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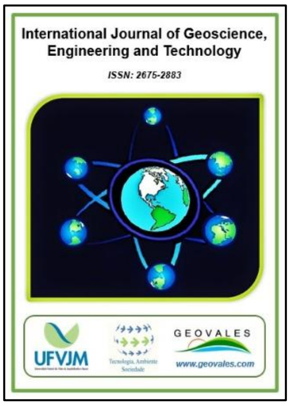

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Variation of compressive strength in colored concrete traces in the city of Teófilo Otoni in the State of Minas Gerais

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Abstract

This work analyzed the variation of strength and workability of concrete traces with inorganic pigment based on iron oxide with levels varying in 3%, 5% and 6% in the city of Teófilo Otoni-MG. 27 specimens were manufactured, submitted to consistency and compression tests with ages of rupture of 7, 14 and 28 days. Colored concrete is a type of exposed concrete, characterized by dispensing with the application of coatings in buildings. Three strokes T1, T2 and T3 were defined with theoretical compressive strength fck of 18 MPa, 25 MPa and 40 MPa at 28 days respectively. The best results were obtained by the T1P3, T2P3 and T3P3 lines with the addition of 3% pigment in both tests. Significant resistance gains were observed at 7 and 14 days and a reduction at 28 days, at 7 days the gains were about 65% for T1P3, 60% for T2P3 and 82% for T3P3 in relation to theoretical resistance. The colored line that obtained the greatest resistance was T3P3, reaching a fck of 43.09 MPa at 14 days and the worst was T3P6 with 25.97MPa at 28 days. In the slaughter tests it was noted that the best workability was obtained with the addition of 3% being 4.5; 4.2 and 8.3 and it was observed that as the addition content increased, the measure of abatement of the mixture was reduced. The most recommended application for application in colored concrete, whose compressive strength was the closest to the theoretical values and the workability of the mixtures were better.

Keywords: Colored concrete, Pigment, Compressive strength.

1. Introduction

The aim of this study was to analyze the workability and compressive strength at 7, 14, and 28 days of concrete mixes with the addition of varying amounts of an inorganic pigment based on iron oxide. This was achieved through slump tests and compression tests on 27 colored concrete specimens produced according to Brazilian standards.

The aggregates used in Teófilo Otoni are derived from the rocks of the region's geological formations, characterized by the presence of the mineral biotite. This will also be considered in this study, as it may influence and alter the properties of the concrete.

Concrete is composed of a mixture of cement, water, aggregates, and, when necessary, additives or admixtures, making it the most widely used construction material in the world (Pedroso, 2009).

Colored concrete, on the other hand, results from the addition of pigments to the concrete mix or the selection of aggregates with specific colors, imparting coloration to the material (Passuelo, 2004).

Such concretes are characterized as exposed, eliminating the need for coatings on structures. This reduces construction execution time and maintenance interventions (Valença and Priszkulnik, 2017).

Colored concrete can be used in a variety of applications, such as road markings, pavers, facades, and pavements. Its use offers distinctive and durable aesthetic characteristics, making it a cost-effective and advantageous option for public works, such as urban space reorganization projects (e.g., plazas, bike paths, affordable housing).

The production of this type of concrete requires greater care during execution to minimize effects such as efflorescence, characterized by the appearance of surface stains on the concrete. It also requires control of the workability when adding colorants to the mix, which can initially contribute to higher material costs (Valença and Priszkulnik, 2017).

According to Sousa, Oliveira, and Gomes (2020), colored additives, commonly referred to as pigments, can be liquid or powder. These are incorporated into the cement-water-aggregate mix in low proportions to enhance fixation and control the hardening of the concrete.

Pigments used to add color to concrete can be classified as organic or inorganic, with inorganic pigments being more suitable for concrete applications. Their properties ensure greater durability and color retention in the concrete (Conceição, 2015).

Studies on the behavior of pigments in concrete need further advancement, as noted: "The use of colored concrete in civil construction still raises doubts and remains little known in the region encompassing the city of Teófilo Otoni" (Sousa; Oliveira and Gomes, 2020).

