CHARACTERIZATION OF THE POWDER PARTICLES SHAPES AND PROPERTIES USING THE FRACTAL THEORY

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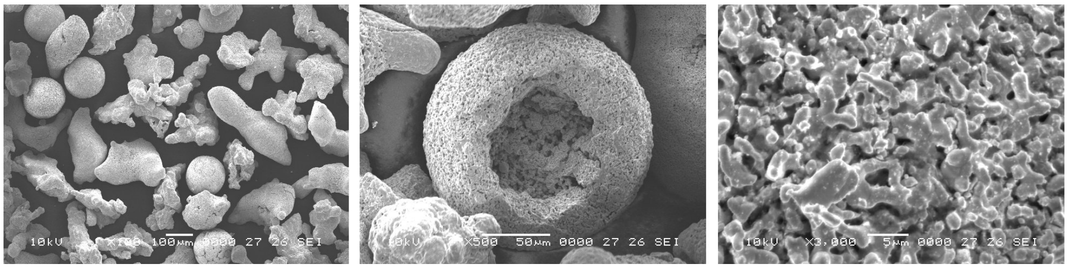
Abstract: Irregular shapes that are characteristic to powder particles obtained by water atomization or other methods, cannot be described using the Euclidian geometry. Conventional factors used to characterize such irregular shapes compares the shape of particles relative to a spherical shape and evaluate the difference between them through different coefficients. All these methods are not accurate and do not provide enough information related to the texture of particles surface. The fractal theory can be applied more accurately revealing new properties of rugged systems as metal powder particles obtained by powder metallurgy technology. Present paper presents a study of rugged particles through counting box method, based on the fractal theory. A software program was developed using the C++Builder language programming for images analysis of different powder particles shapes and sizes. The structural and textural fractals are calculated for each particle analyzed.

1. INTRODUCTION

Particles shape, like particles size and internal porosity are the most important characteristics of metallic powders used in PM technology. These characteristics present a great influence on the technological properties of bulk powders, such as: flow rate, apparent density, compressibility and sinterability. Due to the high degree of irregularity particles shape and size, the quantitative shape and size analysis of such systems is very difficult in terms of Euclidian geometry. During time, it was many attempts to improve the shape/size quantitative analysis through more accurate methods, presented in order of their historical development: conventional shape factors, stereological characterization, morphological analysis and fractal dimension analysis. The purpose of this article is to define mathematically the particles shape using fractal theory, which in turn can be used to predict behavioral characteristics of metallic powders. The earliest studies on shapes morphology using fractal theory was done by Mendelbrot [1-4], using compass rule. Since then were developed other methods like: counting box, mass-radius, pixel-dilation or Caliper method. In the present study, it was used the counting-box method that was implemented in a software program called “Fractalia” - conceived at the Technical University of Cluj [5].

2. EXPERIMENT PROCEDURE

As shown in SEM images presented in fig.1, viewing a particle at increasing levels of magnification appears to reveal an increasing (infinite) surface area. Fractal dimension is quantifying the correlation between irregular shapes, surface topography of particles and their mathematical correspondent values. The fractal dimension (F_D) measure the ratio of increasing detail with increasing scale [1-4].



a) X100 b) X500 c) X3000

Fig.1 Water atomized FeCrMo prealloyed powder (1.5 wt % Cr, 0.5 wt % Mo)

Due to the statistical behavior of powder characteristics, finding the fractal dimension for a bulk powder it's a challenge task that we try to overcome by using an algorithm based on the self-similarity dimension.

The image first needs to be converted to binary (the pixels can be only black or white) and then the contour of the image is extracted with a 1-pixel line width. The Fractalia program can do also a progressive binary image conversion in order to extract more details from the texture of particles.

For individual powder particles, the Euclidian space containing the image is divided into a grid of boxes of size "d" and counting the boxes N(d) which are not empty (the boxes that contain the contour) as it's shown in fig2. Then the size "d" of boxes is changed to progressively smaller size and the counting process is repeated for each "d".

