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The use of fractal parameter for the characterization of structured surfaces

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For structured surfaces, the fractal parameter can characterise in a quantitative way their texture. Fractal dimension associated to surface roughness and surface texture parameters described by ISO 4287:1997 [1] produces the same ranking.

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1. Introduction in surface classification

According to Stout and Blunt [2], surfaces are classified in engineered and nonengineered, as can be seen in Fig. 1:

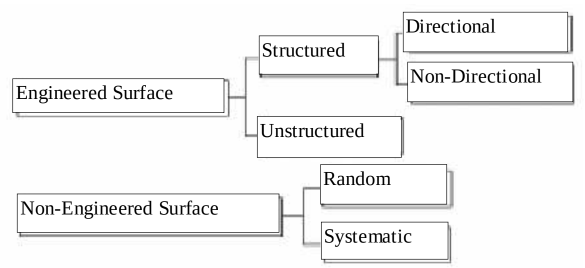

Fig. 1. Surface classification from engineering point of view.

Evans and Bryan [3] define the *engineered surfaces* as those where the manufacturing process is able to generate variation in surface geometry of material in order to be useful for a specific function. *Structured surfaces* are those with a deterministic pattern of geometric features used for a specific function. The geometric surface patterns consist in surface height variation (SHV) as indicated by Kawabata [4], that can be obtained as traces using different methods.

Rosenfeld and Lipkin [5] showed that texture could be studied both statistical and structural. Also, in [3] is made an association between both structured and engineered surfaces, and that of surface texture, which is characterised by ISO standards series for Geometrical Product Specifications (GPS) [1,6].

Generally, a structured surface displays two basic geometrical features:

♦ *Randomness:* where the roughs profile has a random variation in space, and there is no spatial function able to describe it. Randomness is described by both Hurst exponent and some amplitude parameters like skewness and Kurtosis [1]. Skewness measures the symmetry of a profile about its mean line. Surfaces with a positive skewness have high spikes, while surfaces with negative skewness have deep valleys in a smoother primary profile. A skew near zero value indicates more random surfaces. Also, Kurtosis is related to the spikiness of the profile.

♦ *Structural:* where the roughness is not completely independent with respect to its spatial position, but there is a spatial correlation. A. J. Reynolds [7] described the spatial correlation as being longitudinal and cross correlation.

Autocorrelation is a particularly case of spatial correlation, calculated for points belonging to the same set of data, separated by a distance r.

A measure for fractal parameter associated to a rough surface is Hurst exponent (H), expressed by relation 1.

$$H = 1/DF \qquad (1)$$

When Hurst exponent is calculated as beeing near to 0.5 means that the roughness is completely independent with respect to its spatial position across the surface. In this situation each observation is independent of all others. Other values indicate the presence of a spatial correlation that may be visible easily depending on its spatial duration.

2. Experimental

The electro-coated nickel samples from a disperse system were obtained through electrodeposition from modified Watts's electrolytes, having a lower chloride content and a higher Ni^{2+} content.

The electrolysis solution was prepared using deionised (DI) water with conductivity under 1 μs, obtained by passing the water over ion exchange resin plant. In DI water were dissolved inorganic compounds having analytic purity.

The pH of the electrolyte, measured with a Hanna Instruments electronic pH-meter, was adjusted at the value of 4.2, using 98% purity, sulphuric acid. The electrolytes obtained by adding the inorganic compounds were then filtered, over a paper filter.

To study the effect of process on surface texture modelled as fractal, were performed samples using the same quantities of inorganic compounds but different quantity of organic additive 3, as can be seen in Table 1.

This bath is known in the field as PearlBrite® Nickel of Enthone. This kind of bath was chosen for its complexity, it contains a disperse system. In fact is an organic emulsion that has a contribution in obtaining a textured rough surface of electrodeposited nickel coat.

Table 1. The composition of electrolytes.

Sample's number	$NiCl_{2x}6H_2O$ [g/l]	H_3BO_3 [g/l]	$NiSO_{4x}7H_2O$ [g/l]	Organic additive 1 [ml/l]	Organic assitive 2 [ml/l]	Organic additive 3 [ml/l]
1	15	40	420	20	6	0.8
2						1.2

The base material used for samples was brass, with 63% copper. Samples were polished up to mirror quality and were attached to the cathodic pole. The anode used, was electrolytic nickel with a purity of 99.997%, having the same dimensions as the samples.

Electrolyses were performed in standard, thermostated Hull cell [8] of 250 cm^3-volume capacity. The temperature of the bath during experiences was maintained at 530 ^oC.

