New fractal approach for the characterization of lithographic plate surface

Jocelyne Roudet-Rouis
Polychrome France - EFPG Grenoble - France

***Keywords** : Fractal analysis, Variation Method, Surface, Topography, Roughness, Lithographic Plates,*

***Abstract** : The fractal dimension concept has already been applied with success to various groups of offset plates as a means of characterizing different surfaces and their corresponding treatments. The performance of this particular approach is reliable based upon the use of a new algorithm for fractal analysis calculated from stylus profilometer surface roughness measurements. The results obtained show that lithographic plates present fractal characteristics. The values of fractal dimension are higher than 1.5 and discriminate between plates.*
After a thorough discussion of the underlying concepts, we will apply them to the plate surface texture. Correlations of these results with information about treatment process of each plate surface will be pointed out.

I - Introduction

Recent years have seen remarkable advances in our ability to measure and describe the shape of surfaces. Nevertheless, while it is well accepted that the shape of surfaces strongly influences the manner in which they interact, there is still considerable confusion as to which textural features play critical roles, and, equally importantly from a practical viewpoint, which are irrelevant.

In our approach to lithographic plates surface characterization, we chose to explore how surfaces interact and hence tried to determine which aspects of their texture are relevant to their performance in practice.

Indeed, the studies of wettability reported by Fetsko (1988) on non-image area zones were often limited by the roughness of surfaces. Moreover, the water carried by plates (Ström (1993)) and the adhesion of the photoreactives coating on plates are also relared to the geometrical texture of the non-image area zones. This is why a correct approach in studying surface characteristics including texture is very important for the understanding of the transfer mechanisms in the offset process.

Numerous works concerning roughness have been published during the last 10 years. Most of these publications deal with profilometry and classical values of roughness parameters such as Ra, Rt,... . We demonstrated however in a previous paper that these classical parameters of roughness are not sufficiently pertinent to describe correctly the surfaces (Roudet-Rouis (1993)). The alternative we proposed was to study the surface area which is a more reliable parameter with regard to adhesion and wettability.

Nevertheless, this last parameter does not reproduce in a good manner the enormous amount of details visible each time the magnification of a scanning electron microscope is increased. In that sense, the fractal approach appears to offer the possibility of a new and more straightforward method of surface characterization.

In the field of printing and paper technologies, Tosch (1988) was the first to introduce this concept. However, the values of fractal dimension he obtained for the plates surface seemed to be low for that kind of texture.

In this article we will deal again with the fractal concept. Nevertheless, we will demonstrate that using a different method of calculation, viz. the method of perturbation described by Wehbi (1986), the results of the calculation of fractal dimension for offset plates are very interesting and closer to reality (see discussion on the method -III-).

Before developing the new method applied to offset plates, we will review some basic ideas on fractals and on the method of calculation to assess the fractal dimension.

II - Fractal Concept

In conventional Euclidean geometry, we call a one dimensional object a line, a two dimensional object a surface and a three dimensional object a volume and say that a point is zero dimensionsal. We know from Einstein that the only way to understand certain experiments is to consider that physical space as a four dimensional space where time plays the part of a dimension. We are, therefore, accustomed to objects whose dimension is an integer number : 1, 2, 3 or 4.

Beside that, in nature there exist objects capable of being described by a dimension which is not an integer number. These are fractal objects and an object whose geometry can be described by a non-integer dimension is known simply as a fractal.

The genius of Benoît Mandelbrot (1982), "the father of fractals", lays in making the conjunction between the mathematical notion of a non-integer dimension and the geometry of a large number of natural phenomena or objects encountered in nature. He made clear the idea of the existence of physical fractals. With mathematical fractals, the process of division reaches to the infinitely small whereas with physical fractals, the concept of self similarity will remain valid only over a finite range (Sapoval (1992)).

Briefly, a fractal line (whose dimension lays between 1 and 2) is not straight, but "crinkly" so that its length exceeds the distance between its endpoints. Further, for an ideal fractal this same degree of irregularity is present at any magnification, so that as we zoom in closer to the line, it continues to reveal more detail (as a function of resolution of our instrument) but there is no internal way to judge the magnification as for the Koch's curve.

