Surface State Analysis by means of Confocal Microscopy

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Abstract

This article aims at the illustration of the potentialities offered by new imaging technologies : in the present case, confocal microscopy.
Such an approach gives access to surface information like porosity, wear, cracking and roughness, and is thus a very powerful tool for the evaluation on the surface state of various materials : concrete, ceramics, aluminium alloys, textiles.
A perspective is given to exploit and visualize this new data in the best way.

Key-words – concrete, materials, confocal microscopy, image processing.

Introduction : Recalls an confocal microsopy

The invention of confocal microscopy in 1957 by Minsky has opened the way for a constant evolution of this technique, due to the progresses in computer science, electronics and optics. The particular system we are here interested in is the confocal microscope with rotating disk. The TSM (Tandem Scanning Microscope) created by Petran [PETRAN 68] is an improvement of the Minsky system. It consists in a Nipkow disk (fig 1) drilled with hundreds of holes (50 μm diameter).

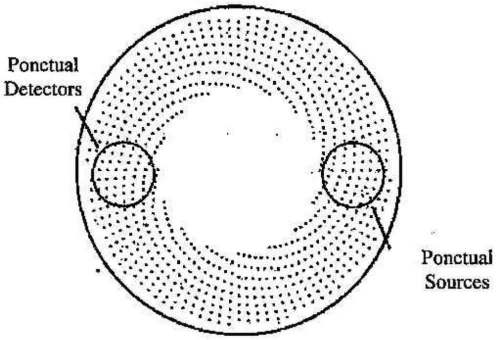


Fig 1. The Nipkow disk

The screening of the sample is realized by the disk rotation [KINO 90]. At any time, several holes are lightened by a white light source in order that the sample surface receives incident beams.

The reflected rays will pass back through the disk only if their meeting point with the material is exactly positioned in the focus plane (see fig 2).

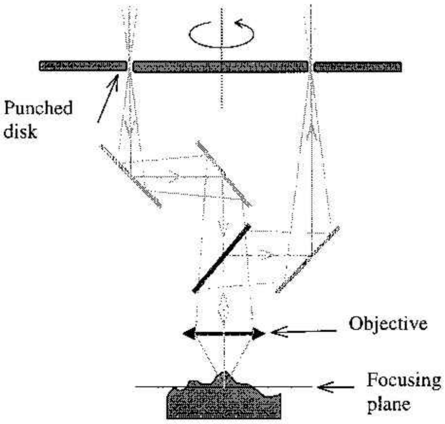


Fig 2. Optical rays path modelisation

In such conditions, at each position of the stage, the sensor (CCD camera) observes the level line situated in the focusing plane i.e. the intersection of this plane with the sample surface (see fig 3).

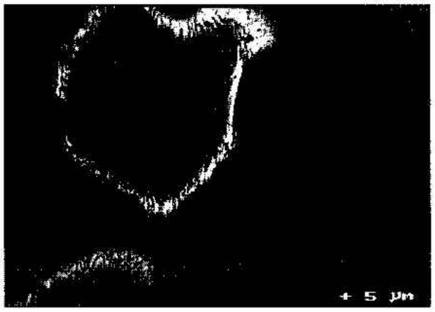


Fig 3. Visualization of a level line.

The relief of the sample is then acquired by moving the programmable stage step by step (with the adequate resolution). In fact, each point (x, y) of the sample will be seen with a maximum intensity when it lies in the focusing plane.

The knowledge of the stage position gives the z-position of (x, y). We are thus able to attach a gray level at each value of the altitude (for example the bright pixels correspond to a high altitude). The observed surface is then associated with a topographic image (see fig. 4)

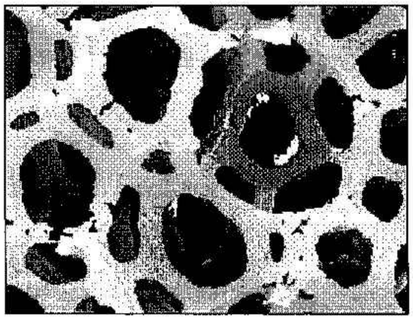


Fig 4. Topographic image of an electrolytic filter

Another information is accessible at the same time: the reflectance of each pixel. In fact, when (x, y) is placed in the focus plane during the vertical translation of the stage, its reflectance is maximum but is not the same from a pixel to another. Thus, one defines the reflectance map as the image where each pixel is equipped with its maximal reflectance.

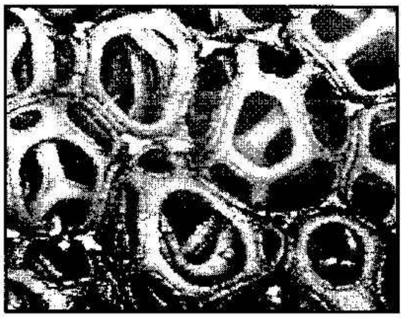


Fig 5. Reflectance image

An example: bubbles in a concrete sample

This is a very classical problem: estimating the volume and positioning of air bubbles in a concrete sample. Such an evaluation may be a solution to estimate the sample resistance to frost.

The classical approach consists in an acquisition of the concrete surface submitted to a tangential illumination.

In this case, the porosities corresponding to the bubbles appear as dark objects compaired to the "background" (i.e. the concrete surface). Such a method is easy to perform but it does not give a precise estimation of the three-dimensional size and position of the bubbles: the unique information directly accessible is the size of the intersections between the concrete surface and the bubbles boundaries. Some mathematical stereological tools allow an estimation of the three-dimensional size distribution based on the two-dimensional acquisition. To perform the model with a good quality it is necessary to assume that the bubbles are spherical, which is nearly exact.

