SURFACE PROFILE EVALUATION BY FRACTAL DIMENSION AND STATISTIC TOOLS

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ABSTRACT

A lot of natural structures in industry applications can be hardly described by conventional methods – statistic tools, because they are complex and irregular. A relatively new approach is the application of fractal geometry that is successfully used in science, but an application in industry is sporadic and experimental only. However, the fractal geometry can be used as a useful tool for an explicit, objective and automatic description of production process data (laboratory, off-line and potential on-line).

Industrial data (from production processes, quality control, production tools, etc.) may have a form of digitalized pictures, time series or a topologically one-dimensional interface (especially a surface roughness or a surface profile). The data in a digital form can be described by the fractal geometry, which expressing the complexity degree of structured data (ideally) by means of a single number, the fractal dimension.

On this account, we are developing three off-line software tools that can be converted to on-line control tools in the future. The article is intended only on application of the fractal geometry with combination of statistic tool for the classification of dividing lines (a surface profile or a surface roughness evaluation) with example from glass industry.

1 INTRODUCTION

Although continuously growing a competitive press to increasing quality of products activates a requirement of an objective measurement and control methods for materials, processes and productions, many structures (e.g. defects, surface, crack, time series from dynamic processes) can be hardly described by conventional methods, because they are complex and irregular. However, a new approach is the application of fractal geometry [1-3] that is successfully used in science. Even though an application in industry is sporadic and experimental only, the fractal geometry can be used as a useful tool for an explicit, objective and automatic description of production process data (laboratory, off-line and potential on-line) [4-7].

2 CLASSIFICATION OF DIVIDING LINES – SURFACE PROFILE EVALUATION

The fractal analysis and statistic tools are tested for a quantification of metal surfaces changes of relatively new materials: iron aluminides in comparison with currently used chrome-nickel steels in contact with the glass melt.

