Construction and Building Materials 123 (2016) 248–253

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Color stability in mortars and concretes. Part 2: Study on architectural concretes

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HIGHLIGHTS

- The color stability in architectural concretes was studied.
- Color was characterized using the CIELAB color space.
- Results from CIEDE1976 and CIEDE2000 color-difference formulas were compared.
- The weathering effect on the concretes color was analyzed.
- Concretes with iron oxides lost the color but retained the hue.

ARTICLE INFO

Article history:
Received 1 February 2016
Received in revised form 16 June 2016
Accepted 29 June 2016

Keywords:
Color stability
Architectural concrete
CIELAB color space
CIEDE1976
CIEDE2000

ABSTRACT

The aim of the present study was determining the color stability levels in architectural concretes. The color was defined using the CIELAB space proposed by the Commission Internationale de l'Eclairage (CIE), while the color stability was evaluated comparing the results coming from the CIEDE1976 and CIEDE2000 color-difference formulas. The color of samples exposed to different environments as well as the color-difference among the different instances of measurement are reported. The studied material was white and grey cement colored with iron oxides or phthalocyanines pigments. Results revealed loss of color in natural environment, important changes when phthalocyanines were used, and better color stability in the Colored Self-Compacting Concrete with iron oxides pigments.

1. Introduction

The architectural concrete is considered a special concrete [1], which stresses the color and texture of the finished surface [2–4]. The great number of surface finish possibilities makes it an attractive material to be incorporated in the modern architecture [5]. Among the most used materials to decorate the appearance of concrete, the white cement and the pigments guarantee the added surface value. The white cement modifies the lightness, and the addition of small amounts of pigment provides the saturation and hue properties. This type of concrete must fulfill not only the physical, mechanical and durability properties with which it was designed, but also some characteristics related to the visual impact expected by the different users; among such visual demands, homogeneity and color stability are some of the aesthetic qualities affecting the surface quality [6].

The limitless finish possibilities of architectural concrete need further studies that guarantee their attainment in all kind of surfaces. For example, if conditions imply a specular surface, the material for the mold should be preferably polished and not absorbent. In order to achieve this aim as quickly and economically as possible, an useful alternative is using mortars (i.e. cement, pigment, mineral addition, sand, and water combinations) and thus to minimize the volume of tests performed with concrete (i.e. cement, pigment, mineral addition, sand, water, and stone combinations) [6,7]. Different proportions of materials allow developing cementitious mixtures with a wide range of properties either in the hardened or in the fresh states. Among them, flowability is one of

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http://dx.doi.org/10.1016/j.conbuildmat.2016.06.147
0950-0618/

the properties that in the fresh state facilitates its displacement in the molds and the color uniformity [6].

The color homogeneity or uniformity is connected to the complete material mixture as well as on the concrete flowability and placement. Color variations on the concrete surface may be caused by changing the materials, their incomplete mixture and/or segregation during the placement, and/or the variations among batches [6–8]. Due to the above-mentioned facts, it is strongly recommended to apply control measures for reducing the effects of possible potential risks.

One of the main uncertainties arising from the need of coloring concrete is associated to the color stability. This depends on both the pigment quality and the concrete durability on the surface [9].

The possibility that the concrete keeps up its original surface color depends on internal and external causes capable of changing completely the color of the surface. Internal causes include typical characteristics of the structure of the materials affecting the different mechanisms of fluids transport. External causes include the interactions between the concrete and the environmental conditions to which it is exposed. When the concrete quality is involved, once the materials deterioration and subsequent loss of its structural function begin, deep and regular inspections become very important. Particularly in the case of architectural concrete, damages such as stains, leaching or specifically color variations, which do not affect the structural properties, become an issue of great interest [10].

In the process of concrete deterioration, the development of calcium carbonate ($CaCO_3$) deposits or efflorescence is one of the factors affecting the concrete coloration. When this process occurs in a colored concrete, the contrast is sometimes more marked. In order to reduce the efflorescence it is recommended to use low soluble salt level materials in the right proportions to minimize porosity [9,10].

