Concrete Surface Tint Defects: Characterization, Parametric Study, and Mechanisms

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Summary

The results presented and discussed are a part of a broader study for which the objectives are to understand what are the physico-chemical mechanisms at the origin of the formation of concrete surface tint heterogeneities, and to identify which solutions can be applied to prevent these tint defects. Consequently, this search involves characterizing light and dark zones of representative concrete samples, and identifying the major parameters by means of laboratory and factory tests designed to reproduce these tint defects. A first conceptual model is proposed to explain the tint heterogeneity formation.

Keywords: concrete surface, mould, physico-chemical characterization, superplasticizer, tint heterogeneity, W/C ratio

1. Introduction

The tint homogeneity of grey architectural concrete is a real concern for the building contractors and owners, whose the requirements are becoming increasingly demanding. The quality control and the visual appearance of architectural concrete are important economic considerations [1]. Grey architectural concrete with no surface treatment (shot-blasting, polishing, etc.) can sometimes have non-homogeneous or irregular tints. Several types of defects exist such as tint variations from one element to another, variations on the same element (i.e. transparency of the cement paste through which the aggregates can be seen, efflorescence [2], juxtaposition of zones of light and dark tint, and so on) [3], [4]. In this paper, we have examined local tint defects on the surface of a same concrete element, characterized by alternating light and dark zones (Fig. 1).

These tint heterogeneities can appear in a random fashion, mainly on the concrete surface that has hardened at the bottom of the mould, and generally under particular cold and damp climatic conditions [1]. However, the detailed analysis of such cases reveals that these conditions alone are not sufficient [1], [5] to fully explain the tint heterogeneities.

The results presented and discussed here are a part of a broader study for which the objectives are to understand what are the physico-chemical mechanisms at the origin of the formation of these heterogeneities, and to identify which solutions can be applied to prevent these tint defects.

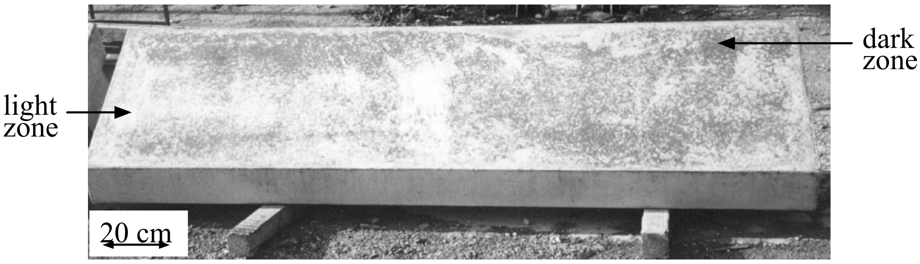


Fig. 1 Concrete precast element presenting tint heterogeneities

Consequently, this search involves characterizing light and dark zones of representative concrete samples, and identifying the major parameters by means of laboratory and factory tests designed to reproduce these tint defects. This paper deals with a few results of the characterization and the identification of the main parameters [6], [7], [8], [9].

2. Experimental program / Methodology

2.1. Microstructural characterization

Light and dark zone characterizations [7] have been made on three concrete samples taken from different industrial sites and considered as representative of the phenomenon, and on a mortar sample made in the laboratory and presenting this type of defects. In this investigation, optical microscope observations have been performed on thin slides about 30 µm thick (concrete surface facing the glass slide); the spotting and the choosing of surfaces of light and dark zones for the achievement of thin slides have been realized by means of stereomicroscope associated to luminance measurements. The optical microscope micrographs have allowed to locate zones for scanning electron microscope (SEM) examinations. These samples have been observed by using secondary electrons and backscattered electrons. X-ray microanalyses and element distribution maps have been also carried out on slides by energy dispersive X-ray spectrometer (EDS).

Note that prior to this study, some characterizations have already been made on non-polished surfaces of concrete presenting tint heterogeneities by means of techniques such as stereomicroscopy, SEM and X-rays diffractometry [1], [5]. These investigations reveal that the dark zones appear more compact than the light zones. No consensus on the nature of the mineralogical constituents has been established. This is probably due to the diversity of the analysed samples and to the fact that the test procedures differ from a laboratory to one another. Moreover, the tint heterogeneities can not accurately be the same ones; different facies may exist.

2.2. Identification of the main parameters

A literature review [5] showed that there were a lot of parameters (cement characteristics, mixture proportions, manufacturing conditions, and mould features) susceptible to be at the origin of the formation of these defects. But, this review was not able to rank these parameters.