For physical objects, there are obvious limits to this invariance of scale that occur at very large dimensions (limited to the size of the object, which can be a planet or the universe itself) and a very small ones (for instance, the atomic regularities that impose a Euclidean unit cell geometry on most materials, at least neglecting thermal vibrations and disorder).

In recent years, many studies of the fractal structure of surfaces have appeared in the literature. It stands to reason that the microgeometry of the surface of bodies will have a large effect on their properties. Moreover, it turns out that the surface irregularity of many actual bodies can often be characterized as self-similar.

Among these studies, the field of printing and papermaking showed recently an interest in new concepts of characterization of surfaces. The number of publications is however still modest.

Lipshitz (1990) explored the fractal dimension of paper by analysing raster-scan data from an optical profilometer and observed qualitative similarities at different measurement scales. Later, Kent (1991) used a modified Richardson algorithm for obtaining the fractal dimension of paper from stylus profilometer measurements. He demonstrated that paper exhibits fractal characteristics but the fractal dimension values of paper surfaces are very low in magnitude (less than 1.05).

In 1988,Tosch (1988) introduced the concept of fractal as a tool for studying the periphery of halftone dots. He showed that the perimeter of halftone dots was scale-invariant with a fractal dimension depending upon substrate surface roughness. Then, in 1992 (Tosch (1992)), he applied this concept to the analysis of offset plates surface without subjecting them to a printing operation. More pointedly, this paper describes a method using fractal dimension (Compass Method) in which the dry edge behavior of ink puddles can be used to quantify the texture of printing plates surface. Tosch demonstrated the validity of using this concept on such perturbed materials. However, the fractal dimension values obtained for several kinds of plates (mechanically or electrochemically grained) vary between 1.12 and 1.4. Considering the texture of offset plates, these values could be considered as quite low. The weakness of these values could be due to the method used for the calculation of fractal dimension which is more or less efficient.

Indeed, all the existing evaluation methods of the fractal dimension of an object are not similar. Theorically they are all expected to give the same results. However, when discretized and applied to digitized data they lead to different results. In particular the compass method is now considered by the scientific community as totally obsolete because of its lack of accuracy compared to more advanced methods. For surfaces such as offset plates, the variation method developed recently by Tricot and al. (1988) is far more useful and we will demonstrate that point on various graining offset plates.

III - Description of a new Method for the determination of the Fractal Dimension - the Variation Method

In 1987, Tricot (1987) introduced a new algorithm for the determination of the fractal dimension. He studied its performances on curves and surfaces with known fractal dimension. The result was a fast and reliable algorithm to estimate the fractal dimension of surfaces.
To demonstrate the improvement obtained with the variation method, all algorithms were applied to the evaluation of the fractal dimension of known theoretical models (Tricot (1987, 1989)), in particular the Weierstrass-Mandelbrot curves and the brownian motion, two classical fractals. The weakness of the most widely used algorithms has been stressed. These methods yielded results with errors ranging up to 5 to 10 %, while the variation method presented a substantial improvement. It provided the basis for a higher dimensional algorithm.

This new method for evaluating fractal dimension is based not on coverings with disks and pixels but rather with ***appropriate defined intervals***. The resulting cover leads to a new class of algorithms yielding a significantly more accurate estimate of fractal dimension.

The variation method was applied with success to the roughness profile of different kinds of surfaces (Tricot (1989), Wehbi (1992)). Wehbi et. al. (1992) transformed this global approach in a local analysis which gives rise to a "perturbation dimension". Indeed, the study of the roughness of surfaces with the concept of fractal is based on these two complementary approaches :

- On one hand, it is well known that the classical amplitude parameters are not conservative as a function of the length of evaluation, which is a characteristic of self-affine fractals,
- On the other hand, the shape of profiles or surfaces exhibit scaling properties (Thomas (1982)), their appearance is much the same whatever the magnification Fig 1.