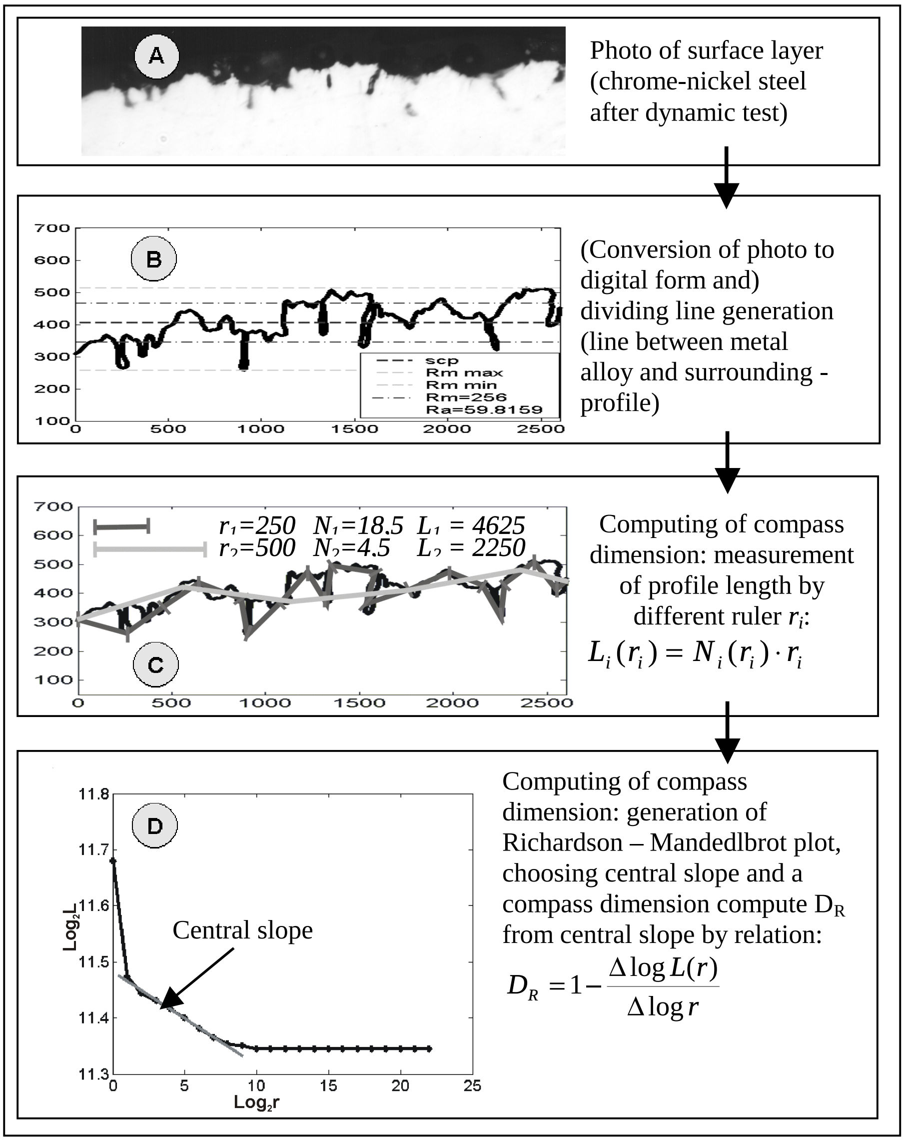

Figure 9: Analysis of surface layer, dividing line generation from photography, evaluation by statistic and compass dimension

Analyses were performed on samples of the iron aluminide Fe28Al4Cr0,1Ce and the chrome-nickel steel X15CrNiSi25 21 - EN 10095 (AISI 310) that were exposed to static and dynamic glass melt effects in different temperatures.

The methodology of the surface profile evaluation is shown in fig. 1. Firstly, classic or better a digital camera takes a photo of a surface layer profile from a microscoped metallographic sample, fig. 1, A. The “classic photo” of the layer profile has to be scanned, that extend time needed to analyses.

Secondly, a dividing line is generated from the digital photography, fig. 1, B, by the software tool that exactly defined the curve between material alloys and a surrounding - a dividing line as a curve is obtained. The generated dividing line is a binary image, where the line is from the black pixels (value 0) and the surrounding from white pixels (value 1). The width of images is 2272 that matches 57,7 μm. Statistic tools and (or) the fractal dimension can describe the curve fig.1, C, D.

3 EVALUATION BY STATISTIC TOOLS

We use basic statistic roughness parameters for the statistical surface profile classification: the average surface roughness (R_a) and the maximum roughness (R_m or R_{max}). The maximum roughness R_m is a distance between a deepest valley and a highest peak. The average surface roughness (R_a) is an area between the roughness profile and its mean line, or an integral of the absolute value of the roughness profile height over the evaluation length. Examples of results are shown in fig. 2. It is possible use others statistical parameters.

4 EVALUATION BY FRACTAL GEOMETRY

As mentioned above, the fractal dimension describes complexity by a single number. The fractal dimension can be estimated by many different methods [1-3]. A compass method [2] is one of them and the method is based on the measurement of the dividing line (roughness profile) by different size of a ruler (fig. 1, C) via the equation:

$$L_i(r_i) = N_i(r_i) \cdot r_i \qquad (1)$$

L_i is a length in i-step of the measurement, r_i is a ruler size and N_i is a number of steps needed for the measurement that is given by a power law:

$$N(r_i) = const. \cdot r_i^{-D_R} \qquad (2)$$

If the line is fractal and hence the fractal dimension is larger than the topological dimension, the measured length increases as the ruler size is reduced (fig. 1, C). Using equations (1) and (2):

$$L_i(r_i) = N_i(r_i) \cdot r_i = const.r_i^{-D_R} \cdot r_i = const. \cdot r_i^{1-D_R} \quad (3)$$

D_R is the compass dimension.

Logarithmic dependence between $\log_2 N(r_i)$ and $\log_2 r_i$ is called the Richardson-Mandelbrot plot (fig. 1, D). The compass dimension is then determined from slope s of the regression line (fig. 1, D):

$$D_R = 1 - s = 1 - \frac{\Delta \log_2 L(r)}{\Delta \log_2 r} . \quad (4)$$

Although the typical dependence consists of three-parts slope, only central part (the central slope) is important for the compass dimension computing. The compass dimension D_R is multiplied by 1000 for better confrontation, $D_{R\,1000}$.

5 EXAMPLES OF RESULTS

The examples are shown in fig. 2. Six digital photos of every metal sample profile in different position were made and analysed. The presented results R_a, R_m and $D_{R\,1000}$ are an average of six measurements on a tested sample and fig. 2 shows only one example of the six dividing lines.

