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# Why automatic image analysis? An introduction to this issue

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**Abstract**

This short paper introduces this special issue on the use of automatic image analysis applied to cement and concrete materials. One paper gives a very short overview of the methods to be used, and the others illustrate by many examples why the techniques of image analysis have to be used for cement and concrete materials. It evidences the importance of knowledge of the morphology of objects. These different papers are presented according to a certain morphological classification. © 2001 Elsevier Science Ltd. All rights reserved.

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## 1. Introduction

Everybody knows that when a material is fabricated, its properties will depend on the morphology of its microstructure, which in turn depends on the process used. There is a strong relation between process, morphology and properties. So, image analysis appears to be the pertinent tool to measure size, dispersion, orientation, shape, numbers, etc., of objects or components, and to evaluate the morphological changes under a process and/or a (temperature, stress, environment, etc.) solicitation [1–3].

In fact, today, image analysis includes several classes of tools: signal treatment, mathematical morphology [4], stereology [5], pattern recognition, and sometimes artificial intelligence [6]. The main objective of image analysis is (i) to obtain a measure or a sorting, which differs from some other activities in image science such as restoration, image correction, computer graphics or synthesis, and (ii) in some cases, if possible to accede to 3D parameters through measurements performed in 2D, using a stereological relationship. As defined by Weibel [5], "Stereology is a body of mathematical methods relating 3D parameters defining the structure to 2D measurements obtainable on sections of the structure".

Image analysis stems from an important demand in terms of needs and specific solutions offered using these techniques. The techniques of image analysis evolve very rapidly thanks to progresses in image acquisition capture and thanks to the development of algorithms and softwares, either general or for specific applications (such as Aphelion, Image Pro +, Micromorph, etc.). These techniques are also currently used in a dynamic way to control, for example, a fabrication process.

To understand the relationships between physical properties and microstructure, it is necessary to accede (i) to the diversity of the morphologies and their characteristics, (ii) to the heterogeneity with a large meaning, (iii) often to the modelling of the microstructure and of its evolution from probabilistic models, and (iv) to the "quality" of the interface between grains or phases from the chemical and structural points of view. Image analysis is the correct tool to investigate the first three aspects, and transmission electron microscopy the fourth one.

## 2. Cement materials

Concrete materials present morphology features which correspond typically to the morphologies observed for composite materials, or for petrographic or geological materials.

In the past decades many morphological parameters of concrete materials have already been measured by manual or semi-automatic methods: for example, see [7–10] or the ASTM standard which proposes always using Rosiwal's method of direct secants (method published in 1898!) to measure pore characteristics [11,12].

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With the development of personal computers, and the progress of image acquisition, image storage, image display, and of new algorithms and softwares, scientists from the civil engineering field ought to use automatic image analysis to characterize their materials by a pertinent and statistical method. Moreover it is the only way to obtain statistical information on homogeneity and dispersion, and to easily accede to the use of probabilistic models and simulations to reproduce realizations of microstructures in three-dimensions [13]. Such techniques are now used in French iron and steel metallurgy to objectively quantify and to offer a better understanding of the steel processes or to accurately characterize steel products [14]. It could be the same for civil engineering materials, and more specially with the development of new classes of materials such as high and very ultra-high performance concretes, new light weight concretes, or reactive powder concretes [15–17].

## 3. Issue content

This special issue on automatic image analysis applied to concrete materials intends to present different types of applications of image analysis, investigated by many laboratories, without really giving all the mathematical foundations, which can be found in specific books [1–6].

The scientist looking for solving morphological problems with image analysis does not generally know how to approach these major books on the subject and is always faced with a time problem. Moreover, as he is generally afraid of the mathematical basis, a brief recall is given on image analysis and mathematical morphology for civil engineering materials [18] to give the reader a better understanding of the methods used by the different authors. In order to illustrate these methods and the various facets of the subject some applications coming from the author's laboratory are then presented [19], and then from many other laboratories.

### *3.1. Grain size of particles*

To illustrate grain size measurements, a paper concerning carbon black aggregates and carbon black aerosol clusters is presented from image analysis taken from optical and transmission electron microscopies [20]. These are materials apparently far from civil engineering, but the method used is the same and, from the morphological point of view, there is no real difference between carbon particles, cement powder, fly ash, or silica fume (except the shape!).

### *3.2. ITZ morphological characteristics*

In materials science, image analysis requires, like in geology and in petrography, a well-suited metallographic section, which means avoiding scratches and particle tearings and to find a correct etching to avoid the development of complex algorithms. Nevertheless in the case of ceramics [21], cement or concrete materials, this step is very difficult to undertake. For such materials specific etchings with colouring are not at our disposal like in biology. So this preparation can be the limiting step.