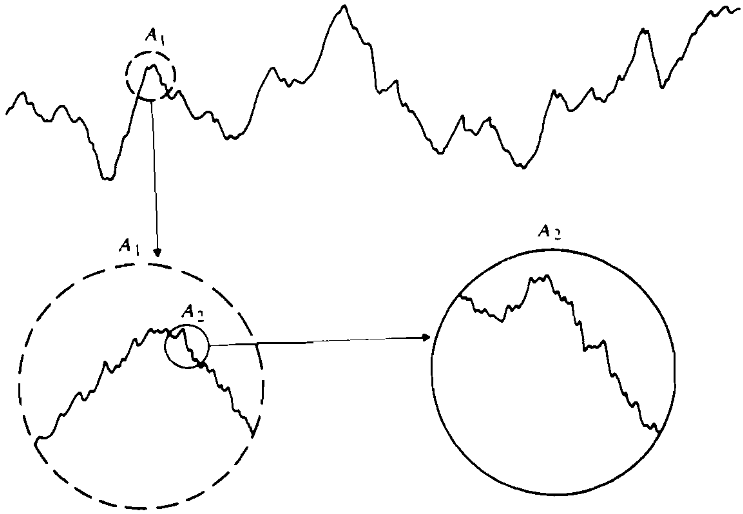

Fig 1: Self-similarity of surface profiles; the appearance is the same whatever the magnification (Thomas (1982))

On these bases, new parameters have been defined with the aim to quantify the degree of perturbation of surface as a function of the window of analysis, that is the observation scale. The decreasing law associated when the size of the window of analysis is decreased is directly related to the perturbation dimension or the fractal dimension.

This method consists of in analysing the variation rate of a parameter with the decrease of the evaluation window and not in determining an absolute value of a parameter. It has been shown that the dimension perturbation may be evaluated by a log–log plot relating for example the variance or another roughness parameter to the width of the window selected.

For this purpose, the roughness profile $z(x)$ - sampled in an interval of length L - is divided into windows of equal width Γ. Inside every windows, of center x_i, a perturbation parameter such as Ra, Rt or σ^2 is evaluated and denoted $p(x_i,\Gamma)$ Fig 2.

The average perturbation on the whole profile is then given by :

$$\bar{p}(\Gamma) = \frac{1}{L}\int_0^L p(x_i, \Gamma)dx$$

The perturbation dimension is defined from the slope of the line by plotting log $\bar{p}(\Gamma)$ versus $\log(\Gamma)$. Thus, each measure represents the mean perturbation of profile defined locally.

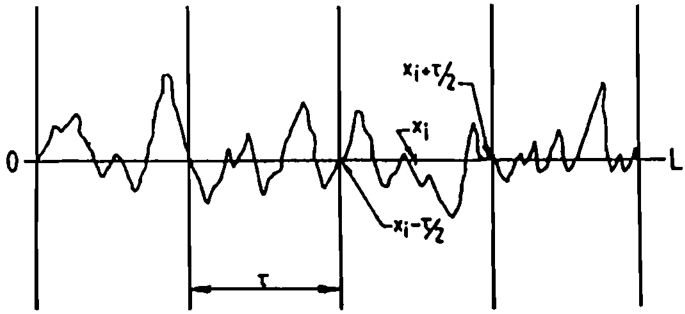

Fig 2: Definition of the Γ-window used for evaluating the local perturbation of roughness profile.

The curves log $\bar{p}(\Gamma)$ in function of $\log(\Gamma)$ are plotted with 2000 points, the width of the window Γ varying in between 2 μm and 1 mm.

The knowledge of this factor provides access to the fractal dimension. Indeed, in the particular case of roughness profiles (self-affine curves), the perturbation dimension and the fractal dimension take the same value.

IV - Application of the fractal analysis to Offset Plates Topography

The purpose of this study was to characterize comparatively plate surfaces with different graining using classical roughness parameters and fractal dimension.

