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Color stability in mortars and concretes. Part 1: Study on architectural mortars

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HIGHLIGHTS

- The color stability in architectural mortars was studied.
- Color was characterized using the CIELAB color space.
- Results from CIEDE1976 and CIEDE2000 color-difference formulas were compared.
- The weathering effect was analyzed on the colored mortars.
- Loss of initial color was a function of the exposure conditions.

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ABSTRACT

Architectural mortars are mixtures used in the building industry when aesthetic surface value is required. Cementitious mixtures with colorant agent, meet this requirement but color stability is not easy to ensure. This study determines the levels of color stability in architectural mortars. The main materials studied were grey cement and yellow iron oxide pigment. The CIELAB color space was adopted to define color and the CIEDE1976 color-difference formula was compared to CIEDE2000 to asses color stability. Results revealed loss of color in natural environments in a short time and excellent color stability in a chamber operating under controlled humidity and temperature conditions.

1. Introduction

Different materials proportions allow developing Portland cement-based mixtures with a wide range of properties either in the hardened or in the fresh states.

The possibility that the mortar keeps up its original color depends on internal and external causes capable of changing completely the surface color. The internal causes include typical characteristics of the material structure affecting the mechanisms of fluids transport. The external causes comprise interactions between the mortar and the environmental conditions to which it is exposed. When the mortar quality is involved, the material deterioration and subsequent loss of its structural function starts as the deterioration progresses. In the particular case of architectural mortar, damages such as stains, leaching or specifically color variations, which do not affect the structural use, have become an issue of great interest.

There is a resistance to mixing pigments and cement due to the few experiences that ensure lasting color. For a pigment to be satisfactorily incorporated into the building industry it is assumed that its response in elements exposed to outdoor weather conditions should be evaluated over a period of 5–7 years. Although there are accelerated aging tests that allow inquiring the color stability, they are not widely accepted, as they have not proved the existence of a correlation between accelerated and real changes. The pigment solidness also depends on its clustering, therefore, it is strongly related to the structural matrix [1].

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In the process of deterioration of cementitious mixtures, the development of calcium carbonate ($CaCO_3$) deposits or efflorescence is one of the factors affecting its coloration. When the process occurs in a colored cementitious mixture, the contrast is sometimes more marked. For minimizing the mortars' porosity, and as results the efflorescence, the use of materials with low level of soluble salts and in the right proportions is recommended [2,3].

On the other hand, independently of the set of mixtures and their interaction with the molds, the color is a sensorial perception that co-exists with three fundamental elements: the object, the illuminant, and the observer [4]. The CIELAB color space proposed by the Commission Internationale de l'Eclairage (CIE) is one of the most used systems to evaluate color. Represented in cylindrical or polar systems, this space is defined by three variables: lightness (L^*), and two coordinates (a^* and b^*) in the first system, or (L^*), saturation (C^*), and hue (h^*) in the second one. The cylindrical system includes the vertical axis (L^*), that indicates clarity or darkness, and a horizontal plane defined by the a^* and b^* axis. The a^* axis represents the variation red-green, being positive ($+a^*$) for red and negative ($-a^*$) for green, while the b^* axis represents the variation yellow-blue, being positive ($+b^*$) for yellow and negative ($-b^*$) for blue [5,6]. At the same time, the saturation indicates how intense a color is, and the hue (h^*) is the angle indicating if the color is red (0°), yellow (90°), green (180°) or blue (270°); Fig. 1 shows the location of these variables. C^* is calculated as shown in Eq. (1) and, h^* as shown in Eq. (2). In addition to the color, this system has allowed determining the choice of cleaning techniques on facades made with rocks [7], observing the evolution of damages caused by fire in concrete [8] and characterizing the mortar color with natural hydraulics limes (NHL) commercial binders for the preservation of historical architecture [9].

$$C^* = [(a^*)^2 + (b^*)^2]^{1/2} \tag{1}$$

$$h^* = arctg\frac{b^*}{a^*} \tag{2}$$

One of the main uncertainties arising from the need of colored mortar is associated with color stability. The stability or solidity of the color indicates the resistance to change of L^*, a^* and b^* due to the action of the radiation or variations in the climatic conditions [10]. To assess the discoloration, it is appropriate to use a color-difference formula [5,11].

