ACTA STEREOL 1995; 14/2: 201-207
ORIGINAL SCIENTIFIC PAPER

USING MATHEMATICAL MORPHOLOGY ON GREY LEVEL IMAGES FOR POWDER MATERIALS

Séverine Mathis, Michel Coster

LERMAT, URA CNRS 1317, ISMRA
6 Bd. du Maréchal Juin, 14050 Caen Cedex, France

ABSTRACT

The visible upper surface shape of powder aggregates is studied with a SEM (scanning electron microscope) using the grey levels in the images. On the one hand, some new parameters for individual analysis such as volume, surface, maximum height or number of maxima per particle are defined. On the other hand, some other parameters and functions can describe the whole powder, such as global roughness or granulometry. Those global parameters were firstly defined for topological studies. They are fitted to powders. Then, for both kinds of parameters, one has to pay attention to images borders as some particles hit the frame. The answer to this problem is different whether one works with individual or global parameters.

Key words: image analysis, morphology, non planar surfaces, powders.

INTRODUCTION

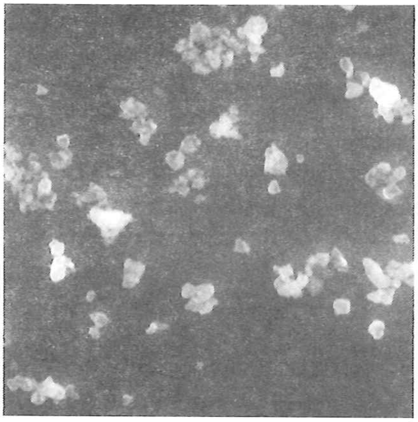
Powders are usually studied using physical methods like sedimentation or laser diffraction, which gives only information about size. Binary image analysis is also often used on thresholded images from SEM or optical microscopes, which gives shape parameters in addition to size parameters. But images should not always be thresholded because the important part of information coming from grey nuances would never be taken into account. Hénault (1992), Prod'homme (1992) and Gauthier (1994) have already been searching for new kinds of parameters based on grey level information on non planar surface images (fractures, ceramic films, simulated surfaces). The scope of our work is different in so far as we do not study the whole image but only areas of interest where the particles of powder are.

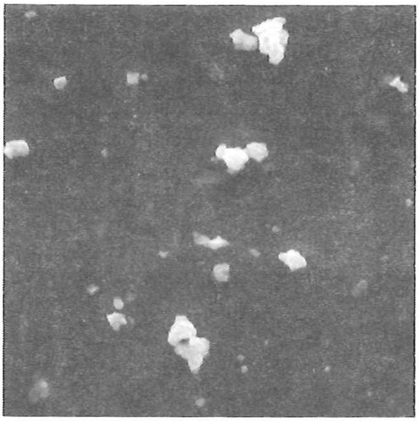
Powders, digital images capture and pre-treatment

Very small powders can be investigated by scanning electron microscope (SEM). Very small powders of different batches of $BaTiO_3$ were dispersed in ethanol and scattered on a mirror polished brass stand. They were then observed using the SEM at 3500 times magnification. Digital images with 512*512 pixels, 256 grey levels and a 70 nm sided square pixel are straightaway obtained. The physical meaning of grey levels in SEM images is complex, but the only information is a grey level that is simply interpreted as an altitude in the following work although it is not the real altitude of the material surface.

Pre-treatment

The powder and the stand must be differentiated. Using Visilog software, the image is smoothed with a 3*3 pixels large averaging filter followed by a median filter as large as the averaging one. If we applied the median filter first, even very high narrow peaks and very deep narrow holes would completely disappear, whereas, using the averaging filter first, it widens those narrow very high peaks and deep holes enough, so that they do not completely disappear with the median filter. Then, it is quite easy to distinguish the powder from the stand with a simple threshold, since the atomic numbers of copper and zinc from the brass stand, are much lower than the atomic number of barium, the stand is much darker than the powder. In the whole image, the stand is set to the grey level 0.





10 μm ----------

Fig.1. SEM image of powder 1.

Fig.2. SEM image of powder 2.

