



Mixing of concrete or mortars: Distributive aspects

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ABSTRACT

This article describes an experimental methodology offering efficiency criteria for granular materials in terms of their mixing distributive capability. The methodology is based on analyzing the distribution kinetics of colored tracer particles which were demonstrated to respond similar to cement particles during mixing. The effect of certain critical parameters such as the mixer type, the volume and the mixer speed are investigated. The influence of mix design characteristics on distribution is also presented for several mixer types. Finally, a comparison of the dispersive versus the distributive capability is achieved for several (mixer, mix design) systems, which opens opportunities for defining rules for transfer and extrapolation.

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1. Introduction

The final properties of mortars and concretes are strongly affected by the quality of mixing. The quality of mixing can be divided into two main phenomena, they are: dispersion and distribution.

The dispersive task deals with the rupture of the transient particle aggregates generally formed, in the very first moments after the water addition, by the capillary forces. Distribution, on the other hand, relates directly to the homogeneity of the final product and corresponds to the ability of the mixer to spread all the particles within the product.

Dispersion has not been extensively studied for granular material and virtually no literature exists for concretes and mortars until the authors of the present paper recently presented techniques to characterize the dispersion capability of mixer/mix design sets [1]. They proposed an experimental methodology incorporating mixing efficiency criteria for granular materials in terms of their dispersion capability. This methodology is based on the analysis of the dispersion kinetics of colored, cohesive, tracer particles that progressively deagglomerated while mixing. There is slightly more literature on distribution compared to dispersion because distribution was perceived as the most important phenomenon attributing to the material reaching its ultimate level of homogeneity in the mixing vessel. However, it is essential to note that one can distribute only what has dispersed thus, distribution and dispersion are complementary and mixing is efficient only when both processes are efficient.

In previous studies, the quality of the distribution process was evaluated through homogeneity characterization. This was measured either by evaluating the variability of the concrete composition, a very tedious task, or by observing the variations on the dependent macroscopic properties of the concrete (strength, rheological character-

istics, etc...). Charonnat [2] defines the efficiency of a mixer as its capability to “uniformly distribute all its constituents in the container without favoring one or the other”. Some authors [3–4] have described similar approaches, but all have also expressed concerns about the relevancy of sampling, which was extensively studied by Robin [5]. Concrete standards, such as EN-206, also provide some very basic guidelines about homogeneity. It indicates that mixing of the concrete constituents must be achieved in “compliant” mixers, and pursued until “a homogeneous aspect of the concrete is reached”. In ready-mix batch plants, concrete is assumed to be homogeneous; whereas, the concrete homogeneity must be verified in field applications and controlled by means of specific procedures. If concretes homogeneity can be proven, then mixing time can be reduced; therefore, the interest of developing mixing efficiency indicators pertaining to concrete homogeneity is industrially attractive. However, assumptions between product homogeneity and the stabilization of continuously measured values are often made at the batch plant. The most often measured value is the electrical wattmeter signal (extensively studied by Chopin [6]), despite the lack of an explicit proven link between signal stabilization and concrete homogeneity.

The current study is aimed at developing a “rapid” technique enabling us to characterize the efficiency of the distributive process during mixing of granular material such as mortars or concretes. It is important to stress that this is different from characterizing the mixing efficiency directly by analyzing the final granular composition of the material throughout the mixing vessel. Clearly, the efficiency of the distribution process is particle size dependent. The distribution of the finest elements of the mix design is more difficult and longer to achieve than the distribution of the largest particles [3]. For this reason, characterizing the ultimate distribution capability of the (mixer, mix design) set is only possible through the development of methods that trace the fine particles of the mix design. In the proposed approach, small colored non-cohesive particles are considered tracers of the cement particles and the evolution of the color

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homogeneity versus the mixing time is used to easily characterize the distributive capability of the system.

2. Methodology development

2.1. Principle

2.1.1. General methodology

The methodology developed for the evaluation of the *distributive* capability of (mixer, mix design) sets is based on the addition of a minor amount of colored particles. These tracers of the smallest elements of the mix design are assumed to behave similar to the powders present in the concrete or mortar. The spreading of the particles in the bulk concrete is thus measured versus time by means of colorimetric analysis performed on small samples extracted at different locations within the mixer. The tracer of choice is a red iron oxide pigment powder by Bayer (synthesized by Lanxess®), referenced as Bayferrox 110P. Its main characteristics are both to have the same mean size as the mean cement particle size and to be virtually non cohesive. It is note worthy that the study of the *dispersive* capability of the (mixer, mix design) system [1] was achieved by means of a cohesive iron oxide pigment (Bayferrox 110G) produced by granulation of 110P particles. Thus, the former dispersive study and the present distributive study are very consistent with each other. The color parameter a^* of the CIE Lab system is used to accurately characterize the red color of each sample.