Many tests were carried out on mortars with the aim to examine the influence of different parameters as the cement alkali content (0.1; 0.6 and 0.8 %), the water to cement ratio (from 0.3 to 0.5), the superplasticizer content (from 0.1 to 0.5 % dry by weight of cement), the superplasticizer nature (mixture of melamine, naphtalene and lignosulphonate; modified-phosphonate; polyacrylate), the curing conditions (20 °C and 100 % RH; 20 °C and 65 % RH; 5 °C and 80 % RH), and the mould type (metal, plastic, wood). All experiment details are described in the articles [8] and [9]. From these laboratory test results, the main influential parameters were identified and a supplementary study was carried out on concrete in a French precast concrete factory [10].

3. Results

3.1. Microstructural characterization

With the polarizing microscope, it appears for all the samples that the light zones are clearly distinct from the dark zones. The tint contrast between both zones existing in natural light is also apparent in polarized transmitted light (Fig. 2). Irrespective of the SEM observation mode and the sample type, the dark zones differ from the light ones by a higher microcracking (Fig. 3). This observation can lead us to make an assumption relative to the characteristics of the dark zones i.e. a hydrate compact structure different from that in the light zones; the hydrates in the dark zones retain more water than those of the light zones [6].

The polarized transmitted light microscope observations of the samples show that the cement matrix of the light and dark zones contains a calcite-based phase (beige polarisation tint) and a phase without geometric shape probably amorphous (brown colour) (Fig. 2). In the light zone, the proportion of the calcite-based phase is higher than that of the amorphous phase. Conversely, in the dark zone, the proportion of the calcite-based phase is lower than that of the amorphous phase.

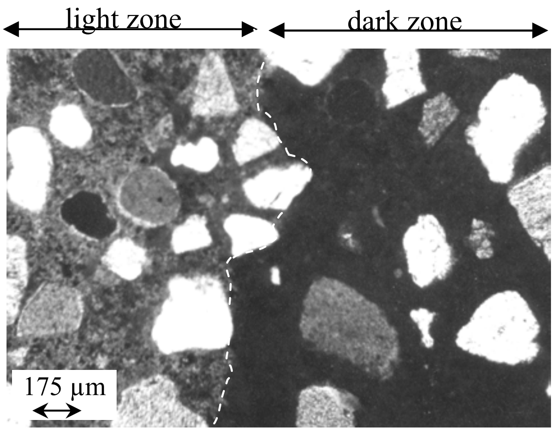


Fig. 2 Optical microscope observation with analysed polarized transmitted light of the slide surface of a concrete sample

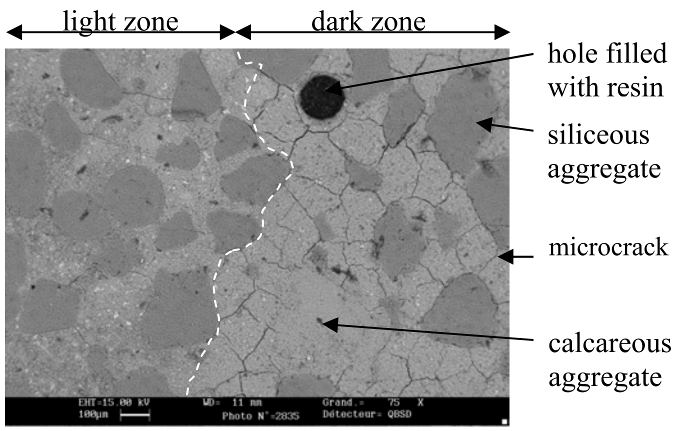


Fig. 3 SEM backscattered electron observation (atomic number contrast) of the slide surface of a concrete sample

The EDS maps made on both sides of the light zone / dark zone interface show that the potassium concentration is higher in the light zone than in the dark zone [7]. Conversely, the sulphur concentration is lower in the light zone compared to the dark zone. Other element distributions such as those of calcium, silicon, iron and aluminium are not significantly different from light to dark zone. The cement matrix of light and dark zones appears to be essentially composed of calcium and silicon [7].

3.2. Identification of the main parameters

Generally speaking, the tint heterogeneities appear on the face that is at the bottom of the mould, not on the levelled face of the specimens. The levelled face has a homogeneous tint. The mortars presenting uniform light tint, irrespective of the curing conditions and the alkali content, were those prepared at the following conditions:

- W/C = 0.5;
- W/C = 0.4 and wooden mould;
- W/C = 0.4 and superplasticizer content of 0.3 or 0.4 % by weight of cement.