3. Fractal dimension of rough profile

An approach that correlates geometric features of surface texture and fractal dimension parameter defines a fractal based texture classification. This paper uses texture analysis of the variations in grey scale of images for surfaces at a microscopic scale. These surfaces are considered as structured.

From experimental work, resulted two textured surface samples, that were imaged using a 100× and 500× scaling, computer video microscopy (CVM) at a resolution of 1024 × 768 × 256, as is presented in Fig. 2.

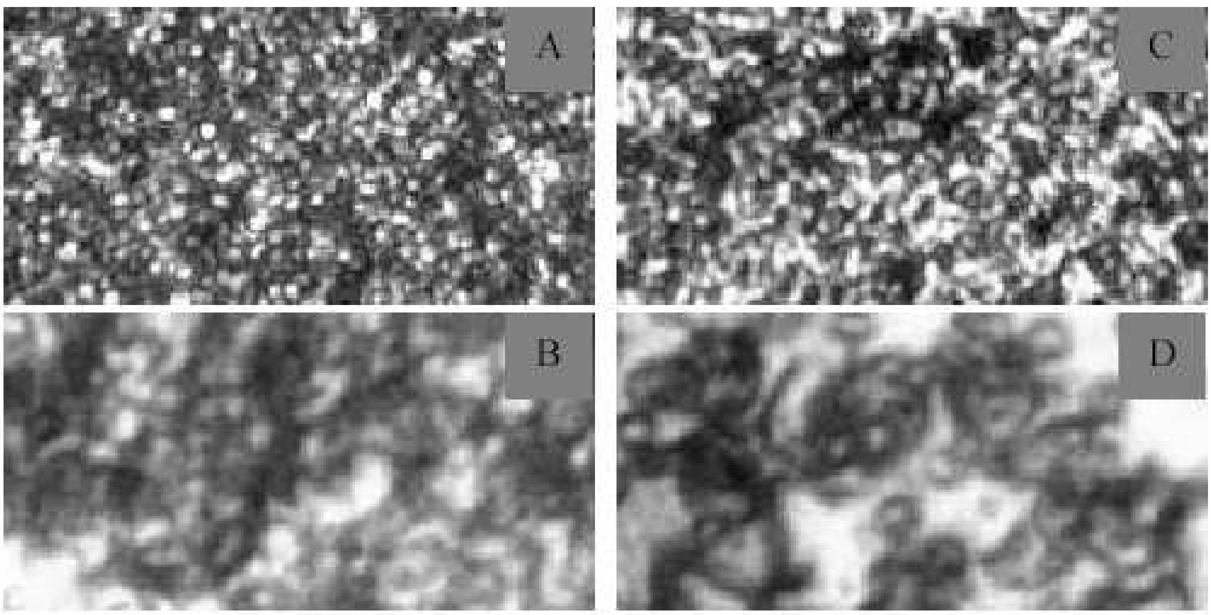

Fig. 2. A. sample 1 at 100×; B. sample 1 at 500×; C. sample 2 at 100×; D. sample 2 at 500×.

As can be noticed A, B, C, D stand for the four pintures of the two samples. Based on grey level of image pixels, then were obtained for all four samples the data series as matrixes with dimension of 1024 × 768.

From every matrix were then extracted vectors with 1024 points along rows and 768 points along columns, that represent the surface profiles studied. Fig. 3 presents the four profiles with 1024 points that are used for calculations along the rows of matrices.

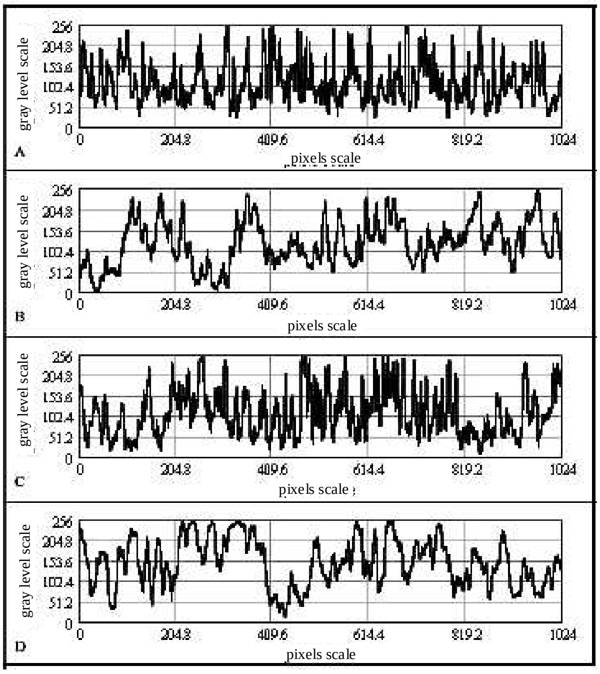

Fig. 3. A: profile 1 at 100×magnification; B: profile 1 at 500×magnification; C: profile 2 at 100×magnification; D: profile 2 at 500×magnification.