2. Region Characteristics

2.1 Study Area Location

The city of Teófilo Otoni is located in the Mucuri Valley in the northeastern part of the state of Minas Gerais (MG), as shown in Figure (1). Its population comprised approximately 134.745 inhabitants in the last census of 2010, within a territorial extension of around 3.242,27 km² (IBGE, 2018).

2.2 Regional Geology

The main geological formations in the Teófilo Otoni region are the Tumiritinga and the São Vitor Tonalite, situated within the Juiz de Fora Complex (Gomes et al., 2012). These formations comprise lithostratigraphic units from the Neoproterozoic period (1000 Ma), with syn- to late-tectonic granites in the Galiléia intrusive suite and syn-tectonic granites in the Rio Doce Group, respectively (CPRM, 1996).

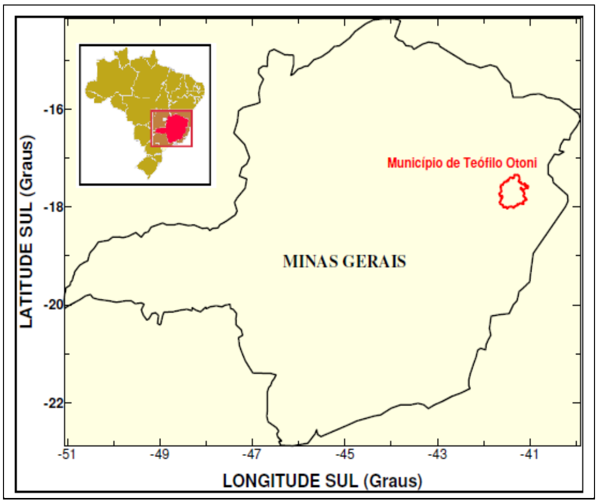

Figure 1 – Location of the Municipality of Teófilo Otoni - MG (Gomes et al., 2012).

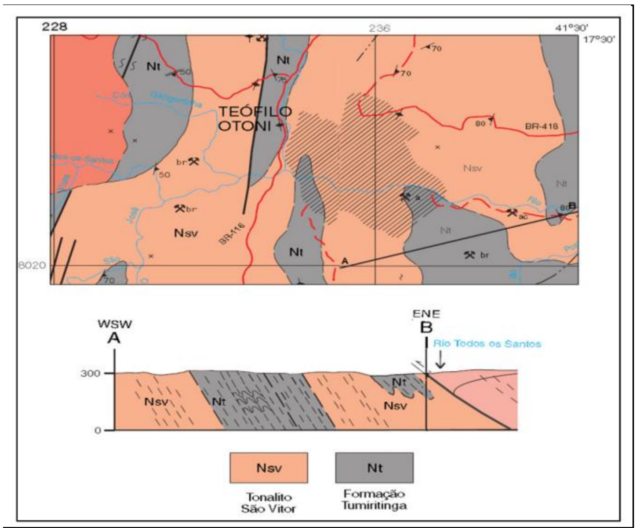

Figure 2 – Main geological formations in the region of Teófilo Otoni. Tumiritinga and Tonalito São Vitor (Adapted from CPRM, 1996; Gomes et al., 2012; Ramos e Gomes, 2016; Sousa, Oliveira, Gomes, 2020).

The São Vitor Tonalite predominates in the eastern, southeastern, and south-central regions shown in Figure (2). This formation can be observed through isolated outcrops along the road connecting Teófilo Otoni to Ladainha. The main petrographic types present in these rocks are biotite-tonalite and hornblende-biotite tonalite, which are gray in color, medium to coarse-grained, and generally foliated. They occasionally exhibit magmatic flow textures with centimeter-sized megacrystals of feldspar. The predominant minerals are quartz, plagioclase, and biotite (CPRM, 1996).

The Tumiritinga Formation, on the other hand, has biotite schistose gneiss as its main lithotype. It is gray in color, fine-grained with occasional medium grains, and displays fine banding interspersed with more quartz-feldspathic levels and more biotitic levels. The essential minerals in the biotite gneisses and schists include quartz, plagioclase, biotite, orthoclase, and cordierite, with the foliation typically being mylonitic (CPRM, 1996).

