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INFLUENCE OF PIGMENTS ON MECHANICAL PROPERTIES OF COLORED CONCRETE

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Abstract: *Influence of pigments on mechanical properties of colored concrete is presented in this paper. The paper is focus on the issue of dosing a powder pigment in the form of iron oxide into a prefabricated dry concrete mixture and its effect on mechanical properties of mixture. Based on the performed experimental tests, it follows that the proportion of added pigment has a fundamental influence not only on the resulting color intensity of concrete, but also on its mechanical properties. The measured values of flexural and compressive strength show a significant decrease with increasing amount of pigment contained.*

Keywords: Colored concrete, Mechanical parameters, Pigments.

1. Introduction

Due to its aesthetic potential, colored fair-face concrete is becoming one of today's preferred building materials among architects and investors. By adding color pigments to the concrete mix, it is possible to extend this range from a limited gray scale by a number of color shades, which can significantly visually enhance the realized architectural work. (Guyer, 2018).

The intensity of the resulting color of hardened concrete is affected by more or less all components that enter the concrete mixture production process, namely the type and color of cement used, type and color of aggregate used, water coefficient, formwork absorption, type of separating agent etc. (Vikan, 2007) and in the case of colored concrete then in particular the amount and color shade of the pigment added. Dosage added pigment is usually referenced to the weight of the binder. The pigment itself is always added by weight, not by volume. Confusion could lead to an undesirable variation in the intensity of the resulting color, which is caused by fluctuations in the bulk density of the pigment used (Chipperfield, 2012).

The maximum amount of pigment in terms of intensity and the final color shade is limited by the so-called color saturation. That means when a certain dose of added pigment is exceeded, the color shade of hardened concrete no longer changes, or there is a very small color deviation. At the same time, the pigment as another component added to the concrete mixture can, due to its chemical composition, significantly affect the processes taking place at the time of concrete hardening and thus have an effect on its final mechanical properties (Ticha, 2010).

Knowledge of the optimal concentration of pigment in the concrete as follows from the above, is absolutely essential, both for the final desired appearance of the fair-faced concrete and for its final mechanical properties. This paper therefore focuses on the causality between the amount of pigment added to the concrete mixture, resulting color intensity and the effect on flexural and compressive strength.

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2. Materials and Measuring Methods

Seven concrete mixtures with different amounts of added pigment to the dry precast concrete mix were tested. The prefabricated mixture minimizes the influence of the composition and production of concrete on the measured properties and guarantees better objectivity of the results. Black and red iron oxide powder pigments were used as color additives. The reason for choosing these two pigments was that color of concrete to resemble the look of brick. So the concrete can then replace, for example, damaged parts of the historic masonry structure or only visually complement the building appearance. The pigment was dosed into the mixture in batches from 0.25 to 1.2 weight percent of the total weight of the dry concrete mixture. The water content of each mixture was adjusted according to the optimal consistency. The ratios of the individual components of the colored concrete mixture are shown in Tab. 1.

Tab. 1: Composition of the concrete mixtures.

Composition [g]		3E	3EI	3EII	3EIII	3EIV	3EV	3EVI
Dry mixture of concrete		1000	1000	1000	1000	1000	1000	1000
Pigment	Red	1	3	4	5	5	5	6
	Black	1.5	3	4	5	6	7	6
[%] by weight of the total amount of dry mixture		0.25	0.6	0.8	1.0	1.1	1.2	1.2
Water		160	170	170	175	175	180	180

Fig. 1: Samples.

The density, as a fundamental physical characteristic of the material, can be used also for calculation of other parameters. Especially bulk density ρ_b [kg m^{-3}] was determined on the vacuum saturation principle using Archimedes' weight (Pernicova, 2007).

The color intensity was measured using the Color-catch-nano tester, which indicates and measures RGB values. The RGB value is a composite image of three basic colors: Red-Green-Blue. Combination of these three colors will create a one unique color. Colorcatch Nano colorimeter accurately measures the color of smooth or textured surfaces by technology allows to measure 50,000 pixels separately. It has a built-in internal camera and light source, so the resulting data not affected by external light conditions. The comparison of the RGB color range depending on the amount of pigment added (Utesena, 2018).

The mechanical parameters were tested according to the ČSN EN 196-1 standard. Compressive and flexural strength were determined. Samples wit dimension of 40 x 40 x 160 mm were prepared for each measurement. The flexural strength f_{ct} [N/mm^2] was measured using standard three-point bending test, and calculating according to equations:

$$f_{ct} = \max \sigma_t = \max M / W \quad (1)$$

$$M = F_t . l / 4, \quad (2)$$

where F_t is load at the moment of break [N], l is distance between bracket, σ_t is tensile stress [MPa], M is flexural moment [N.mm] and W is section modulus at point of break [mm^3]. The compressive strength was determined using the same test device on the remainders of the specimens after bending test. The individual compressive strengths f_c [N/mm^2] are calculated from the following formula:

$$f_c = F / A_c, \quad (3)$$

where F is maximum load at the moment of break [N], and Ac is sectional area of specimen, on which applied load force [mm^2]. Final strength is calculated as the mean value from the individual values.

3. Results and Discussion

First, the basic material properties of the tested colored concrete were determined. First, the bulk density ρ_b [kg m^{-3}] as the basic physical characteristic was measured by the gravimetric method. Bulk density and mechanical properties are summarized in Tab. 2.

Tab. 2: Basic physical properties of colored concrete.