The mortars presenting uniform dark tint, irrespective of the curing conditions were those prepared at the following conditions:

- W/C = 0.35 and superplasticizer content of 1.6 % by weight of cement.
- W/C = 0.3 and superplasticizer content of 2.5 % by weight of cement.

The mortars presenting tint heterogeneities, irrespective of the curing conditions were those prepared at the following conditions:

- W/C = 0.4, and plastic or metal mould;
- W/C = 0.4, superplasticizer content of 0.1 or 0.2 % by weight of cement and plastic or metal mould;
- W/C = 0.35 and superplasticizer content of 0.7 % by weight of cement and plastic mould.

It is important to note that the three types of superplasticizer studied lead to the same observations. The tint contrast between the light and dark zones is greater for mortars with a W/C of 0.4 without superplasticizer than for mortars with a W/C of 0.4 and a superplasticizer content of 0.2 %. Otherwise, the mortars stored at 5 °C and 20 °C have different tints overall; the W/C = 0.4 mortars stored at 5 °C were darker than the W/C = 0.4 mortars stored at 20 °C. However, the difference in luminance between the light and dark zones for these two specimens is the same irrespective of the storage temperature. Moreover, the defects of these mortars stored at 20 °C and 95 % RH and at 5 °C and 80 % RH are still visible ten months after demoulding. At 20 °C and 65 % RH, the defects tend to attenuate with the time. However, they are still evident several months after demoulding.

From these laboratory results, the objective of the tests on concrete performed in a factory was to check the influence of the water and superplasticizer dosage on the tint heterogeneities. The results of the tests carried out in some industrial conditions on concrete elements confirm those carried out in laboratory conditions on mortar samples, notably for the water to cement ratio [10]. Indeed, the elements presenting tint heterogeneities correspond to concrete compositions for which the water to cement ratios are low compared to those of the other elements.

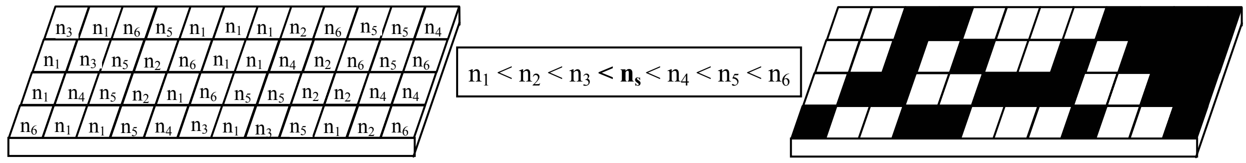
4. Discussion

From all these results, a conceptual model is proposed to explain the surface tint heterogeneity formation. It can be divided into three steps corresponding to the concrete/mortar evolution.

First step : from the mixing to the casting

A first concept can be established on the basis of the existence of a link between the surface tint and the cement matrix density. Indeed, the characterizations show that both zones exhibit a different behaviour with respect to water absorption by capillarity and water retention. At the same relative humidity, the dark zones have higher water retention than the light zones. The cement matrix of the dark areas appear more compact than that in light areas [6]; the mineralogical difference between dark and light zones appears essentially quantitative with the light zones containing more calcite and the dark zones more C-S-H hydrates.

Assuming that the superficial layer of the mortar can be represented as a juxtaposition of unit volumes, each of them with a determined binder (cement) volume fraction, n_i (Fig. 4). The binder volume fraction distribution at the time the concrete is cast, affect the packing density of the superficial layer at early ages. The binder volume fraction is influenced notably locally by the W/C ratio and the superplasticizer dosage. Assuming also that for a given mixture, there is a "threshold" value, n_s, of the binder volume fraction, beyond which dark zones are likely to appear. The zones, where the binder volume fraction is less than n_s, would be light in tint (Fig. 5). Moreover, the binder volume fraction of the superficial layer presents a mean value n depending directly on the W/C ratio used. At the time of the placing, the superficial layer of the face that is at the bottom of the mould is made up of unit volumes for which the binder volume fraction n_i varies around the mean value n.