Overall, the geology of Teófilo Otoni is characterized by the presence of biotite schist, gneisses, occasional marble, fluvial sediments, and clays (Gomes et al., 2012).

The rocks used for aggregate production in Teófilo Otoni are of gneissic origin, as shown in Figure (3). According to Parreira (2016), gneisses exhibit good mechanical strength, chemical stability, and low impurity content.

Gneissic rocks originate from metamorphic processes resulting from the transformation of sedimentary rocks (paragneisses) or igneous rocks (orthogneisses). These rocks are characterized by their incipient foliation and compositional banding structure, alternating between felsic layers (quartz and feldspar) and mafic layers (biotite and amphibole) (Best, 2008 cited in Parreira, 2016).

Figure 3 – Coarse aggregate (gravel 0) of gneissic origin (Grupo pedreira Mix Mattar, 2020).

Biotite is a hydrated potassium, magnesium-iron-aluminum silicate found in igneous, metamorphic, and sedimentary rocks. This mineral belongs to the mica group, and its presence can be identified by the iron content in its composition. It is characterized by its perfect cleavage, forming thin lamellar sheets that range from brittle to flexible and elastic, as shown in Figure (4) (Parreira, 2016).

Some properties of the mineral biotite can be observed in Table (1).

Table 1 – Biotite properties (Adapted from Parreira, 2016).

Properties of biotites	
Chemical Formula	$K_2(Mg,Fe^{2+})_{6-4}\ (Fe^{3+},Al,Ti)_{0-2}\ Si_{6-5}\ Al_{2-3}O_{20}(OH,F)_4$
Hardness	2.5 to3.0
Density	2.8 to 3.2
Luster	Reluzente
Diaphaneity and Color	Generally dark green, brown to black, rarely light yellow
Diagnostic Properties	Characterized by micaceous cleavage and dark color
Crystallography	Monoclinic system, prismatic class
Optical Properties	Biaxial
Habit	Placose, laminated, foliated
Cleavage	Perfect basal pinacoids {001}
Fracture	Due to its cleavage, it does not present fractures, but rather thin flexible and elastic leaves
Streak	White

According to Parreira (2016), the biotite present in aggregates used for the production of concrete and mortar significantly affects their workability and strength due to its lamellar shape. This shape hinders the adhesion between the cement paste and the aggregates, requiring a greater amount of water in the mix to achieve proper fluidity and to fill void spaces.

Figure 4 – Quartzite with the presence of biotite sheets in its composition.

3. Methodology

The methodologies employed in this study are both qualitative and quantitative in nature. A bibliographic review was conducted to understand and master the subject matter through the existing available literature, and experimental research was carried out to obtain results through laboratory tests.

The experiments were conducted following the procedures outlined in the standards ABNT NBR 5738/2015: Concrete - Procedure for molding and curing test specimens, ABNT NBR NM 67/1998: Concrete - Determination of consistency using the slump cone test, and ABNT NBR 5739/1994: Concrete - Compression test on cylindrical specimens.

Three mix designs by mass, designated T1, T2, and T3, were defined with theoretical compressive strengths (fck) of 18 MPa for reinforced concrete structures, 25 MPa for structural applications, and 40 MPa for projects such as bridges, respectively. These designs were based on a table of granite rock mixes from Rio de Janeiro (RJ), as shown in Table (2).

Table 2 – Mix proportions of specimens (mass ratio).

Mass concrete mixtures				
concrete traces	**Compressive Strength (MPa)**	**Use of cement (Kg/m³ of concrete)**	**w/c ratio (l/ Kg)**	**concrete mix ratio**
T1	18	276	0,73	1: 2,71: 3,52
T2	25	344	0,61	1: 2,17: 2,94
T3	40	514	0,44	1: 1,08: 1,56

A total of 27 colored concrete specimens were produced: 9 with the addition of 3% pigment by cement mass, 9 with 5%, and 9 with 6%. These specimens underwent compression tests at the ages of 7, 14, and 28 days and were also subjected to slump tests.