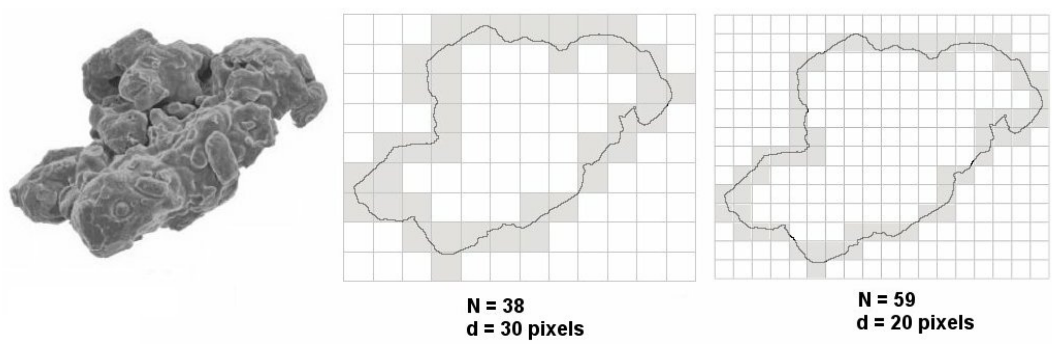


Fig.2 Counting-box method

$$F_D = \lim_{d \to 0} \frac{\lg N(d)}{\lg \frac{1}{d}} \qquad (1)$$

The logarithm of N(d) versus the logarithm of 1/d lead to a line whose slope corresponds to the fractal dimension by counting-box method (eq.1). At some value for grid size "d" the regression line slope is changing, revealing the increasing influence of surface topography particle over the structural dimension, as can be seen in the fig.3.

The fractal dimension which is characteristic of the shape of particle is defined as the structural fractal, since the fractal dimension which is useful for describing the texture of particle is defined as textural fractal. Both fractals take values between 1 and 2. A value close to 1 corresponds to Euclidian shapes or boundary respectively and an infinite ruggedness has fractal dimension equal to 2 (the boundary curve fill all plane).

3. RESULTS AND DISCUSSION

The powder particles analyzed with Fractalia and ImageJ software was obtained by water atomization, sieved and for each granulometric class were taken pictures by SEM and metalographic microscope through transparency method. The structural fractal is equal with the slope of regression line Y1 and textural fractal is equal with the slope of regression line Y2 that are drawn in the graphs obtained with Fractalia program (fig.3, table 1).