For data series obtained, present work is performing a fractal dimension calculation based on Sevcik's algorithm [9].

In comparison with Sevcik's calculation [9], the normalisation for data increments is calculated according to formula 2. This adjustment was made to have the same scale for all data sets. Otherwise the range affects the result, as we presented in [10] for different calculation methods.

$$y_i = \frac{y_i - 1}{255 - 1} \qquad (2)$$

Fig. 4 presents the graphical calculus of fractal dimension DF for a vector of 1024 points from every sample.

Based on fractal dimension, is calculated the Hurst coefficient, whose value [10,11] indicates the presence of randomness feature along data.

Then, the whole procedure is followed for vectors of surface profiles with 768 points, along columns, that represent the perpendicular direction for analysing as was presented before. Table 2 resume a fractal based texture analysis that affords a classification of structured surfaces.

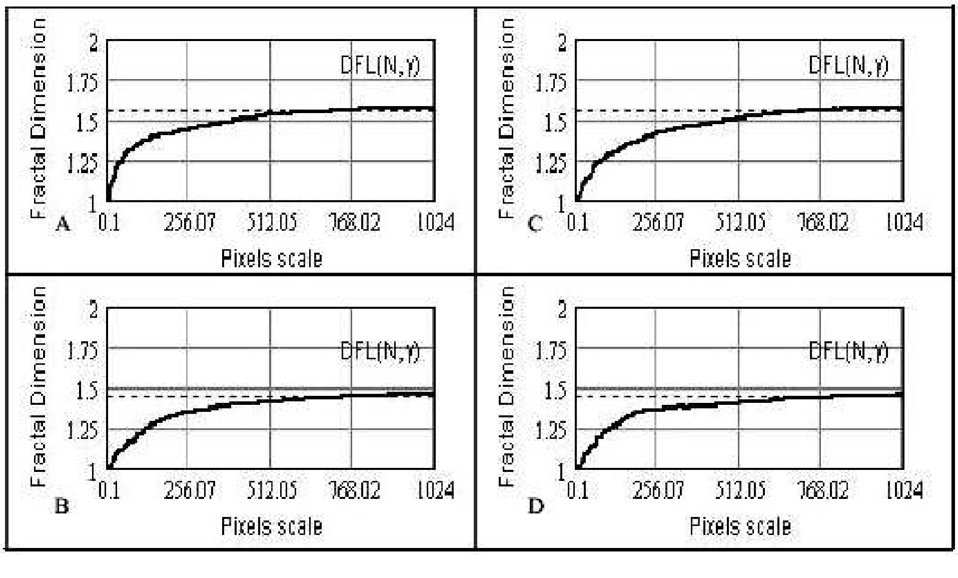

Fig. 4. Fractal dimension calculated for samples: A: 1.573, B: 1.460, C: 1.565, D: 1.451.

Table 2. DF and H calculated based on Sevcik algorithm calculated for both the rows first and columns of matrixes with dimension of 1024 × 768.

Sample		Fractal Dimension D_F		Hurst Coefficient H	
		1 to 1024	1 to 768	1 to 1024	1 to 768
1	A	1.573	1.562	0.635	0.640
	B	1.460	1.445	0.684	0.692
2	C	1.565	1.561	0.639	0.640
	D	1.451	1.418	0.689	0.705

4. Agreement with standardised roughness parameters

In order to distinguish between different surface roughness is necessarily to calculate some surface parameters that measure profile shape and spacing.

As defined by ISO 4287:1997 the amplitude parameters [1,12] evaluate the roughness profile of a surface that differ in shape or spacing. The profile could be represented by a continuous or discrete signal. In Table 3 are stated the amplitude parameters: peak and valley as well as average of ordinates. The calculus for all profiles is presented in Fig. 3.

Table 3. The calculation of amplitude profile parameters.