Distribution of the binder volume fraction during casting　　　Tint after hardening

Fig. 4 Schematic representation of a mortar/concrete by a juxtaposition of unit volumes

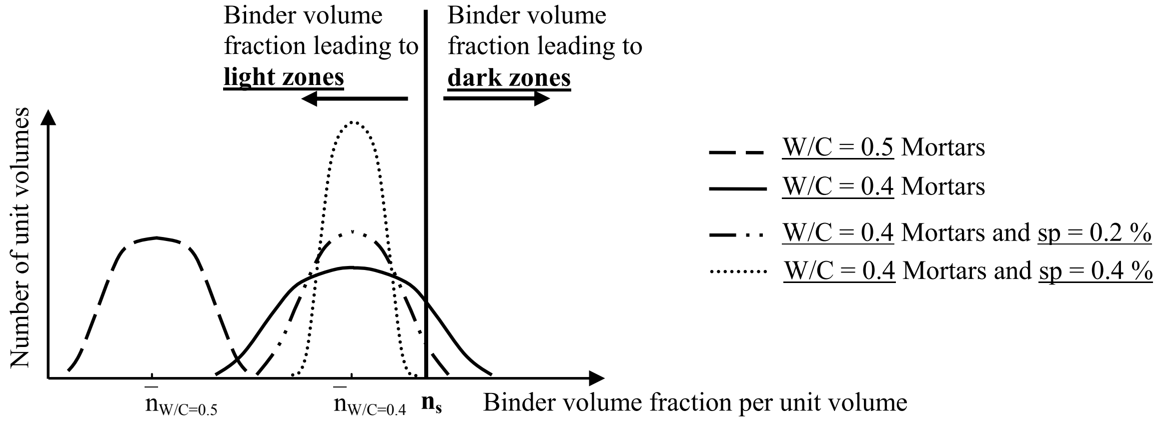


Fig. 5 Schematic representation of the distribution of binder volume fraction during casting in the unit volume of mortar/concrete

Assuming this model and applying it to the results obtained from this study, it seems that the binder volume fraction in all the unit volumes of mortars with a W/C of 0.5 would be less than n_s (Fig. 5). On the contrary, the mean binder volume fraction of mortars with a W/C of 0.4 would be assumed to be close to the critical value n_s. For these mortars, a part of the binder volume fraction distribution in the unit volumes would exceed n_s, leading locally to dark zones (Fig. 5). The use of a superplasticizer disperses the cement particles decreasing or preventing cement particle packing, increases the homogeneity of the binder volume fraction distribution, and probably leads to a more narrow distribution around the mean value (Fig. 5). Adding enough superplasticizer to the mortars with a W/C = 0.4 would lead to a binder volume fraction less than n_s in all the unit volumes, resulting thus in a light tint. This seems to occur with mortars with a W/C of 0.4 and a superplasticizer content of 0.4 % by weight of cement.

Second step : from the casting up to the demoulding

After the casting, for the moulded faces, the fresh mixture is in contact with the mould (metal, plastic) and eventually with the demoulding product; the material transfer with the outside environment are non-existant. For the levelled face, the material transfer can occur. During this step, the cement hydration develops; the distribution of the pore size would be different in the light zones and in the dark zones. At the time of the demoulding, irrespective of the curing temperature, some mortars present tint heterogeneities. This result shows that the low temperature is not a sufficient condition for the formation of these tint defects.

Third step : after the demoulding

The relative humidity can modify the tint after the demoulding. At 20 °C and 65 % RH, the carbonation rate is maximum; moreover, light and dark zones tend to lose water so that both zones tend to become lighter. Material transfers such as calcium, potassium can occur from the middle to the surface of the mortar/concrete. Some components based on these elements (calcite, etc.) can notably develop on the surface.

5. Conclusion

The microstructural characterizations of light and dark zones constitute an essential step in this broad study for which the objectives are to understand the physico-chemical mechanisms at the origin of the formation of tint heterogeneities. The microstructural observations of samples taken from different industrial sites and sample made in laboratory show notably that the potassium concentration is higher in light zones than in dark zones, and that iron, manganese, chromium and titanium are not at the origin of the tint of dark zones. The mineralogical difference between light and dark zones appears essentially quantitative : the light zones contain more calcite and the dark zones more C-S-H.

The main results of the laboratory experiments carried out on mortars indicate that only two of the studied parameters have a major influence on the tint homogeneity: the homogeneity of the binder volume fraction and the absorption properties of the mould. The conceptual model proposed is based on the existence of a link between the mortar surface tint and the cement matrix packing density at early ages which depends on the binder volume fraction distribution during casting. It is assumed that there is a "threshold" value of the binder volume fraction, above which, dark zones could appear on the surface of mortar/concrete specimens made with grey cement, and below which, zones would be light. A decrease in the W/C ratio tends to increase the average binder volume fraction and, consequently, the distribution of the packing density of the cement matrix, which can lead to tint heterogeneity formation. The addition of enough superplasticizer to cement matrix tends to homogenize the binder volume fraction distribution on the mortar surface, resulting in a more uniform tint.

6. References

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