There are advantages when mortars studies are carried out. Evaluations conducted on concrete interlocking blocks with inorganic pigments revealed denser structures when black pigment was used [12]. The flow of mortars with yellow, red, black or green pigments proportions varying from 3% to 12% was also evaluated; the experimental results showed that with yellow or red pigment, the flow decreased rapidly with increasing pigment content. To avoid this effect it was necessary to increase the amount of mixing water or to use a superplasticizer to obtain the flow (180 mm). When green or black pigment was used, no significant fluidity changes were observed [13]. The so called "Okamura" method, which starts the analysis with mortars was developed for dosage of self-compacting concrete [14–16]. It assumes the concrete as a material consisting of two phases: the mortar and the coarse aggregate. This method was verified in self-compacting concrete with fibers and high strength [17] and colored self-compacting concrete [18].

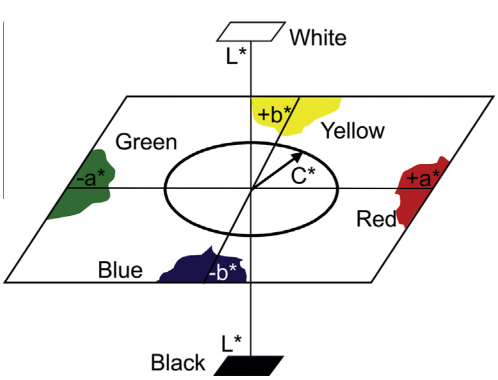

Fig. 1. CIELAB color space.

The color analysis as a function of time involves relating the L^*, a^*, and b^* values. Therefore, using a parameter such as the total color-difference (ΔE), where those variables are included may be simpler than making evaluations of each of them.

This paper describes the methodology used to evaluate the color stability on mortars exposed to two environments. To avoid "color" subjectivities, CIELAB color space was used to define color values. Accordingly, the CIEDE1976 (ΔE^*_{76}) and CIEDE2000 (ΔE_{00}) color-differences formulas were used to evaluate the color stability.

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 (SCC) [19]. According to the IRAM 50000 standard, similar amounts of commercial Portland cement with calcareous filler (defined in this paper as G1) and ordinary "grey" Portland cement (G2) were used. Chemical compositions, physical and mechanical features of cements and filler are detailed in Table 1. The G1 is equivalent to CEM II/AL 42.5N cement and the G2 is equivalent to CEM I 42.5N cement of European standard.

The pigment was yellow Meranol S.A.C.I.®, density = 3.80 g/cm^3. In order to increase the mixtures flowability and reduce the water contents, an ether polycarboxylated (GLENIUM B 255, solid content about 18%) of BASF Argentina S.A.® was included as a superplasticizer.

The mixtures were prepared using tap water, and a silica natural sand (fineness modulus: 2.39, density 2.63 g/cm^3, and absorption rate 0.5%).

Table 2 shows the different materials and proportions used for mortars production. The F group was made with G1 cement, while the N group with the G2 one. Both mortar groups contained a superplasticizer and yellow pigment at 2%, 4%, or 6% relationship in cement weight (pigment/cement or (p/c)). To evaluate the possible effect of the pigment increment on the mortars fluidity and viscosity, the pigment was replaced by the same volume of filler (FC). The solid additive incorporated in the F and N groups was expressed as a cement weight relationship of 0.40% and 0.35%, respectively. A water/cement relationship = 0.50 was used in both groups.

2.2. Environments

Before and after 18 months of exposure to: 1) a chamber (C1) operating under controlled humidity (55 ± 5%) and temperature (21 ± 2 °C) conditions; or 2) the natural environment (A1) of La Plata station (urban-industrial area), annual average

Table 1
Cement and filler.

Chemical composition (%)			Cement		Admixture
			G1	G2	FC
CaO			61.9	64.1	50.2
SiO_2			20.1	21.3	9.2
Al_2O_3			3.3	3.7	1.1
Fe_2O_3			3.2	3.6	0.7
SO_3			2.4	2.5	0.1
MgO			0.6	0.7	0.3
K_2O			0.9	1.0	0.4
Na_2O			0.0	0.1	0.1
LOI			7.0	2.2	37.8
Physical and mechanical features					
f'c	1 d	(MPa)	13.8	24.0	–
	28 d	(MPa)	52.2	62.2	–
Density		(g/cm^3)	3.09	3.11	2.8
Specific surface Blaine		(m^2/kg)	364	337	–

LOI: loss on ignition.