Sample	Bulk density	Flexural strength	Compressive strength
	[kg.m^{-3}]	[MPa]	[MPa]
3E	2006	8.0	40.7
3EI	2062	6.2	32.1
3EII	2024	4.8	28.7
3EIII	1997	4.5	23.1
3EIV	1943	6.5	22.6
3EV	1955	6.1	23.0
3EVI	1913	5.9	21.6

To illustrate the difference in value of mechanical properties are the data from the above tables visualized in Fig. 2.

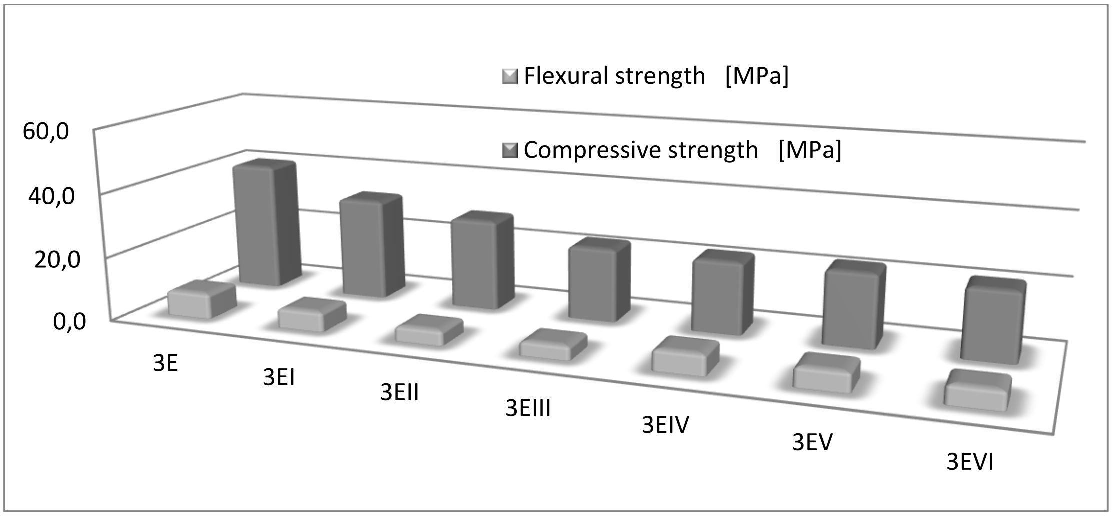


Fig. 2: Mechanical properties [MPa].

The results show that with increasing amount of pigment there is a decrease in mechanical properties, it applies especially for compressive strength. Sample 3E with a pigment content of 0.25 % (by weight of dry concrete mix), has the Compressive strength is approximately 50 % higher than for sample 3EVI with a pigment content of 1.2 %. The results of flexural strength show the same trend that the strength decreases with increasing amount of pigment. A slight difference in strengths can be seen in the type of pigment used. Samples 3EV and 3EVI have the same amount of pigment (1.2 wt.%) but sample 3EV, where there is more red pigment, has the compressive strength about 7 % and the flexural strength approximately 3 % higher.

Using the Colorcatch instrument, the color shades of the individual samples were taken and expressed in the RBG number. The aim was to determine the resulting color when the amount of pigment is still acceptable with respect to mechanical properties and when it is necessary to adjust the composition of the concrete mixture itself. Detail picture of the measured area are given in Fig. 3.

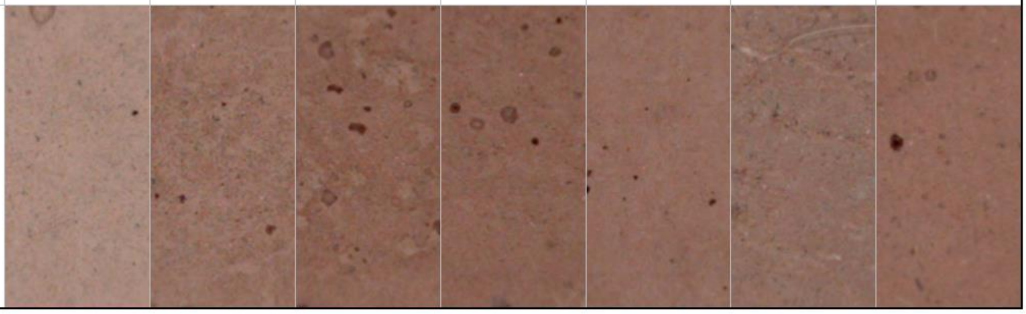
Sample	3E	3EI	3EII	3EIII	3EIV	3EV	3EVI
Detailed photos from Colorcatch Nano camera							

Fig. 3: Visual measurement of colored concrete surface.

4. Conclusion

The article deals with the influence of admixture in form of colored pigment on the mechanical properties of concrete. The results show that with increasing amount of pigment there is a decrease of mechanical properties, both in the compressive and flexural strength. By adding aproximatelly 1 wt % of pigment to the mixture, the strength is reduced by 50 %. Therefore it can be said that in order to maintain good mechanical properties, the amount of pigment in the mixture is limited and the resulting concrete colors are recommended in lighter shades.

When comparing RGB scanning values taken from the sample surface, different colors were measured. However, when visually comparing the appearance of the sample, there is no obvious difference in the samples, where the amount of pigment varies in the order of tenth wt %.

In order to design buildings made of richly colored exposed concrete, it is therefore necessary to replace the normal concrete mixture to ultra-high performance concrete, denote as UHPC. UHPCs are mixtures that are defined by high values of mechanical properties. By designing the appearance of resulting structure, it is necessary to take into account the specific color of the pigment, because different kinds can affect the resulting properties differently.

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