The colored mixes were identified based on their composition. For instance, mix T1 with 3% pigment addition was designated as T1P3, with 5% as T1P5, and with 6% as T1P6, and so forth for the other mixes, as shown in Table (3).

Table 3 – Compositions of each mix with varying pigment content.

Percentage of pigment	**T1**	**T2**	**T3**
3%	T1P3	T2P3	T3P3
5%	T1P5	T2P5	T3P5
6%	T1P6	T2P6	T3P6

According to Corsini (2011), the maximum recommended pigment content for application in concrete is approximately 8% of the cement mass. Chemical engineer Giselle Martins states that "There are studies proving that above 8% pigment, saturation occurs, and a more vivid color cannot be achieved." She also adds that the incorporation of fine materials in large proportions can contribute to a loss of mechanical strength in the concrete (Corsini, 2011).

The experiments were conducted at the Mix Mattar Quarry concrete plant located in the city of Teófilo Otoni. The materials used in the preparation of the mixes included: Portland slag cement of the CPIII – E – 32 type, manufactured by Cauê; crushed stone (size 0) and artificial sand with 3% moisture, both of gneissic origin; tap water from the public supply system; and an inorganic red iron oxide-based pigment manufactured by LANXESS.

For the preparation of the concrete specimens, calculations were initially performed to determine the dosage of materials for each mix design by mass.

To ensure greater accuracy in the quantities of each material used in the mixtures, electronic scales were employed. Aggregates were measured using a Toledo brand scale, while the cement, pigment, and water were measured with a Balmak ELP – 10 digital scale, as shown in Figure (5).

Figure 5 – Weighing of coarse aggregate for mixing concrete.

The mixing of materials for concrete production was carried out mechanically using a CSM brand concrete mixer, as shown in Figure (6), resulting in fresh concrete mixtures.

Figure 6 – Mechanical mixing of concrete constituent materials.

After being removed from the mixer, the temperature of each mixture was measured, and the mixtures were subsequently subjected to slump tests to determine their consistency, as described in NBR NM 67/1998, as shown in Figure (7).

Figure 7 – On the left, a freshly colored concrete mix and on the right, a consistency measurement (Slump Test).

A portion of the mixtures was placed into cylindrical molds measuring 20 x 10 cm with an area of 78.54 cm². These were filled in two layers, compacted manually using a steel rod with 12 strikes per layer, as shown in Figure (8), following the procedures outlined in NBR 5738/2015. The specimens remained in the molds for 48 hours until hardening, as illustrated in Figure (9).

According to NBR 5738 (ABNT, 2015), the compacting rod must be made of steel, cylindrical, with a smooth surface, (16.0 ± 0.2) mm in diameter and 600 mm to 800 mm in length, with one or both ends semi-spherical and having a diameter equal to that of the rod.

Figure 8 – Densification of the mixture in the cylindrical test specimens with the aid of the steel rod.

Figure 9 – Molds filled with the densely packed mixtures.

Once hardened, the concrete specimens were removed from the molds and stored in a reservoir containing water for wet curing at 7, 14, and 28 days, as shown in Figure (10).

According to Metha and Monteiro (2008), concrete curing refers to the set of conditions that facilitate cement hydration, including time, temperature, and humidity, starting from the moment the concrete mixture is placed into the formwork.

For a given water-to-cement ratio, the longer the curing period, the higher the concrete's strength. This is because cement particles undergo extended hydration, improving the concrete's properties and consequently contributing to increased strength (Metha and Monteiro, 2008).

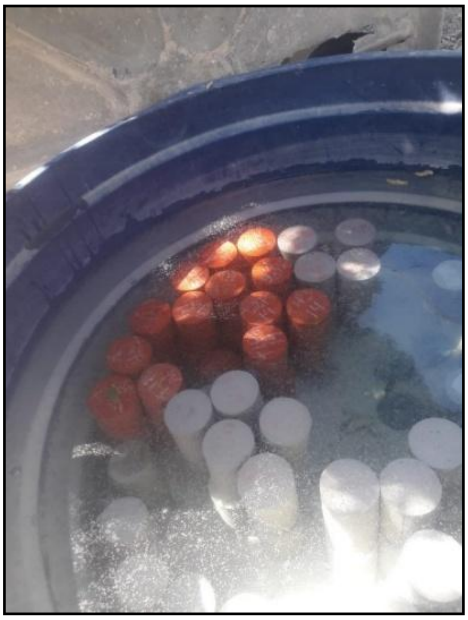

Figure 10 – Test specimens subjected to wet curing.

