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Use of computer assisted image analysis for the determination of the grain-size distribution of sands used in mortars

G. Mertens *, J. Elsen

Afdeling Geologie, Katholieke Universiteit Leuven, Celestijnenlaan 200E, 3001 Heverlee, Belgium

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Abstract

A quantification procedure for constructing the sieving curves of sands used in mortars, from two-dimensional data obtained by image analysis of thin sections, has been developed. To test the suitability of this procedure, thin sections were made from ten fluorescent epoxy-impregnated mortars, containing five different sands of which the sieving curves had previously been determined. Whereas previous investigations were typically based on independent and individual micrographs, a new approach has been adopted in which measurements are performed on single composite images. Two stereological models, based on cubic and spherical particles respectively are applied to the examples and the results compared with the sieving curves. The results obtained show a reliable congruence, especially for the spherical model and when shape factors of sectioned grains are high. Sieving curves and grain-size distribution curves established from image analysis may have virtually the same precision, but the latter has a lower reproducibility.

Keywords: Image analysis; Particle size distribution; Aggregate; Mortar

1. Introduction

Historical mortars have two main components: the binder, which is usually lime or hydraulic lime, and the aggregate [1], which in most cases consists of a locally available sand [2]. Knowledge of the grain-size distribution of the aggregate in these mortars, which plays an important role for restoration applications, is invaluable [3]. Combined with the volume fraction of aggregate used, this is necessary for designing compatible mortars. Furthermore, the sieving curve of a sand is a fingerprint of the geological formation from which the sand is taken, so that it is an important tool for tracing the origin of the raw materials [4]. A generally applied method of establishing the grain-size distribution of the sand is to attack chemically the mortar sample with an appropriate acid [5]. The binder is dissolved and the insoluble residue is used to construct the sieving curve. However, part of the aggregate may not be resistant to the acid attack and readily dissolve [6,7]. The large amount of sample required [8] is an additional restriction of this method. A different approach is required to obtain reasonable results when only a limited amount of sample is present. Image analysis of thin sections can overcome the limitations of the acid-attack method. Traditional optical or scanning electron microscope (SEM) images can be processed by image analysis methods to allow measurement of the sectioned grains. Well-established stereological calculations are used to convert these 2D data to the required 3D values [9,10].

In most studies, data are acquired from analysis of a set of individual images [6,11]. For statistical reasons, these single images need to be taken in an arbitrary and independent manner. An intrinsic problem of this approach is that, due to the limited resolution of digital cameras, small grains cannot be detected and measured. A possible solution is to choose a higher magnification, but this increases the edge effects, so those larger objects may not entirely lie within the field of measurement. Hence, larger grain-size populations are underestimated. The great spread of particle sizes is the most important difficulty to overcome. The proposed approach deals with this problem by making measurements on single composite pictures made up of a large set of individual images. In this way, edge effects are reduced without any loss of resolution and many particles are

* Corresponding author. Tel.: +32 16 327586; fax: +32 16 327981.
E-mail address: Gilles.Mertens@geo.kuleuven.be (G. Mertens).

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Table 1
The table shows the type of sand, the surface area of the digitised frame, the number of micrographs assembled, the number of objects in the measuring frame and the mean shape factor (cf. infra) of the objects in each thin section

Sample	Sand	Surface area (cm^2)	# Micrographs	# Objects	Mean shape factor (Q)
M01	Rhine sand	5.08	285	4237	0.7060
M02	Rhine sand	4.69	300	4008	0.6822
M03	Fine scouring sand	1.05	150	6122	0.6699
M04	Fine scouring sand	1.33	145	6387	0.6844
M05	Random sand 0/4	3.67	198	5548	0.7319
M06	Random sand 0/4	3.84	247	5126	0.7078
M07	Random sand 0/2	5.09	342	10206	0.7186
M08	Random sand 0/2	2.33	150	3641	0.7122
M09	Normalised sand	3.91	208	6203	0.7049
M10	Normalised sand	4.36	289	6648	0.7010

simultaneously measured, giving statistically reliable results. These show that the quantification procedure is successful. However, besides the effectiveness of the new approach, some limitations on the stereological probability distribution for homogeneous sands remain. Variability in grey-level distributions and a need for visual inspection of the composite images limit the method to be used in a non-automated procedure.

2. Experimental procedure

Ten mortar samples were prepared using five different sands (Table 1) according to Belgian standard NBN 771-10, which is currently used for the preparation of cement-based mortars. Since the procedure is oriented towards the application to ancient (mainly lime) mortars, hydraulic lime (Unilit TD 13N) was preferred to Portland cement as a binder. After drying, the samples were twice impregnated under vacuum with a fluorescent (FITC) dyed epoxy resin to enhance the contrast between the sand grains and the inter-granular space. Thin sections with a thickness of 30 μm were prepared from these mortar samples.

The micrographs were acquired with an Evolution LC digital camera attached to a Zeiss petrographical microscope. The images, which have a resolution of 833 pixels/mm, were made using a Zeiss 5X objective and incident fluorescent light. Subsequently, the micrographs were processed with the Image Pro Plus® software package. To verify the pertinence of the image analysis approach, comparison with another valid technique is necessary. Sieving analysis is probably the most widespread, generally accepted and easiest way of collecting information on the grain-size distribution of aggregates. For the five sands used as aggregates, the sieving curves (Fig. 1) have been established according to Belgian Standard NBN B 11-013.

3. Procedure

3.1. Image treatment

For the micrographs acquired in the RGB colour model (Fig. 2A), the intensity channel (Fig. 2B) has been calculated according to the following formula:

$$I = \frac{R+G+B}{3} \tag{1}$$

This gave the best contrast between aggregates and the inter-granular space, facilitating the thresholding operation (Fig. 2C). Additional image treatment before binarisation was unnecessary since the arbitrary boundary between grey-level of aggregates and matrix can be easily distinguished. This is shown in the pixel intensity profile in Fig. 2(B2). However, thin sections are strictly speaking not 2D sections. The section of a particle in the lower

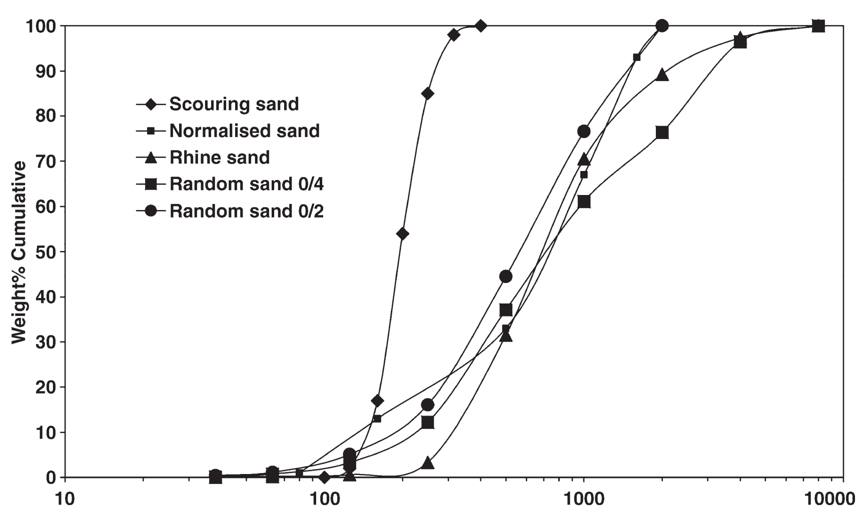

Fig. 1. Grain-size distributions of the aggregates determined by sieving.