The color analysis as a function of time involves relating the L^* (lightness) and the coordinates a^* and b^* values. Therefore, using a parameter such as the total color-difference (ΔE), where those variables interfere may be simpler than making evaluations of each of them. Color measurements in concrete exposed to different environments or curing conditions show changes in the color parameters with a lightness increase associated to the humidity loss and a saturation decrease attributed to the efflorescence occurrence. The concretes were prepared by adding yellow, red, or black iron oxides to white or grey cement. The observed changes in concretes with white cement were greater, while the highest stability was achieved with concretes without pigments. The surface cleanness was not enough to reach the original color parameters in samples subjected to different environments and the hue changes were remarkable. In particular, when the samples were exposed to humidity the changes were less important compared to the effect of the humidity/drying cycle or the ultraviolet radiation. Finally, important lightness increases and saturation decreases were more significant when using red pigment in samples exposed to outdoor conditions [11]. On the contrary, other accelerated aging experiments conducted in concretes with yellow, red, or black iron oxide pigments showed low saturation increases, which were attributed to efflorescence incidence, and also great changes in saturation after the white particles were removed [12]. Recently, another study conducted to develop a cover to protect building materials improved the resistance to weather highlighting the good color stability [13], though the exposure period was very short (4 months).

This paper gives a description of the methodology used to evaluate the color evolution on concretes exposed to different environments. To avoid "color" subjectivities, color values defined according to the CIELAB color space. The CIEDE1976 and CIEDE2000 color-differences formulas were used to evaluate the color stability. In particular, it is shown an application of the method by comparing the color stability between the Colored Self-Compacting Concrete (C-SCC) and the Colored mechanically compacted Concrete (CC).

2. Materials and methods

2.1. Materials proportions

The mixtures were developed using local materials (La Plata, Province of Buenos Aires, Argentina) with the characteristics recommended in the bibliography to be used in Self-Compacting Concretes [14]. According to the IRAM 50000 standard [15], two batches of grey Portland cement with calcareous filler (identified in this paper as G1 and G2), and one of ordinary white Portland cement (as W: IRAM 50001 standard) [16] were used. As well, two batches of different calcareous filler (FC1 and FC2) were employed in order to increase the viscosity and reduce the cement amount. The G1 and G2 are equivalent to CEM II/AL 42.5 N cement, while the W is equivalent to CEM I 42.5 N cement of European standard. Chemical compositions, physical and mechanical features of cements and fillers are detailed in Table 1.

Table 2 shows the main characteristics of the yellow (Y, y), red (R, r) and black (b) iron oxides, and those of the green (v) and blue (z) copper phthalocyanine pigments here studied, provided by Alquimia S.A.® and Meranol S.A.C.I.®. In this Table, the capital and lower case letters identified the Alquimia S.A. and Meranol S.A.C.I. suppliers, respectively.

Table 1
Cement and filler.

Chemical composition (%)			Cement			Admixture	
			G1	G2	W	FC1	FC2
CaO			62.0	61.9	65.1	50.9	50.2
SiO_2			19.9	20.1	21.8	4.9	9.2
Al_2O_3			3.2	3.3	4.41	1.3	1.1
Fe_2O_3			3.4	3.2	0.24	0.8	0.7
SO_3			2.4	2.4	3.63	0.4	0.1
MgO			0.7	0.6	0.95	3.5	0.3
K_2O			0.9	0.9	0.16	0.4	0.4
Na_2O			0.1	0.0	0.14	0.1	0.1
LOI			5.2	7.0	2.81	31.8	37.8
Physical and mechanical features							
f'c	1 d	(MPa)	17.9	13.8	27.2	–	–
	28 d	(MPa)	45.7	52.2	66.3	–	–
Densitiy		(g/cm^3)	3.11	3.11	3.09	2.8	2.8

LOI: loss on ignition.

Table 2
Pigments.

Color		Identification	Density (g/cm^3)	Minimum size (μm)	Maximum size (μm)
Iron oxide	Red	R	4.75	0.1–0.5	1.0
		r	4.85	–	–
	Yellow	Y	3.70	1.0	8.0
		y	3.80		
	Black	b	4.75	0.5–1	4.0
Carbon black	Black	Cb	1.90	0.001-0.01	<0.1
Copper phthalocianyne	Green	v	2.00	5–25*	50*
	Blue	z	2.00	<20*	40*

* Agglomerated particles.