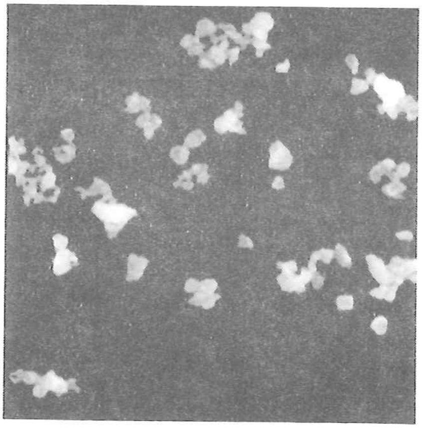
MEASURES

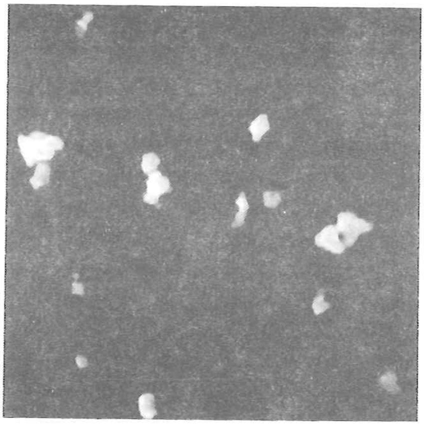
Two kinds of measurements are used: By individual analysis, each objet is studied one after another, results are statistically meaningful. By global analysis, all the different objects of an image are studied at the same time and some global parameters describing together all the objects of several images are calculated.

Individual analysis (one object after the other)

For individual analysis, one has to get rid of objects that hit image borders. Probability of an aggregate to appear entirely in the field of images is taken into account for the calculation of histograms and statistics using the Miles & Lantuéjoul's correction.

We can distinguish metrics parameters from topologic ones.





10 μm ----------

Fig. 3. Pre-treated image of powder 1.

Fig. 4. Pre-treated image of powder 2.

Metric parameters

The easiest parameter to calculate is the volume of the aggregate umbrae; it is the addition of the grey levels of all the pixels in the aggregate. (As long as we do not see hidden faces of the aggregate, we can not calculate the aggregate volume, but only the volume of the aggregate umbrae.) We did also calculate the triangular area of the aggregate upper surface : The triangular area of the aggregate umbrae is the areas addition of all the elementary triangles touching the surface of the aggregate. As soon as one point of an elementary triangle is on the aggregate, its area is taken into account. Therefore, the extern area, from the outside borders with the grey level 0, to the inside borders of the powder, is taken into account. If the inside border grey level is high, this extern area is large. The ratio of the aggregate umbrae triangular area to the binary aggregate area is the surfacic triangular roughness (R_A) of the aggregate umbrae. In the same way, we can calculate the aggregate umbrae linear roughness, which is the ratio of the outline cross section length (with polygonal approximation) to the binary crossing length in the same direction, usually the digital images frame directions. For the undergoing surfacic triangular roughness (Fig 5), the relationship between grey levels and altitudes was chosen supposing that aggregates were nearly as high as large.

Topological parameters

Aggregation processes can provide various topologies. A simple way of characterising the aggregation mode is to count the numbers of regional maxima (peaks) and of regional minima (holes) in each aggregate. Aggregates are supposed to be made of convex grains stuck together. For each visible grain in the image, there is one maximum, whereas it needs at least three joined grains to get a minimum. So, there are generally more maxima than minima. The more the powder is aggregated, the more numerous are the grains per aggregate and so, the maxima per aggregate. The more compact the aggregates are, the closer together the grains are and the more numerous minima per aggregate are observed.

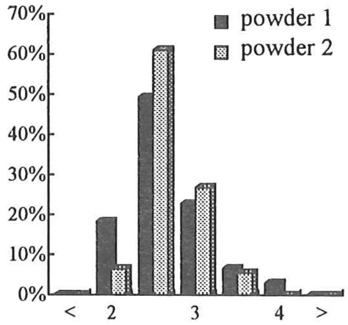


Fig. 5. Surfacic roughness distributions for powder 1 and powder 2.