6 CONCLUSION

Although fractal and statistic results correlate in these examples of results (a profile with higher R_a and R_m has higher $D_{R\,1000}$), the estimated fractal dimension (in this article the compass dimension) is information about structure, but R_a and R_m are statistic information. This information can correlate, but it is not rule. The compass dimension indicates complexity of profile, which can be used as added information to statistic or as a single profile specification. The estimated fractal dimension can also be used for others dividing lines types such as a surface roughness classification.

The results of our research (from application to digitalized pictures, time series or a dividing line) show that the fractal dimension is potentially a powerful tool for explicit, objective and automatic description and quantification of complex data [4-7]. The possibilities of successful applications in industry are believed to be large.

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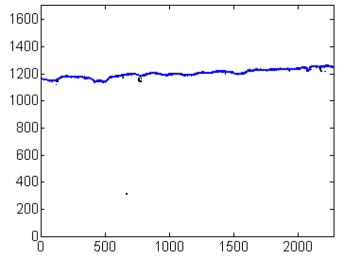
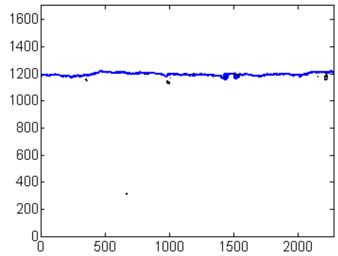
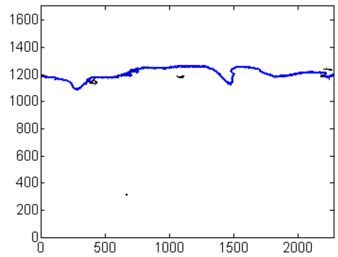
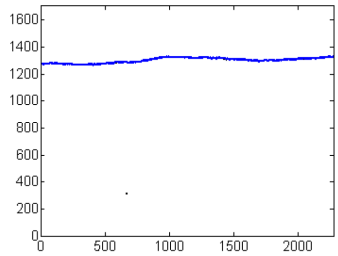
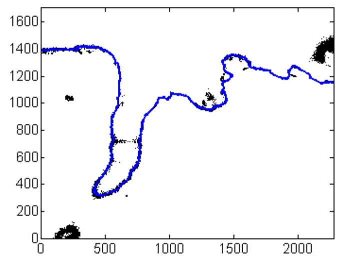
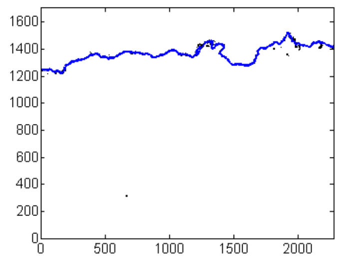
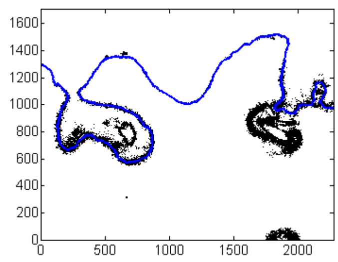
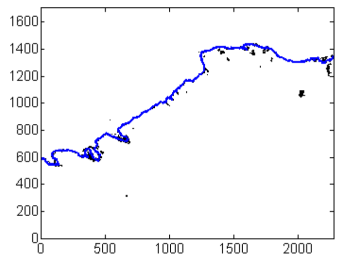
	Chrome-nickel steel EN 10095 (AISI 310)		FA - iron aluminide on base Fe_3Al	
	Dividing line - roughness profile (size in pixels)	R_m [µm] R_a [µm] $D_{o\ 1000}$ [-]	R_m [µm] R_a [µm] $D_{o\ 1000}$ [-]	Dividing line - roughness profile (size in pixels)
Ground state		3.07 0.79 1029.2	1.56 0.29 1055.8	
$1100^{O}C$, 24 hour		4.28 1.01 1056.4	1.54 0.47 1012.0	
$1250^{O}C$, 96 hour		28.11 8.59 1121.6	5.52 1.39 1100.3	
$1350^{O}C$, 96 hour		24.08 6.09 1185.4	22.64 8.09 1124.0	

Figure 2: Examples of dividing lines chrome-nickel steel material and iron aluminide, after static glass melt effects in different temperatures and results of analyses

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