Clay-based bricks porosity estimation using Voronoi diagram segmentation

S. JIDA¹, H. OUALLAL², B. AKSASSE¹, M. OUANAN¹, M. EI AMRAOUI³, and M. AZROUR²

¹: Department of Computer Sciences, Asia Team, Laboratory M2I, Faculty of Sciences and Techniques Errachidia
²: Department of Chemistry, Faculty of Sciences and Techniques Errachidia
³: Department of Physics, Faculty of Sciences Meknes, Moulay Ismail University, Morocco

s.jida@edu.umi.ac.ma, b.akssasse@fste.umi.ac.ma.

Abstract

This work intends to apprehend the contribution of image processing techniques and computer vision in the characterisation of clay-based material known in Meknes-Morocco region. One of various characteristics to describe clay in a qualitative manner is porosity as it is considered one of properties with “kill or cure” effectiveness. For this, we use Scanning Electron Microscopy (SEM) images, as they are proved the best tool to characterise the quality of microscopical pore structure of porous materials. As we are only interested in pore region, we first apply segmentation based on Voronoi Diagram and 1D histograms. The results show a good match in comparing the imaging measurements with the experimental calculus using chemical process.

I. Introduction

The structural ceramic tiles and clay material industry is an important regional industrial segment consuming an important quantity of raw material especially the clay. Many coefficients can affect the quality of the clay-based material, one of them is porosity measurements. The effects of porosity on the physical properties of clay have been demonstrated in many studies on sintering and in development programs designed to establish production. Chemistry have provided us various techniques to calculate the void. For example, porosity can be estimated by computing volumetric measurements of core samples, or from geophysical logs, which calculate a property of the rock and infer porosity, or from Petrographic Image Analysis (PIA), which is pore size evaluation of a small sample. This field is conducted towards the measurement of porosity from clay samples, because it affords the basic concepts for understanding.

In computer science field, numerous projects use imaging methods and image analysis to characterize the porous media behaviour [1]- [6]. Examples of applications using images are structure quantification [7]- [9], flow modelling [5], [10], and mechanics of porous media [11], [12].

Here we consider both image processing techniques regarding the porosity measurement and the chemical experiments applied for the porosity measurement. The performance of some of the methods described will be demonstrated by comparing the imaging results with the experimental calculus.

The rest of the paper is organized as follows, we describe the chemical analysis method we have used in order to measure porosity for the clay samples is section II. Next, we describe the segmentation method we have used to estimate the porosity in section III. Later, in section IV, we demonstrate the utility of imaging techniques by comparing our results with those obtained.
by chemical analysis. Finally, we discuss and interpret the obtained results and we conclude the paper.

II. Chemical analysis method

The method usually used to measure the porosity of ceramic products can be summarized in the following steps:

1. Dry the sample in an oven at 150 °C for 2 hours or at 110 °C for 24 hours;
2. Determine the dry mass (\(M_{\text{sec}}\));
3. Put the samples in a bath of distilled or filtered water and boil them for 5 hours, taking in consideration that the specimens are covered with water.
4. After boiling, leave the samples for an additional 24 hours in the bath;
5. Determine the mass (\(M_h\)) of each sample suspended in water. Perform the weighing by placing the specimen in a basket attached to the scale;
6. After determining the hanging mass, lightly wipe the sample with a lint-free tissue or cotton tissue to remove any excess water from the surface;
7. Determine the saturated mass (\(M_{\text{sat}}\));

The measurement procedure should be performed as quickly as possible to minimize errors caused by water evaporation from the sample.

Finally, we calculate the porosity by applying the following equation (1)

\[
P = 100 \left( \frac{M_{\text{sat}} - M_{\text{sec}}}{M_{\text{sat}} - M_h} \right) \%
\]

In total, we have four samples of clay in three different firing temperature: \(S_0\) is a brut clay. \(S_5\), \(S_{10}\) and \(S_{15}\) are respectively three clay samples with 5%, 10% and 15% of organic matter. The principal objective of adding the organic matter is to see its impact on the porosity in terms of firing temperature along with a high mechanical resistance in high temperature.

III. Scanning electron microscopy images

Here, we describe a non-destructive process using computer vision for porosity estimation. This technique is basically used for characterizing materials such as ceramic. Its basic principle is to give a shot of electron beam to the studied surface, the atoms of the sample release secondary electrons with lower energy, these latter are processed by a detector giving the surface micrograph of the sample on a control screen. To observe a non-conductive ceramic samples, carbon or platinum metallization is required to make them conductive.

The scanning electron microscopy used is FEI QUANTA 200 United States.