The interfacial transition zone (ITZ) is an important feature for concrete materials. But it appears as complicated and variable. So, it is important to quantify this zone in order to understand its role better: the arrangement of the CSH crystals and of the pores included, for example, with regard to the mechanical and/or transport properties. But the problem is to be able to define this zone correctly using an automatic method: one of the most important difficulties is to obtain the correct threshold leading to a correct evaluation of its size and thickness [22–24]. If a model is proposed in that way, a correct comparison must be performed with the experimental results [24].

### *3.3. Hydration process*

Many techniques, notably physical ones, can be used to investigate the hydration process of a cement. Automatic image analysis can also be used but, as partially for the ITZ, the choice of the magnification is an important factor. Using an algorithm based on the entropy maximization, the surface area fraction of anhydrous remnant cement grains for a given maturity has been evaluated and these authors have considered the magnification of 200× as correct [25].

### *3.4. Dispersion, mean-distance and orientation of phases*

Quantification, size, dispersion and shape of different phases are classical studies performed by automatic image analysis. But in some cases to extract only the phases of interest requires specific morphological tools and more or less complex algorithms. A segmentation procedure of the clinker is proposed using the logarithmic image processing (LEP) model, as the chemical etchings are never reproducible enough and as there are variations of shape and hue of the segmented phases in clinkers [26].

Knowledge of the morphology of air-voids is important as well as their size distribution and their dispersion, as air-voids play a very important role in the freeze-thaw resistance. Three different methods are proposed to investigate their dispersion, based on the co-occurrence matrices, the simple and crossed-covariances [27], and their size distribution, via the use of two shape factors, to accede to the spacing factor, $\bar{L}$, as defined in the ASTM C 457 standard [28,29].

Regarding the air-void inter-distances, three different methods are also proposed and discussed: the measurement from (i) the half-distances between two voids' nearest neighbours (called count-dilation method), (ii) the half-distances between all neighbours (called SKIZ method) and (iii) the distance function [30].

Orientation of small clasts in tillite, which the authors consider as a natural concrete is investigated from the rose of intersections [31], while the orientation of microcracks and of fibres in a fibre reinforced concrete (FRC) was investigated from the rose of directions [19].

### 3.5. 3D analysis of surfaces

Confocal microscope is a more recent equipment which can also be used for cement and concrete materials. It can give access to the surface state such as air-voids, microcracks, roughness, and also on the wear behaviour [32].

### 3.6. Microcrack morphology

Microcracking in mortars and concretes is a very important phenomenon to know objectively as it plays a major role in the mechanical behaviour and the permeability characteristics, with well-known consequences during freeze-thaw. Moreover it enables access to damage parameters which are of importance for mechanical engineers. One of the difficulties in such investigations is to choose a correct magnification, which depends on the phenomenon to be investigated, as everything in our world is not fractal!

Three different investigations are presented, where the emphasis is put on the distribution of crack widths at a multiscale and on the establishment of a microcrack network [33], on the use of colour image, shape analysis and edge corrections to access a macroscopic microcrack network of a few tens of cm$^2$ [34], and on the comparison of a microcrack network with a probabilistic model at the microscale level, to follow the flow computation [35].

### 3.7. Models

Finally, the last four papers concern models. Concrete image can be modelled by probabilistic models: (i) they reproduce many types of morphologies observed at the microscopic scale by simulation, (ii) they summarize all the morphological characteristics to some parameters, (iii) they estimate the morphological characteristics accessible with difficulty by the experience (as some 3D properties), and (iv) they enable some predictions of physical behaviour from a correct knowledge of the morphology. Random simulations give access to 3D microstructures which can be used in computational software [14,36–38].

Using a Voronoi tessellation for the gravel and a Boolean model of spherical grains for air-voids, a 2D model is proposed for the mesostructure of a concrete [39]. Another method is proposed to generate a given geometry of cracks which will be statistically representative of a fluid flow in a macrocrack: it is based on the damage field calculated in a macroscopic–microscopic approach of the macrostructure [35]. In the case of plaster, a Boolean model with parallelepiped grains is proposed to model that microstructure, to estimate the contact properties between the microstructural units made of gypsum needles in order to establish a relationship with toughness or elastic behaviour [40]. The