In the previous section, we described the advantages of using the perturbation method to calculate the fractal dimension of surfaces from roughness profiles. This technique was applied with success to the surface characterization of various offset plates.

Experimental conditions

The surface profiles discussed in this article were obtained from a Scanning Mechanical Microscope (MMB), Wehbi (1986), which is consists of a diamond stylus profilometer fitted with a high resolution X-Y translation stage governed by a logic card and controlled by an IBM PC/AT computer. The tip radius of the stylus is roughly 1 µm and the vertical resolution is 0.01 µm.

Numerous 3D maps and 2D profiles were recorded on every plates surface. Several offset aluminium and chromium plates with appreciably different graining were selected (see Table 1).

Plate	Kind of Graining
Al 1	Pumice grained aluminium
Al 5	Pumice grained aluminium
Al 4	Electrograined aluminium
Al 2	Electrograined aluminium
Al 6	Electrograined aluminium
Al 7	Electrograined aluminium
Al 8	Electrograined aluminium
Cr 10	Chromium on smooth aluminium
Cr 11	Chromium on pumice grained aluminium

Table 1 : Description of the origin of the plates

The classical roughness parameters were obtained from 3D maps covering area of 256μm x 265μm with steps of 1μm (largest area obtained with the smallest resolution). The number of sampled points is statically sufficient and the covered areas are representative of the sampled surfaces.

However, for fractal analysis, these ares do not cover scales sufficiently wide in the surface plane. This is why, fractal analysis was carried out from profiles with the following sampling conditions :

- Number of points : 2000 points
- Sampling interval : 1μm
- Length of evaluation : 2000μm

The perturbation dimension was calculated from the roughness parameter Ra by plotting the value of log Ra as a function of log(Γ). For all the plates, the plotted points (logRa, log(Γ)) showed in general a good alignment over more than 1 decade (the value of Γ varying roughly in the interval 30-450 μm) which justifies this fractal analysis for offset plate surfaces in the range of scale which interests all the transfers in the offset process Fig 3.

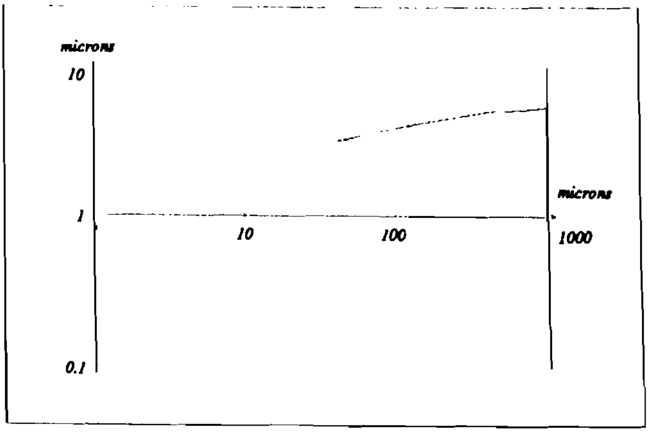

Fig 3 : Perturbation dimension curve of (log Ra) as a function of (log τ).

Results and Discussion

The fractal dimension values, as well as the classical roughness parameters, are presented in Table 2.

First of all, the remarkable point of this study is the fact that for all the plates (electrograined, pumice grained aluminium and chromium plates) the value of fractal dimension is above 1.5 which is higher than in previous published works[4, 10]. This remark is important and validates the variation method. This method permits one to obtain more realistic values of fractal dimensions according to the texture of the plate surfaces. From this point of view, these results are the **premium** applied to such offset materials.