Using these parameters, we hope to distinguish the difference between both powders. One (powder 1) encloses aggregates made of numerous small grains stuck together, which should lead to a high number of extrema per particle, whereas the other (powder 2) encloses some bigger grains not so often stuck together, so logically less maxima and minima per particle. We also expect more regional maxima than minima because the aggregates are neither very large neither very compact. Moreover, SEM images stress the peaks whereas the holes are mixed up with shadows and they seem connected. In each aggregate the number of regional maxima and regional minima were automatically counted (Fig 6). 171 aggregates of powder 1 and 94 aggregates of powder 2 were analysed.

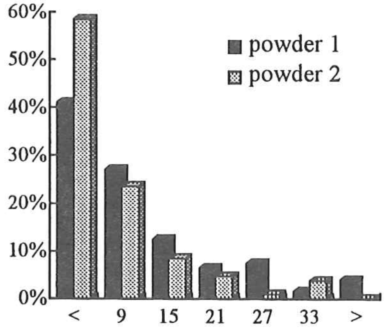


Fig. 6. Maxima numbers per aggregate.

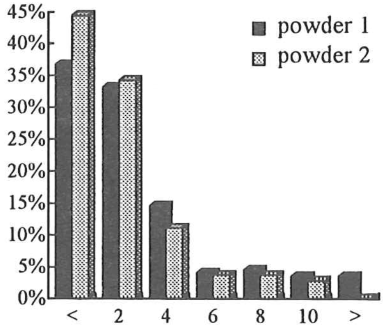


Fig. 7. h>maxima numbers per aggregate h=16.

Table 1. Powder 1 is more aggregated than powder 2.

extrema numbers per aggregate		powder 1		powder 2	
		mean	standard deviation	mean	standard deviation
	minima	6.4	6.6	3.9	4.5
	maxima	12.5	12.4	8.2	7.7
(h=16)	h>minima	2.0	2.0	1.2	0.5
	h>maxima	3.3	3.2	2.6	2.3

With parameters such as the number of extrema per aggregate, narrow peaks count as much as large ones, high as much as low ones, narrow holes as wide ones, deep or shallow. Using openings, one can get rid of narrow peaks, with closings, one can fill up narrow holes. Thanks to h-extrema defined by M. Grimaud (1991), one can count only peaks higher than h, and holes deeper than h.

Several possible definitions of a minimum depth were proposed by M. Grimaud, the best one according to its mathematical properties, is the following : The depth or dynamics of a local minimum is the minimum of the dynamics between this local minimum and the catch basins whose minima are at a lower grey level. Lets take a function $\mathbf{R}^2*\mathbf{R}$, with a reconstruction $R_f(f\text{-}h)$ of f-h under f, f maxima of dynamic lower than h are eliminated. The $R_f(f\text{-}h)$ maxima number is the number of maxima higher than h in f, or the h>maxima number of f (Table 1 & Fig 7).

Extrema whose dynamics are 1 grey level upon 256 in the image, are very difficult to perceive, whereas maxima whose dynamics are higher than about 16 grey levels are very easy to see. h>extrema per aggregates ($h \approx 16$) are better visually fitting parameters than simple extrema and they show the differences between both powders. Notice that with h=0, h>extrema are exactly classical regional extrema.

Global analysis (images after images)

We talk about global analysis as opposite to individual analysis, however we do not study the image as a whole, as in previous studies about non planar surfaces, but we make our measurements only on the image aggregates all together. We do not study aggregates after aggregates but all the image aggregates together even those who hit the images borders.

Morphological transformations are nevertheless applied to the whole image (they are not geodesic). The measure mask theorem must be applied for any erosion or dilation and growing morphological transformations must be avoided, so that the aggregates positions on the stand do not disturb the measurements.