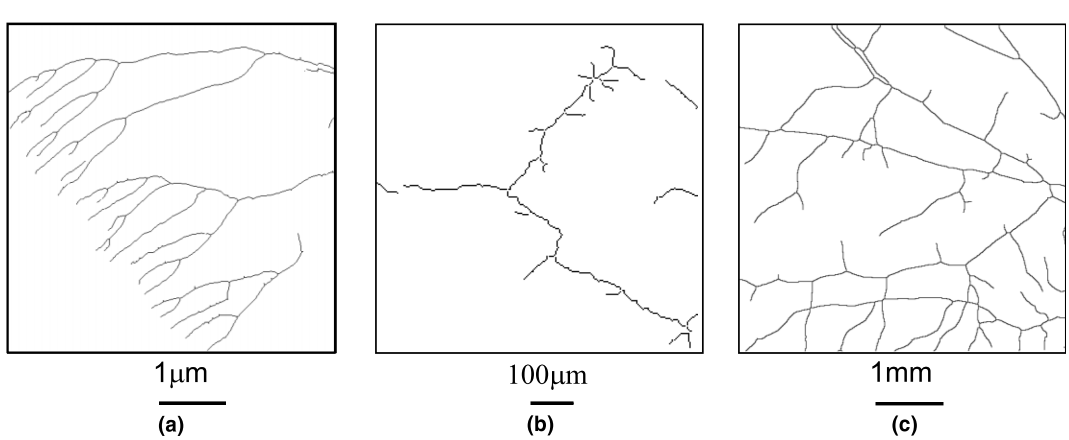
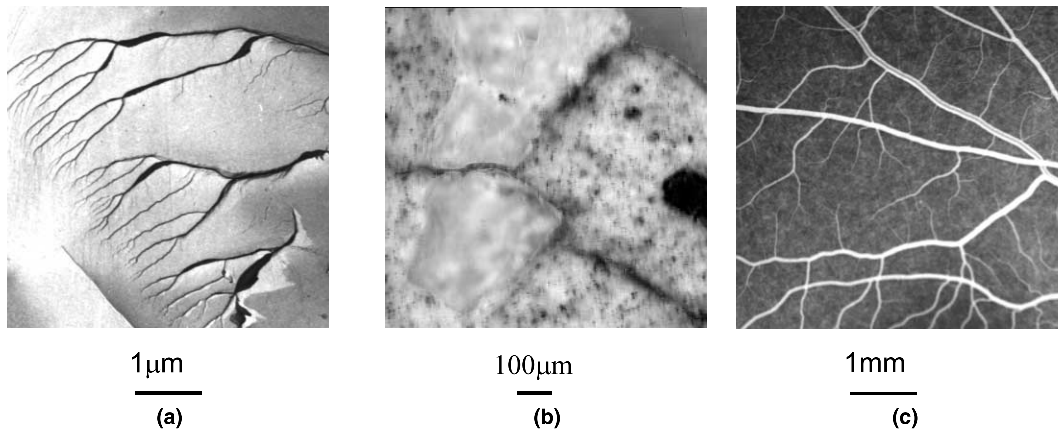



Fig. 1. Micrographs after some image processing of a vascular tree in eye fondus, river pattern in titanium carbide crystal and a microcrack in concrete.




last paper concerns an understanding of the relationship between microgeometry and transport properties (fluid flow) of porous media, in the case of sedimented particles (aggregates) of upper shoreface and tidal channel sandstone, with that given by synthetic 2D numerical simulations based on the porosity and the autocorrelation function [41]. Such an investigation can be extended to many geological materials and, of course, to cement and concrete materials.

## 4. Conclusion

As one can see, civil engineering materials can be considered, from the morphological point of view, as many other types of materials. Image analysis is a multidisciplinary tool, for which at a certain step of the image processing the morphologies look like the same features, even if the magnification is not identical.

Fig. 1 illustrates some networks of irregular lines observed during image processing of three different "materials" [42–44]: one is coming, of course, from concrete [43], the others from eye fundus [42] and a river pattern in a carbide crystal [44]. Morphologically there is no difference, even if the magnification is not the same.

Image analysis is a powerful tool which rapidly gives objective results and in a way entirely automatic. Moreover it is an essential and unavailable technique to test the homogeneity of any object or material. But the most difficult problem to solve remains the metallographic preparation to obtain a correct image of the microstructure, which can be thresholded easily enough: that deals with concrete materials (or ceramic!).

Thanks to the increasing power of personal computers and image capture systems, today it also becomes a tool for industrial control which has to operate in real time. Consequently the speed of the image processing must be adapted to the speed, for example, of a production line [14], like for specific applications on military images or in robotics. This dynamic morphological approach can also be of interest for civil engineering materials.

Nevertheless the different papers in this special issue on automatic image analysis devoted to cement, mortar and concrete materials demonstrate how it is possible to use the different techniques of automatic image analysis to quantitatively characterize the microstructure of such materials. It also illustrates how it is possible to use probabilistic models to accede to more complicated parameters that cannot be directly obtained from a measurement on a 2D metallographic section or without a hypothesis on the morphology. It must replace manual methods, to be more objective and statistical.

## 5. Nota Bene

Fig. 1 corresponds respectively to: (a) river pattern in a titanium carbide crystal, (b) microcracks in concrete, (c) vascular tree in eye fondus.

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