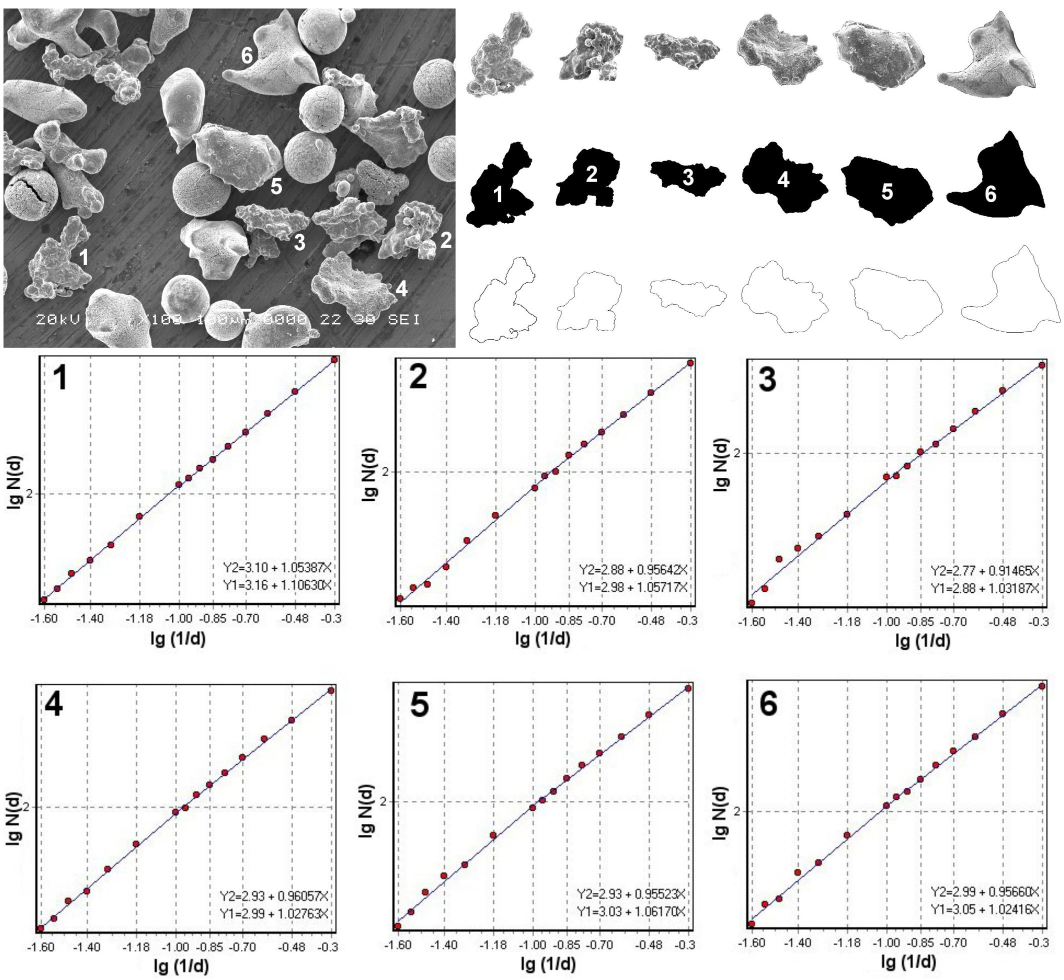


Fig.3 Structure and texture fractals. Water atomized FeCrMo prealloyed powder (+125 μm powder size, 1.5 wt % Cr, 0.5 wt % Mo)

These factors together with the imperfections of digital images that are physically limited in resolution lead to a spreading effect of measured fractal dimensions by different software applications. For that reasons we had calculated the fractal dimensions F_D (one scanning), mean fractal dimension (over multiple scanning) and mean fractal dimension without horizontal intervals (or slope corrected F_D). The horizontal intervals arise spuriously as a limitation of pixels and grids – after a point as box size decreases, the number of boxes required to cover the image stay the same over a long interval of change in size (especially for high values for box size). This causes plateaus in the log-log plot without to reflect the real features of image pattern and has to be removed obtaining the slope corrected fractal dimension.

Table1. Results obtained with FracLac plug-in for ImageJ and Fractalia software (fig.4)

No	Foreground / total pixels	Fractal dimension F_D (Fractalia)	Mean fractal dimension F_D (FracLac)	Correlation regression line	Mean F_D without H intervals (FracLac)	Circularity	Pixel density
1.	1212 / 45980	1.1063	1.1017	0.9974	1.0984	0.8453	0.0372
2.	650 / 30927	1.0571	1.0357	0.9938	1.0338	0.8639	0.0269
3.	524 / 23002	1.0318	1.0348	0.9942	1.0265	0.7532	0.0321
4.	698 / 49980	1.0276	1.0249	0.9957	1.0242	0.9013	0.0213
5.	692 / 52800	1.0617	0.9992	0.9968	0.9958	0.8810	0.0194
6.	802 / 69160	1.0041	1.0205	0.9954	1.0204	0.8098	0.0189