Metric parameters

We calculated the "triangular surfacic roughness mean in measure" of all aggregates in our images. With individual analysis, we calculated the "triangular surfacic roughness mean in number". If one calculates the surfacic roughness mean with the binary aggregate area weighting, one gets the "surfacic roughness mean in measure". But we get it straightaway for all the aggregates of an image by executing the ratio of the total triangular area of all the aggregates of the image to their total binary area. The "surfacic roughness mean in measure" is also the "global surfacic roughness". The mean of global surfacic roughness in each image with powder binary area weighting is the global surfacic roughness for all images powder. The result is of course different from the triangular surfacic roughness mean in number calculated with individual analysis.

Global triangular surfacic roughness is 2.66 for powder 1 and 2.87 for powder 2 .

We also applied a grey levels opening granulometry to our powders. The i large granulometric density is :

g(i)= (i large open volume - (i-1) large open volume) / starting volume (1)

Several images mean must here be weighted by their starting volume. Notice that thanks to pre-treatment, the stand grey level is 0, its volume is nil and it does not disturb our measurements.

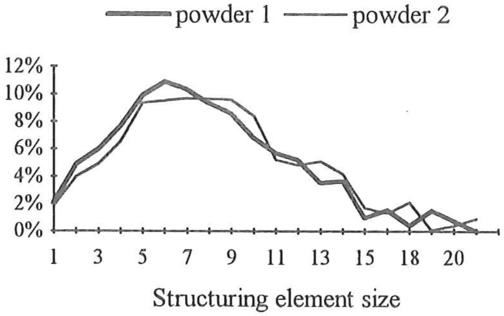


Fig. 8. Granulometric densities.

Topological parameters

Finally, we calculate the extrema and h>extrema numbers, per powder unit area and not any more per aggregate. These parameters are much quicker to calculate than individual parameters because all the objects in the image are taken into account simultaneously. We get straightaway the extrema number "mean in measure" without giving up aggregates touching images borders. Shell correction is needed in these calculation in order not to count several times extrema on images borders. Moreover, the measure mask theorem is still to be applied because of reconstructions. Here also, the average over several images must be weighted with powder binary area. Applying these preceding corrections, these parameters are unbiased.

Table 2. Extrema numbers per area unit.

unit per 10000 pixels	powder 1		powder 2	
or per 50 μm^2	h=0	h=16	h=0	h=16
h>minima	64	16	38	7
h>maxima	127	32	98	31

The great advantage of global analysis on powders, is that we can analyse big aggregates though they often hit the images frames, as well as and simultaneously with small aggregates. Finally, calculations are quicker for global than for individual parameters.

CONCLUSION AND PROSPECTS

We have already found parameters fitted to powders and unbiased using grey levels. These parameters such as numbers of extrema or h>extrema and granulometry agree with visual sensations in grey level images, and could not be evaluated on binary images. Therefore, it is really a promising method to interpret digital grey level images. Roughness is not an easily understandable parameter on SEM images but it should be more interesting on confocal topographic images. Granulometry, numbers of extrema per aggregate or per area unit, can be useful to analyse confocal topographic images but they are already interesting on SEM images to know about powder aggregations.

REFERENCES

Bhanu Prasad P, Lantuéjoul C, Jernot JP,Chermant JL Unbiased estimation of the Euler-Poincare Characteristic, Acta Stereol 1989; 8/2: 101-6.

Coster M, Chermant JL Précis d'analyse d'images Les Presses du CNRS 1989; 560 pages

Gauthier G, Rebillon JO, Coster M, Henault E Grey tone level images characterization by morphological functions : application to non planar surfaces, Acta Stereol 1994; 13[1] : 155-60.

Grimaud M La géodésie numérique en morphologie mathématique Application à la détection automatique de microcalcifications en mammographie numérique Thèse de Doctorat de l'Ecole Nationale Supérieure des Mines de Paris 1991.

Hénault E, Chermant JL Parametrical investigation of grey tone image Acta Stereol 1992; 11[suppl I] : 665-70.

Lantuéjoul Ch On the estimation of mean values in individual analysis of particles Microsc Acta 1980; 5 : 266-73.

Prod'homme M, Chermant L, Coster M Texture analysis of ceramic films by image processing Acta Stereol 1992; 11[suppl I] : 261-6.

Presented at the 9th International Congress for Stereology, Copenhagen, August 20th to 25th, 1995.