III.1 Image analysis method

Before attempting any kind of treatment, we proceed to an image enhancement due to the presence of some noise. This fundamental pre-processing step help the further steps to work well and to leads to successful interpretation. For this purpose, we apply a filter that reduces the noise level.

III.2 Segmentation techniques

Here, we give a description of the segmentation method we have used in investigating of the sample used. For measuring the porosity, the pore size and the pore distribution of the clay, the result of segmentation was used. Segmented images are none other than a binary image. Thus, a whole package of grey level treatment can be exploited. Our choice is the Voronoi Diagram.

The Voronoi diagram as data representation structure has been extensively studied in the geometry and applied in different disciplines. Regarding the image analysis, the Voronoi
diagram arouses a particular interest. In fact, it is an effective way to describe, manipulate and interpret geometric entities. Among the work based on the use of the Voronoi graph, we can cite color image segmentation [13], [22], texture segmentation [14]. All these works share in common the fact that they apply VD directly on the image itself.

In order to avoid the high computational time, [15], [16] proposed a new approach based on VD using the generated clusters of intensity values given in the vertices of the external boundary of Delaunay triangulation (DT). They applied this method in order to segment face features. In this approach, the authors applied VD on a few selected point (<=255) from 1D image histogram instead of the image itself that result from gray intensity frequencies. The VD is used then to construct the DT which is the dual of VD. From DT, we can conclude to the convex hull set of the feature points which are the outer boundary of DT. Three main points are extracted from the set: two global maxima are obtained by extracting the top two values in the DT list of vertices; which correspond to the peaks in the histogram, and the minima that fall between the two peaks. These unique feature points are then sorted in ascending order to outline a one-dimensional vector (V) containing values that form the ranges with which merging and splitting decisions are made.

IV. Tests and results

In figure 1, we give the result of segmenting clay SEM images using VD. In the raw (b), the segmented pores are colored in green or red regions.

![Figure 1](image)

*Figure 1 Segmentation results: (a): original images, (b): the corresponding VD segmentation*

For the four clay images, we calculated the percentage of pores existing compared to the whole image. We obtained a noteworthy result described in the following figure2.
From the figure above, the estimation is close enough to the chemical analysis. We can explain the increase in porosity estimation using the imaging method to the fact of having different type of pores (cavernous) and also fractures sample, consequently, the SEM image show them as pores.

The figure shows the evolution of porosity in term of calcination temperature. By analysing the results, we can confirm the sample’s porosity is very important towards the lowest temperatures (800°C) for the different pieces elaborated because the sintering phase is not done well at this temperature [17].

Comparing the two figures, we can notice an important increase in porosity with the introduction of the organic matter as it heightens from 13,5% for the support with 0% of organic matter to 23,5% with 10% of organic matter at 1000°C and in parallel the volume goes from 13,63% for the supports with 0% of organic matter to 35,94% with 15% of organic matter at 1000°C. At this point we made sure to keep the porosity as high as possible despite the high firing temperature by adding the organic matter.

For the imaging method we have tested, Voronoi diagram exploitation seems to give better estimation. The choice of segmentation method shouldn’t be randomly but with suited processing. Recall that the main purpose of any segmentation method is to have an optimal
partition based on a given criterion. This requires the definition of the criterion as well as a rule for assigning each point to the appropriate class.

As the pores have an undefined geometric shape, we calculate the pores diameter by using the Feret’s diameter, it’s a measure of an object size along a specified direction. In general, it can be defined as the distance between the two parallel tangents on opposite sides of the image of randomly oriented particle [18].

In figure 4 below, we calculate pores distribution of the three temperature to see the effect of firing on pore’s behaviour.

![Figure 4 Pore size distribution in raw clay](image)

From figure 4, we can notice a decrease in pore size as long as the firing temperature increases. Some of the particles begin to melt and form a new component; glass; between the others that pulls them even closer. A crucial observation is the decrease of pore size from 900°C which is in agreement with the expected trend in refractory clay materials in which new crystalline phases develop [19]-[21].

V. Conclusion

In this work, we have presented a segmentation method in order to extract pore region in clay-based bricks for porosity estimation using a non-destructive computer vision process. The VD based porosity estimation is compared with traditional with chemical analysis. The segmentation phase is seen to be crucial for a correct quantitative image analysis microstructure. From the obtained results, imaging techniques are seen to be more objective, reliable and economical either in time execution and in chemical analysis requirements. From porosity estimation to pore size distribution, imaging method can be used widely to describe clay-based materials such as correlating the imaging porosity estimation with some other physical characteristics like mechanical strength and transport properties.

References


