ can also be decomposed and reordered into 4 interleaved trees A, B, C, D, by using the separable filter bank technique. The approximations and details of the 4 trees are denoted respectively ($a^a, d^a_{hg}, d^a_{gh}, d^a_{hh}$), ($a^b, d^b_{hg}, d^b_{gh}, d^b_{hh}$), ($a^c, d^c_{hg}, d^c_{gh}, d^c_{hh}$) ($a^d, d^d_{hg}, d^d_{gh}, d^d_{hh}$). Where, the subscript $hg$, $gh$, $hh$ refer to the different combination of lowpass and highpass filter on the rows and columns. At each level, the approximation coefficient can be expressed by four real coefficients ($a^a, a^b, a^c, a^d$). For each suband, the details $d^a, d^b, d^c, d^d$ can be interpreted as the real and imaginary parts of two complex processes $d^+$ and $d^-$:

$$d^+ = (d^a - d^d) + i(d^b + d^c) \qquad d^- = (d^a + d^d) + i(d^b - d^c)$$

Thus, the details of the 3 subbands provide 6 complex subbands, instead of 3 real subbands as in the real case. After $J$ levels decomposition, the surface areal data $f(x, y)$ can be replaced with:

$$W_J[f(x,y)] = \left(a_1^C, d_1^C\right) = \left(a_2^C, d_2^C, d_1^C\right) = \left(a_J^C, d_J^C, d_{J-1}^C, \cdots, d_1^C\right)$$

where, $d_j^C = (d_j^{-15^0}, d_j^{+15^0}, d_j^{-45^0}, d_j^{+45^0}, d_j^{-75^0}, d_j^{+75^0})$

In the present study the DT CWT technique was applied to the coated sheet steel product in order to separate the longer wavelength features (the large pits) from the short wavelength features (i.e. the small scale local features of the emboss.

## 3. Measured results

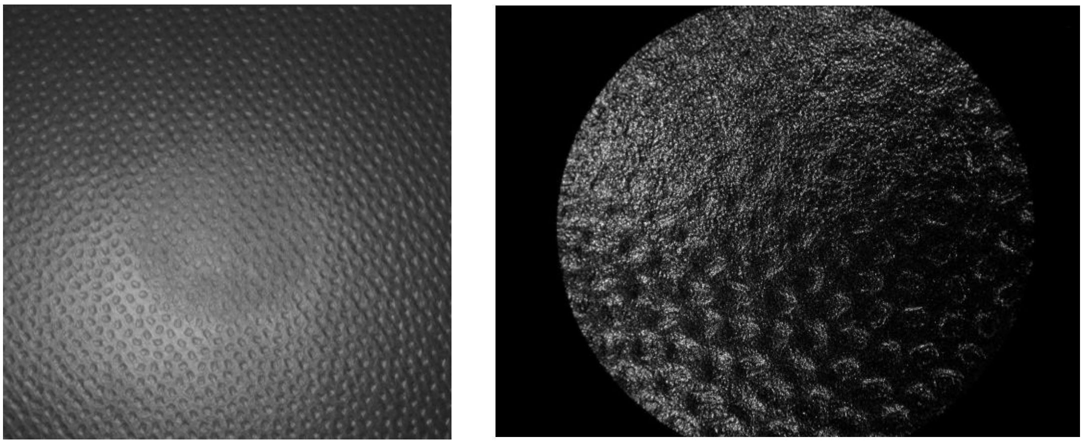

Fig. 1. a) Optical image of damaged zone; b) zoomed image on damaged region boundary.

In order to study the effects of the pressure spots undamaged sample sheets were pressed under controlled conditions designed to simulate the storage and transport conditions of the sheet. The applied loads used were consistent with those observed in storage and transport of the coils. The “damaged” was limited to a small area in order to isolated the pressing effect.

All the surfaces were measured using a contacting stylus instrument operating in areal mode (Taylor Hobson Formtalysurf). Surface maps of the undamaged and damaged area are shown in Fig. 2. For the purposes of analysis each area was measured fifteen times. The surface maps, plotted on the same scale show the overall decrease in feature height as a result of the depth of the large pits being reduced. Conversely when the areal roughness parameters were calculated the Sdr parameter (surface area ratio) indicated that the real surface area of the damaged zone was larger than the undamaged zone. Sds (0.18 undamaged region, 0.24 “damaged” region). This would suggest that the small scale roughness was increased in the damaged region.

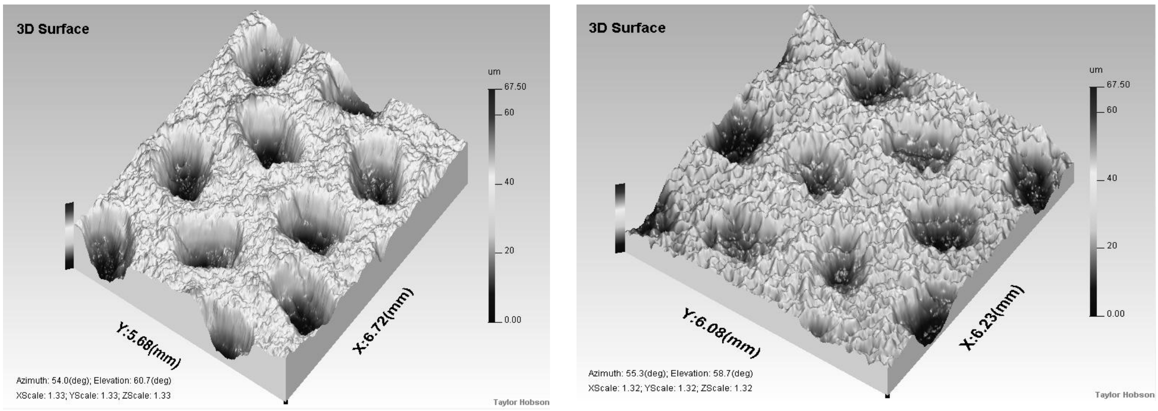

Fig. 2. Filtered results.