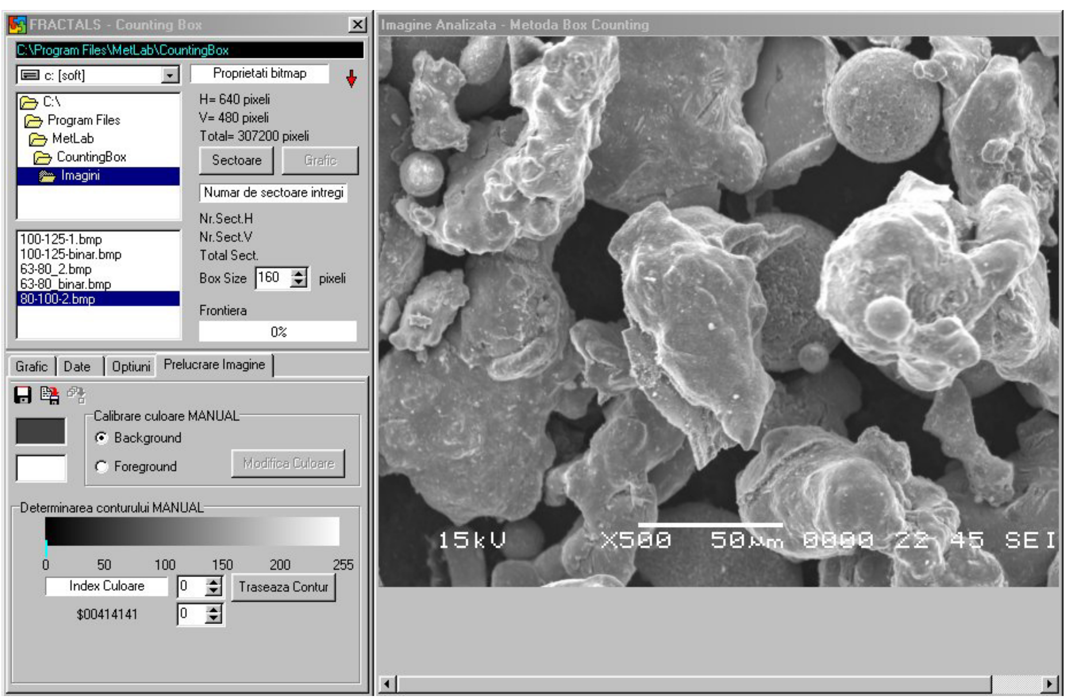


Fig.4 Screen capture of Fractalia program [5]

Because of limited resolution that are inherent of digital images (the minimum box size can not be smaller than one pixel) instead of increasing scale for particle image in order to increase resolution, we have done a progressive binary conversion, as is illustrated in fig.5. As the progressive binary conversion steps are increased, the texture of particle is revealed more accurately. Starting for an 8-bit image particle (256 grey colors, see picture from fig.5), the color palette is divided in equal intervals, depending on the number of binary conversion steps considered.

For each color interval, Fractalia program is searching for the pixels that have the color inside of that interval and it does the pixel binary conversion to black or white, depending on the selected color for background and foreground respectively, as is shown in fig.5.