Samples	Rt (µm)	Ra (µm)	Surf. area %	Fractal Dimension			
				Perp	Par	Obli	MAX
Al 1	3.2	0.31	109.26	1.68	1.63	1.67	**1.68**
AL 5	2.7	0.25	106.89	1.62	1.56	1.63	**1.63**
AL 4	5.7	0.63	140.50	1.73	1.75	1.73	**1.75**
AL 2	7	0.80	154.87	1.82	1.73	1.73	**1.82**
AL 6	7.9	0.70	142.42	1.62	1.66	1.67	**1.67**
AL 7	3.5	0.37	117.99	1.71	1.74	1.69	**1.74**
AL 8	2.3	0.25	108.68	1.73	1.73	1.70	**1.73**
CR10	2.5	0.33	114.12	1.62	1.57	1.56	**1.62**
CR 11	3.7	0.29	111.54	1.80	1.73	1.69	**1.80**

Table 2 : Classical parameters calculated from 3D data and fractal dimension calculated from 2D profiles in three different directions : Perp (perpendicular), Par (parallel,) Obli (oblique). The last column concerns the maximum value of fractal dimension which represents the fractal dimension of the objects

Moreover, taking into account the algorithm of this method, the obtained values are precise to the second decimal. This implies that the gap between two values is significant and the results obtained allow the analysed plate surfaces to be discriminated.

As we explained previously, fractal dimension values are obtained from 2D-profiles in order to obtain a more precise and more representative description of surfaces in trems of scaling properties. As the analysed plates often present anisotropic characteristics, we calculated the fractal dimension from profiles in three major directions : perpendicular, parallel and oblique (45°) related to the sense of lamination. In this present case, it is the maximum value obtained which is taken as the fractal dimension of the considered object.

Concerning the dispersion of the values of fractal dimension as a function of the direction of scanning, we noticed that the largest dispersion of values are obtained with chromium samples. The chromium plate Cr 10 is characterized by a well-defined monodirectional anisotropy as pointed by its autocorrelation function show in Fig 4.

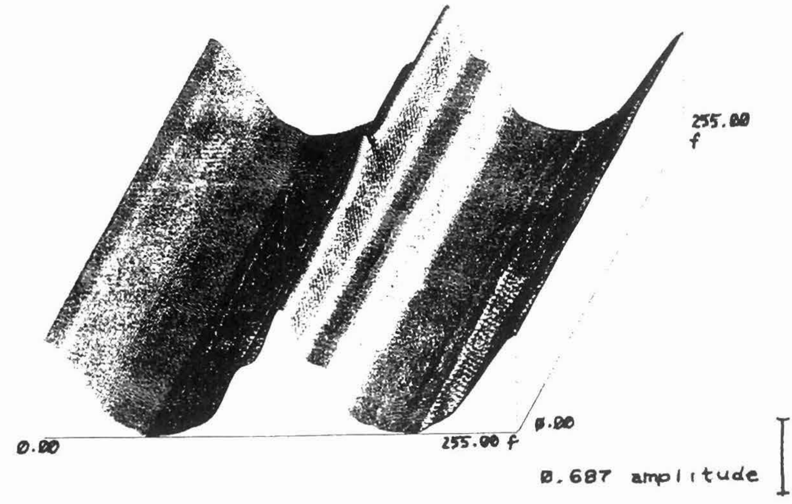

Fig 4 : Autocorrelation function of the plate CR 10 calculated from data relative to a 256μm x 256μm, 3D-map

Among aluminium plates, some of them such as AL 6 or AL 4 are characterized by a spatial isotropy, represented by their autocorrelation function (Fig 5 and 6). The values of fractal dimensions in the three directions are then very similar.

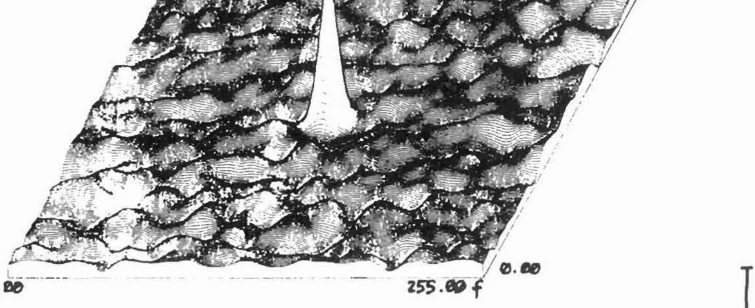

Fig 5 : Autocorrelation function of the plate AL 4 calculated from data relative to a 256μm x 256μm, 3D-map.