Parameter	Name	Profile							
a. Peak and valley parameters									
		A(1_100×)		B(1_500×)		C(2_100×)		D(2_500×)	
		1024 pnts	768 pnts	1024 pnts	768 pnts	1024 pnts	768 pnts	1024 pnts	768 pnts
		I	II	III	IV	V	VI	VII	VIII
R_v	Maximum profile valley depth	113	107	123	82	109	105	150	133
R_p	Maximum profile valley height	141	144	127	129	145	141	102	110
R_t	R_{Total} height of the profile	254	251	250	211	254	246	252	243
b. Average of ordinate parameters									
R_a	Arithmetical mean deviation of the assessed profile	113	108	123	120	109	106	150	140
Rsk	Skewness of the assessed profile	0.78	0.65	0.08	0.66	0.59	0.40	-0.05	0.19
Rku	Kurtosis of the assessed profile	-0.10	-0.05	-0.72	-0.16	-0.49	-0.55	-0.94	-0.78

As one could see, the skewness calculated for rough profiles obtained by electrodeposition of composite layer, suggests the presence of spikes above Ra. Case VIII is an exception from the rule, that suggests the presence of isolated valleys. In fact the skewness is very sensitive to presence of isolated peaks or valleys. Also spiky profiles are qualitatively sugested by Rp bigger than Rv for all samples.

Both Hurst exponent and skewness indicate a correlation effect along the studied data. This effect will be studied in the next chapter with the help of autocorrelation spectral analysis.

5. Ranking with spatial correlation

This chapter demonstrates that the Hurst coefficient and structural geometrical features characterized through autocorrelation analysis produce the same ranking.

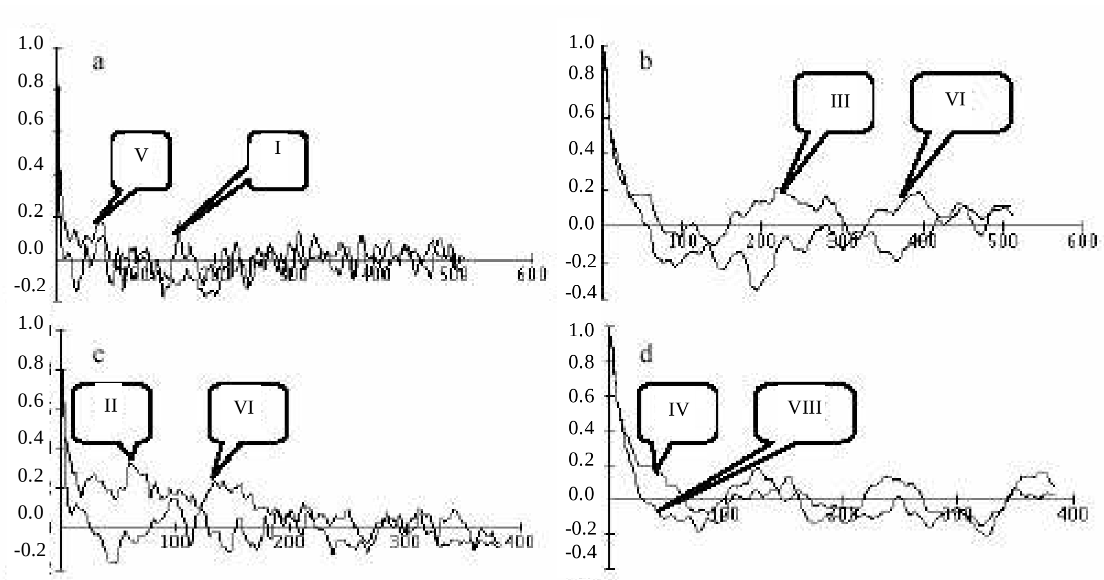

Fig. 5. Auto-correlation estimation for data used in calculation of fractal parameter.

Fig. 5a presents the autocorrelation graph for sample 1 at 100× magnification (I) and sample 2 at 100×-magnification (V). Both of them exhibit a dependence of roughness along the direction of vector composed from 1024 points.

Fig. 5b shows a spatial correlation effect along the direction of vectors with 1024 points, for sample 1 at 500× magnification (III) and sample 2 at 500× magnification (VII). One could notice that Fig. 5b exhibits a bigger correlation than 5a, fact in agreement with Hurst coefficient prediction, as can be seen in Table 2.

Figs. 5c and 5d present an autocorrelation effect along the direction of vectors with 768 points: for sample 1 at 100× magnification (II) and sample 2 at 100× magnification (VI) respective sample 1 at 500× magnification (IV) and sample 2 at 500× magnification (VIII). Also can be seen an agreement with Table 1 concerning the strength of the effect.

6. Conclusions

The fractal dimension is an important parameter able to describe geometrical features of a surface, like randomness and structural aspects.

The fractal parameter is quantitatively influenced be the magnification scale but in qualitatively way one could notice the same ranking. Therefore, it is important to use the scale where the geometrical patterns are well developed.

The classification of structured surfaces in directional and non-directional can successfully be made with the help of fractal based texture analysis. A study along two perpendicular directions is able to clearly make a distinction.

The fractal dimension completes the information brought by amplitude parameters with effect on profile reconstruction.

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