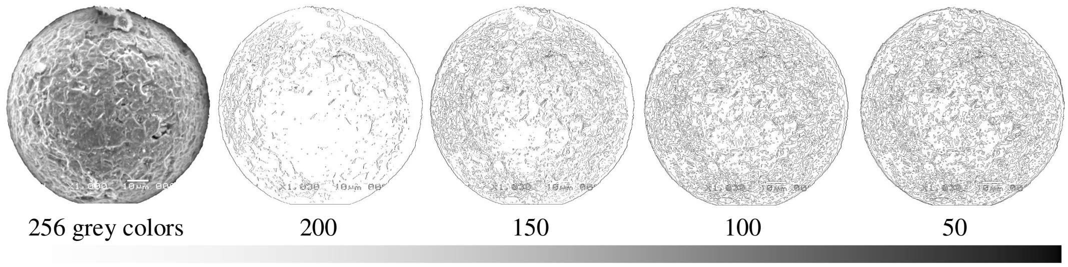


Fig.5 Progressive binary conversion using Fractalia program

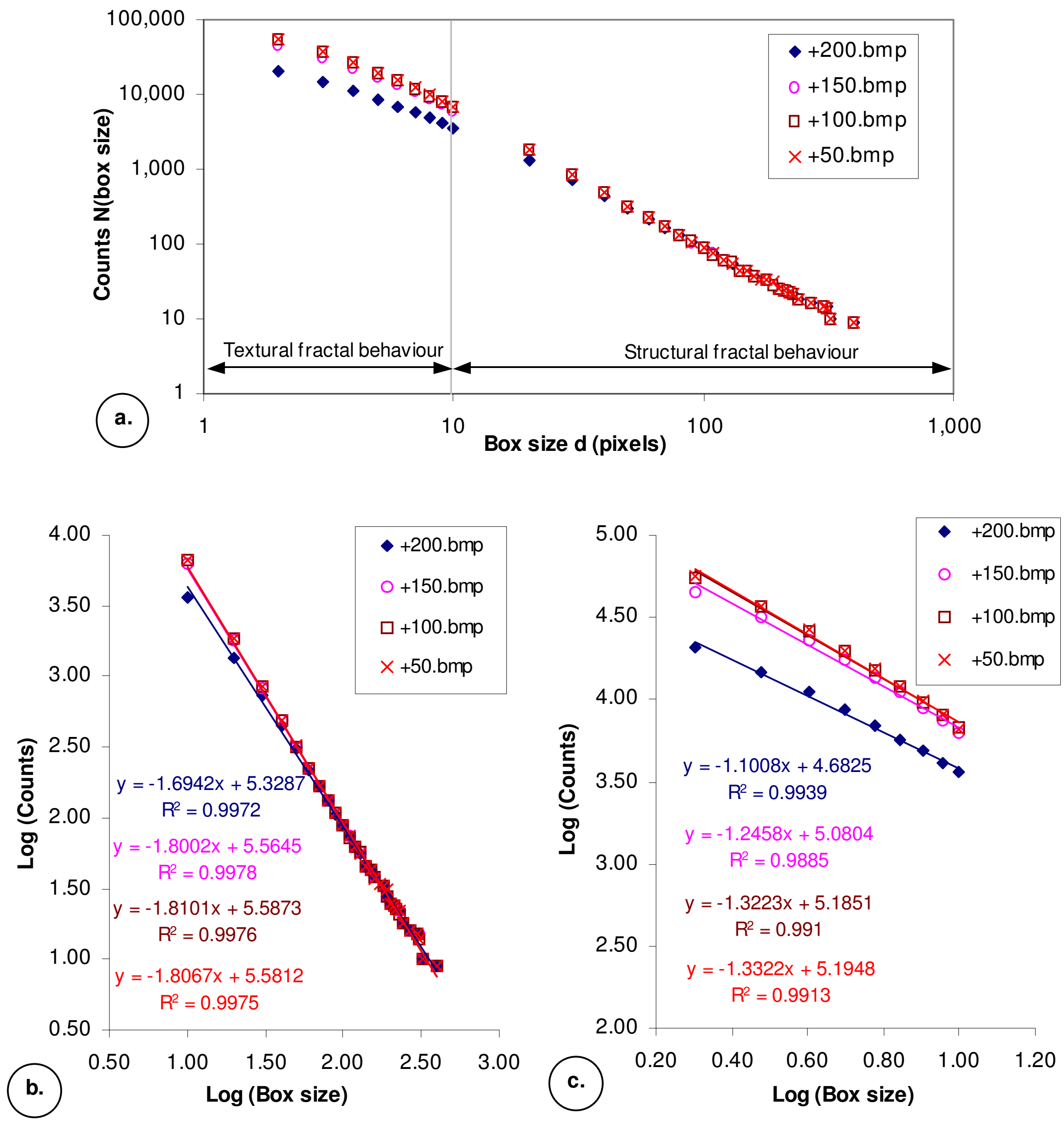


Fig.6 Structural and textural fractals behavior for the progressive binary converted images a). all binarized images; b) structural and c) textural behavior details

As can be observed in the diagrams presented in fig.6 and fig.7, the increased details of the texture particle surface lead to higher values for the texture fractal dimension while the structural fractal remain constant. In the example analyzed, the texture fractal dimension is converging to 1.332 value.

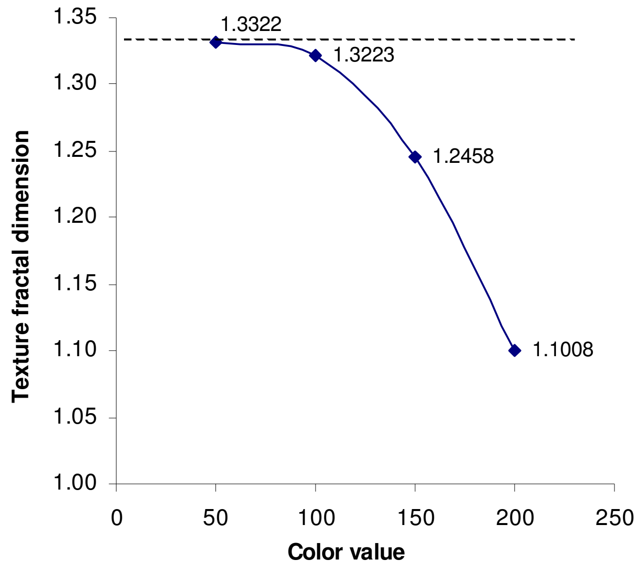


Fig.7 Converging of textural fractals dimension for the progressive binary converted images

4. CONCLUSIONS

- The fractal theory is representing a new modern method for the images analysis that can offer more and accurately information about the structure and texture of powder particles. The fractal dimensions can be used to establish mathematical correlations between powder technological properties and particles characteristics.
- A software for image analysis and fractal calculator was realized using C++Builder language programming. The fractal dimensions are calculated by counting box method.
- A new method was proposed to investigate the texture of powder particles by progressive binary conversion of images. The conventional methods for particles analyzing doesn't offer information about the texture particles (that is an important property for many surface phenomena as: chemical reactivity, sinterability etc.

Reference

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