In order to verify the increase in roughness in the damaged region it was necessary to filter the surface data in such as a way as to remove the long wavelength features of the surface (the large pits) whilst preserving the fine scale roughness. This was accomplished by using the Dual-Tree Complex Wavelet Transform (DT-CWT) filter. The results are shown in Fig. 3. Figure 3 shows a filtered areal map across the boundary of the damaged and undamaged region. In order to show the increase in roughness in the damaged zone 700 2D profiles were extracted from across the filtered area and the profile roughness computed the results are platted across Fig. 3b.

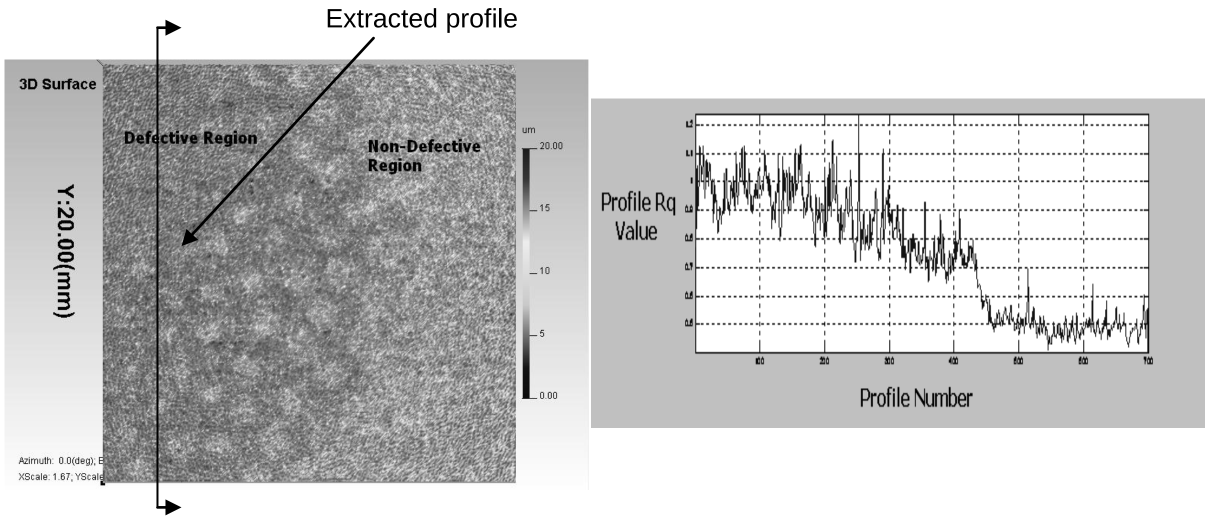

Fig. 3. a) DT-CWT filtered surface of boundary zone; b) extracted profile roughness.

## 4. Discussion

The Dual-Tree Complex Wavelet Transform (DT-CWT) filtering appeared to successfully separated the long wavelength features and the fine scale roughness. The 2D profile extraction figure 3b clearly shows that the damaged region was significantly rougher at the fine scale than the undamaged region. Consequently it appeared that the backside of the sheet appeared to have flattened the deep pits whilst imposing a rough fine scale structure. The rear side of the sheet was measured and was found to posses a roughness of Sq = 0.87um which was comparable with the fine scale roughness of the damaged region which has a profile roughness average of Rq = 0.92um It is this fine scale roughening that gives rise to the poor visual perception of the coating and any solution to the problem could be based around reducing the roughness of the backside of the sheet.

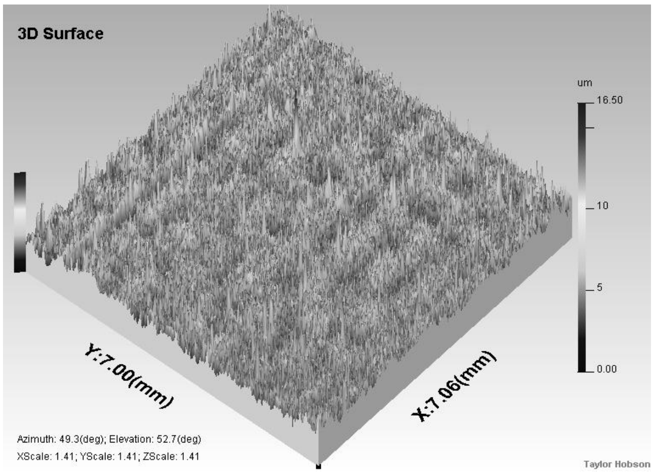

Fig. 4. Sheet backside topography.

## 5. Conclusion

In this paper, a method for decreasing the spatial component of the measurement error of the triangulation scheme has been described. The method is based on polarization filtration of the radiation scattered from the surface. The experimental investigations performed have given an increase in the accuracy of measurements by a factor of more than two.

It has been shown that using this method for decreasing the triangulation measurement error is more advantages under inspection the smooth surfaces of high class surface processing.

The technical solutions described in this paper were used in the development of a unit to measure the geometrical parameters of cylindrical products for atomic applications.

## 6. Acknowledgements

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