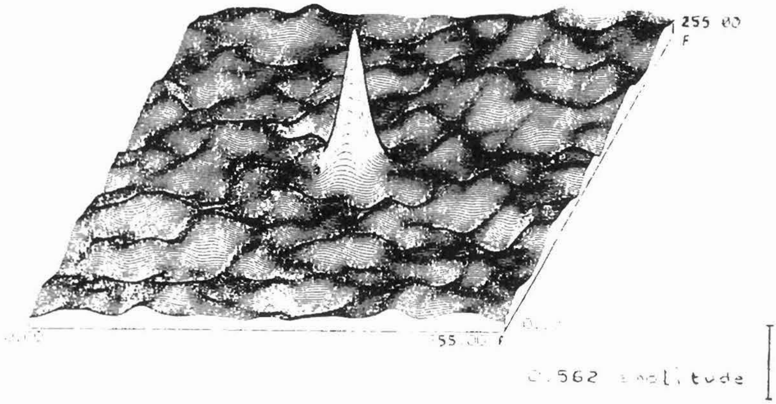

Fig 6 : Autocorrelation function of the plate AL 6 calculated from data relative to a 256µm x 256µm, 3D-map.

If we compare the results relative to roughness parameters and fractal dimension, we observe that there is no significant relationship between them. The fractal dimension is therefore independent of the classical roughness factors.

Indeed, for plates which have similar values of the roughness amplitude (Ra, Rt), the values of fractal dimension can be totally different. The example of electrograined plates AL 2 and AL 6 is significant. These two plates present almost the same range of Rt (respectively 7 and 7.9 µm) and Ra (0.80 and 0.70 µm), but the values of fractal dimension are very different (respectively 1.82 and 1.67). On the contrary, electrograined plates with different values of Rt such as Al 4, Al 7 and Al 8 present similar values of fractal dimension (1.75, 1.74, 1.73).

For pumice grained plates, Al 1 and Al 5 classical roughness values are quite close but the gap for fractal dimension is already 0.05.

Chromium plate Cr 10 is composed by micro crystals of chromium deposited onto a smooth aluminium plate. This plate presents the lowest value of fractal dimension 1.62, which is indeed not far from the fractal dimension of pumice grained plate Al 5 (1.63). Nevertheless, the surfaces of these two plates present a totally different texture.

The second chromium plate CR 11 is rather special. This is a pumice grained aluminium plate onto which micro-crystals of chromium are deposited. In this example, two kinds of roughness features are combined. The result is that the adding of micro-crystal of chromium increases considerably the degree of perturbation of this surface and then the value of fractal dimension becomes higher than that of chromium and pumice grained plate (1.80).

We can conclude from this study that the value of fractal dimension contains information about texture which is not present in the other classical roughness parameters. This notion of fractal dimension involves thus a necessary complement to the roughness characterization of plates texture.

A study of the relationship between the structure and the properties of plates allowed us to confirm that point. The interesting results of this study will be developed in a future publication.

Table 2 also shows the values of surface area for each plates. These values were calculated from 3D data acquisitions. The problem with surface area lies in its limitation. Indeed, to be comparable the values of surface area must be taken from surfaces presenting the same range of Rt (the gap must be < 1µm). The plates described in this study cannot be compared because the gap between Rt is largely above 1µm even for a same class of graining treatment. With fractal dimension, we have an index without dimension which allows to compare and classify all the plates on the same scale, and this in spite of their different textures.

The criterion of fractal dimension is from this point of view more useful.

The last point we would like to underline concerns the profilometer itself. At many times this apparatus was criticised because the results given by classical roughness parameters were not sufficiently enough significant. We demonstrated in this work that the use of this apparatus with a new method (variation method for the fractal analysis) could become a very useful element in the study of surfaces.