The ratio of 110P particles added to the mix is typically 0.8% of the total mass of cement particles in the mix design. This value could have been lowered because it is mainly based on the analytical capability of the colorimeter. However, it should generally remain in the range (0.4%–1.0%), which was proven to have a negligible effect on the rheological characteristics of the mix design. The selected amount of colored powder was added at a single given position on top of the free surface of the mix, right after the addition of water but prior to mixing. This position depends on the type of mixer and although this is generally not critical, it must ideally be the same position for all the experiments performed with the same mixer. After the addition of the tracer, mixing would resume for a predetermined duration and after which mixing would stop in order to achieve the sampling protocol.

The ideal characterization of the heterogeneousness of the material in the mixer can be determined by the evaluation of the so-called “segregation” [6] which covers two concepts. The *intensity* of segregation characterizes the magnitude of the heterogeneity in the mixer, whereas the *scale* of segregation is an indicator of how heterogeneity is spatially structured in the mixer. If it is possible to obtain the intensity of segregation by means of statistical data processing, it is much more difficult to obtain the scale of segregation, since the latter would require a precise location of where the samples were withdrawn from within the mixer. Moreover, since the link between the scale of segregation and the physical causes is difficult to achieve, the present study exclusively focused on determining the intensity of segregation as a means to describe the heterogeneity of the concrete mix.

A “true” measurement of heterogeneity is not possible due to the statistical bias induced by sampling. The number of samples and their size with respect to the concrete volume are critical factors for the relevancy of the whole analysis. The estimation of the mixture’s heterogeneity ideally requires the extrapolation of “measured” values of the mean and variance from the examined properties (a^*) in order to obtain estimations of the “true” values of the mean and of the variance. In addition, since it is based on a sampling process, the notion of heterogeneity is not univocal and intrinsic to the state of a material submitted to mixing. It must be associated with characteristic scales.

If N is the number of samples, V_T the total volume of the mixer, and V_e the volume of one sample, we can define the different characteristic scales of the problem:

- The observation scale V_0 , simply defined as $V_0 = V_e$

- The heterogeneity scale V_h , defined by the ratio $V_h = V_T/N$
- The tracer scale V_t , defined as the mean volume of the tracer particles

Typically, the tracer scale must be much lower than the observation scale; otherwise the analytical variability becomes significantly high. However, this is not a significant issue since the tracer particle size is very small. Ideally, $V_0 = V_h$, which would indicate that the total volume of concrete or mortar would be analyzed after splitting into equal sub-volume samples. Although such experiments are exceptionally described in literature [4], this would be unrealistic on a daily basis if the experimental productivity was a concern. V_h must ideally be lowered in order to evaluate the heterogeneity at the smallest possible scale. Lowering the V_h would increase the total number of samples N , thus increasing the cost associated with the analytical protocol. The comparison between the observation scale and the heterogeneity scale indicates how accurately each sample characterizes a sub-volume of the mixer. Since V_0 by definition represents the volume of the minimum accessible heterogeneity, it would also always be equal to or lower than V_h . Therefore, the material heterogeneity is only estimated at the scale V_h and the *precision* of heterogeneity (at the minimum scale V_h) is an increasing function of the ratio between V_h and V_0 . It is thus important to analyze a sufficient number as well as a large quantity of samples. If the size of the sample is imposed by the analytical tools, then the choice on the number of samples remains undetermined.

Statistical values can be described for a^* . If p is the *true* mean and μ the *measured* mean then:

$$p = \frac{1}{V_T} \int_V a^*(V) dV, \quad (1)$$

p cannot be directly determined by using a sampling procedure, whereas the measured mean can be easily extracted from the experimental set of data a_i^* :

$$\mu = \frac{1}{N} \sum_{i=1}^N a_i^* \quad (2)$$

The *true* variance is:

$$\sigma^2 = \frac{1}{V_T} \int_V (a^*(V) - p)^2 dV \quad (3)$$

For the same number of samples N randomly “distributed” in the material, the *measured* variance S^2 is:

$$S^2 = \frac{1}{(N-1)} \sum_{i=1}^N (a_i^* - \mu)^2. \quad (4)$$

The total experimental variance is the addition of all the variances involved in the processes:

$$S^2 = S_M^2 + S_A^2 + S_S^2 \quad (5)$$

where:

S^2 is the experimentally measured variance,

S_M^2 is the mixing induced variance,

S_A^2 is the analytical variance,

S_S^2 is the sampling induced variance,

S_M^2 is the variance of interest. For a^* the analytical errors are small because the colorimetric analysis is precise and accurate, hence S_A^2 can be neglected as an initial approximation. Regarding the sampling induced variance S_S^2 , it is quite difficult to estimate because it is not only a function of the sampling procedures but also an increasing function of the level of heterogeneity in the medium under investigation.

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