The use of a confocal acquisition is here very efficient. The sample appears as a small concrete block whose surface intersects a lot of air bubbles. As previously seen, the topographic image permits an estimation of the altitude corresponding to each pixel of the bubbles bottom.

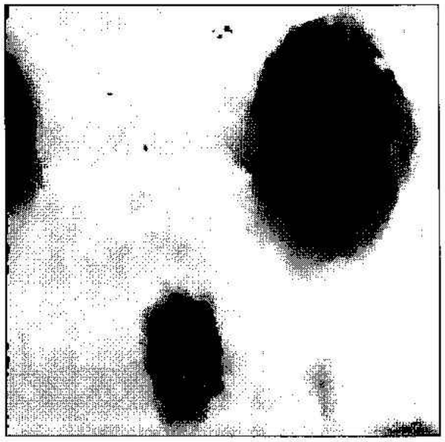
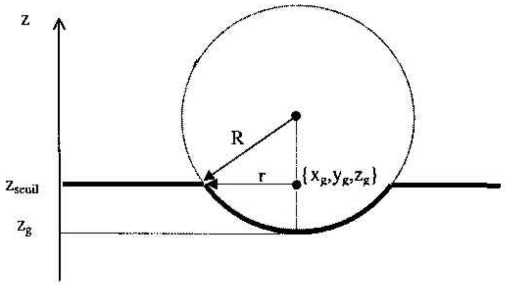


Fig 6. Topographic image of a concrete sample

From this relief information, it is easy to derive an estimation of the volume of each bubble, according to the following formulae:



$$R^2 = r^2 + \left(R - \left(z_{seuil} - z_g\right)\right)^2$$

$$R = \frac{r^2}{2\left(z_{seuil} - z_g\right)} + \frac{\left(z_{seuil} - z_g\right)}{2}$$

$$V = \frac{4}{3}\pi R^3$$

Fig 7. Volume estimation of a bubble.

Finally, it is possible to merge the topographic image and the reflectance one, in order to obtain a realistic representation of the concrete surface (fig. 8)

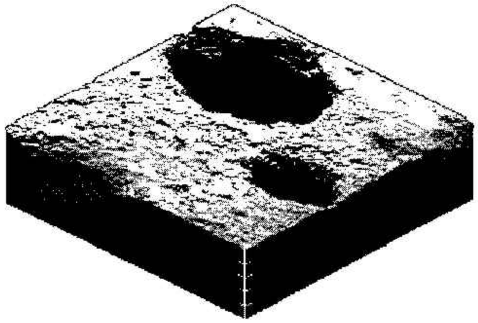


Fig 8. A realistic view of the concrete surface

Measurement precision

a) Theoretical spatial resolution

It is important to estimate the precision of a confocal 3D image. Here we refer S. Martinez [MARTINEZ 98] thesis, taking into account the formulae of Kino and Xiao [Kino 90]. The theoretical resolutions are given in the following array :

Resolution	**Magnification/ numerical aperture**	**Objective alone**	**Objective + disk**
Axial	X 50 / 0,85	0,67 μm	1,90 μm
	X 100 / 1,25	0,26 μm	0,43 μm
Lateral	X 50 / 0,85	0,22 μm	0,33 μm
	X 100 / 1,25	0,15 μm	0,22 μm

b) Vertical precision

After noise filtering, we want to know the vertical precision in a topographic image. Some experiences [Pawley 90] indicate "a priori" a value of 0,1 to 0,2 μm.

To verify such values, dependant of the optical elements (objective ...) and also of the mecanical structures of the TSM stage the same sample has been acquired under different magnifications and with a fixed resolution of 0,2 μm between each focusing plane.

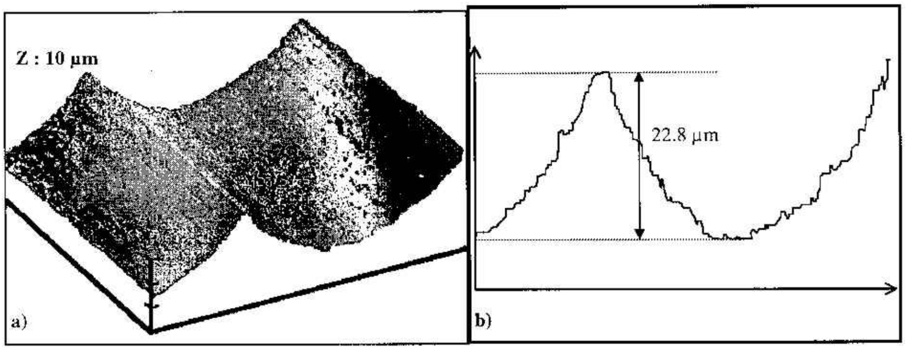


Fig 9 a) Sample used b) Depth measurement

For various objectives (x 10, x 20, x 40,x 60, x 100) and for a fixed resolution of 0,2 µm, the measured depth of the sample is always of 22, 80 µm.

Thus the vertical resolution between two optical cuts is 0,2 µm.

Conclusion

The confocal approach is at the same time efficient, quantitative, and very precise (at the scale of a micrometer) and appears as a powerful and promising substitute to the more classical MEB images for material estimation.

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