V - Summary and Conclusion

A new fractal determination method (the variation method) was applied with success to the characterization of offset plate surfaces. The introduction of an index of perturbation for qualifying the surface roughness is based on a simple concept. It consists in determining not the absolute value of an amplitude parameter (such as Ra, Rt or σ), but its variation rate as a function of the decreasing width of the evaluation window.

Moreover, the variation method not only yields good results for isotropic surfaces but can also be applied to real anisotropic surfaces

The results presented in this work are examples chosen as characteristic from measurements on over twenty different plate surfaces covering a wide variety of textures. Our results outline clearly the interest of using the variation method for the determination of the fractal dimension.

The general conclusions of this fractal dimension study are :

- the fractal dimension of plates are high in magnitude (above 1.5) and correspond to very perturbed surface as expected,

- this new approach allows to differentiate with success the different offset plate surfaces analysed,

- each kind of graining does not necessarily lead to the same fractal dimension. Some more subtle factors associated with the graining process are to be considered with great attention. The result is that the fractal dimension represents really the state of the texture,

- fractal dimension being a parameter without dimension, it becomes a more pertinent and powerful factor related to surface area for the comparison of plates,

- with the fractal approach for the characterization of surface, it becomes possible to reduce considerably the enormous number of classical parameters actually necessary to the description of surface.

In conclusion, the perspectives of using this concept for the understanding and the modelling of processes in particular when rough surfaces are involved are interesting. One major question still remains, it is related to the physical meaning of the actual value of the fractal dimension in this specific context of offset plates.

IV - BIBLIOGRAPHY

Fetsko, J.
1988 - *"Relationship of ink/water interactions to printability of lithographic printing Inks"* Surface Interactions, Part 2, NPIRI, February 1988.

Kent, H. J.
1991 - *"The Fractal dimension of paper surface topography"* Nordic Pulp and Paper research Journal, vol 6, n°4, pp 191.

Lipshitz, H., Bridger, M. and Derman, G.
1990 - Proceedings of the TAPPI Coating Conference, pp 216.

Mandelbrot, B.
1982 - *"The fractal geometry of nature"*
W. H. Freeman and Company, San Francisco.

Roudet-Rouis, J. and Goodman, R.
1993 - *"Three dimensional topographic characterization of lithographic plates"* TAGA Proceedings, pp 398.

Sapoval, P.
1992 - *"Les Fractales"* CPE Etude, n°125, ADITECH Paris.

Ström, G.
1993 - *"The importance of surface energetic and dynamic wetting in offset printing"* Journal of Pulp and Paper Science, vol 19, n°2, J79.

Tosch, R., Trauzedel, R. , Hromek, B.
1988 - *"Fractal analysis of halftone dots"* Paperi ja Puu - Paper and Timber, vol 10, pp 887.

Tosch, R.
1992 - "Fractal analysis on selected material surfaces" TAGA Proceedings, pp 252.

Thomas, T. R.
1982 - *"Rough Surfaces"* Longman Group Limited, New York.

Tricot, C., Dubuc, B., Quiniou, J.F., Roques -Carmes, C., Zucker, S. W.
1987 - *"The variation method : a technique to estimate the fractal dimension of surfaces"* Visual Communication and Image SPIE, vol 845, pp 241.

Tricot, C., Quiniou, J.F., Wehbi, D., Roques -Carmes C. and Dubuc, B.
1988 - *"Evaluation de la dimension fractale d'un graphe"* Revue Phys. Appl., vol 23, pp 111.

Tricot, C., Dubuc, B., Quiniou, J.F., Roques-Carmes, C., Zucker, S. W.
1989 - *"Evaluating the fractal dimension of profiles"* Physical review A, vol 39, n°3.

Wehbi, D.
1986 - *"Approche fractale de la rugosité des surfaces et implications analytiques"* Thèse de Doctorat es Sciences Physiques, Besançon.

Wehbi, D., Roques-Carmes, C., Tricot, C.
1992 - *"The perturbation dimension for describing rough surfaces"* Int. J. Mach. Tools Manufact., vol 32, n°1/2, pp 211.