The specimens, after being removed from the water reservoir, underwent a process of end-surface grinding using a Stuhlert brand grinding machine (Figure 11).

According to ABNT NBR 5738/2015, the grinding process for specimens involves the mechanical removal of a thin layer from their bases to ensure flat, undistorted, and bulge-free surfaces. This ensures that no interference occurs in the potential strength of the concrete during compression testing.

Figure 11 – Concrete specimens rectification.

The ground concrete specimens were subjected to compression tests using a Solocap digital electric press, with a precision of ± 1% and a maximum capacity of 1000 kN, to determine the concrete strengths at 7, 14, and 28 days (Figure 12).

Figure 12 – Test specimen subjected to compression test in electric press.

The strengths obtained from the compression tests, expressed in kN, were converted into MPa using Formula (1). These values were then compared to the theoretical strengths for each mix design to evaluate the influence of pigments on the concrete and identify potential interferences.

$$fck\ (MPa) = \frac{\left(\frac{fck(kN)}{Acp}\right)}{9{,}81} x100 \quad (1)$$

4. Results and Discussions

The results of the compression tests performed on the colored concrete specimens are presented in Table (4).

Table 4 – Results obtained from the compression tests of cylindrical concrete specimens.

Compression test results				
Composition	**fck**	**Resistance (MPa)**		
		7 days	**14 days**	**28 days**
T1P3	18	11.70	15.06	16.39
T1P5		9.61	21.96	15.73
T1P6		8.53	10.12	14.40
T2P3	25	15.07	21.80	23.50
T2P5		18.23	22.39	19.76
T2P6		16.60	23.13	22.43
T3P3	40	32.82	43.09	36.69
T3P5		25.77	38.48	35.63
T3P6		24.62	42.51	25.97

To facilitate the visualization and understanding of the obtained strengths, these results are presented graphically in Figures (13), (14), and (15).

Figure (13) shows the strengths obtained from the breaking of colored concrete mixes T1, T2, and T3 at 7 days.

As observed in the results shown in Figure (13), significant strength gains were achieved at 7 days, particularly for mixes with 3% pigment addition. The strength reached approximately 65% for T1P3, 60% for T2P3, and 82% for T3P3 relative to the theoretical strengths for each mix.

With the addition of 6% pigment, a decrease in strength was noted: around 27% for T1P6 and 25% for T3P6 compared to mixes with 3% addition. However, an atypical behavior was observed in mix 2, as it showed higher strength with a 5% pigment addition (T2P5), reaching 18.23 MPa, and lower strength with 3% addition (T2P3), achieving only 15.07 MPa. Mix T2P6 achieved a 9% gain compared to T2P3.

Figure (14) presents the strengths obtained from the mixes broken at 14 days.

From the results shown in Figure (14), it is evident that the colored mix with the highest strength gain was T3P3, achieving an fck of 43.09 MPa, exceeding the theoretical strength of mix 3 (40 MPa at 28 days) by about 7%.

For composition T3P5, a reduction of approximately 11% in strength was observed compared to T3P3, while T3P6 showed a 9% increase compared to T3P5.

The composition with the lowest strength gain was T1P6, reaching only 10.12 MPa, approximately 44% lower than the theoretical fck for mix 1 (18 MPa at 28 days). However, T1P5 exhibited an 18% gain relative to the theoretical strength of this mix.

The compositions of mix 2 showed slight variations with pigment additions, achieving 21.80 MPa for T2P3, 22.39 MPa for T2P5, and 23.13 MPa for T2P6.

Figure (15) corresponds to the strengths obtained from the compression tests of the colored mixes broken at 28 days.

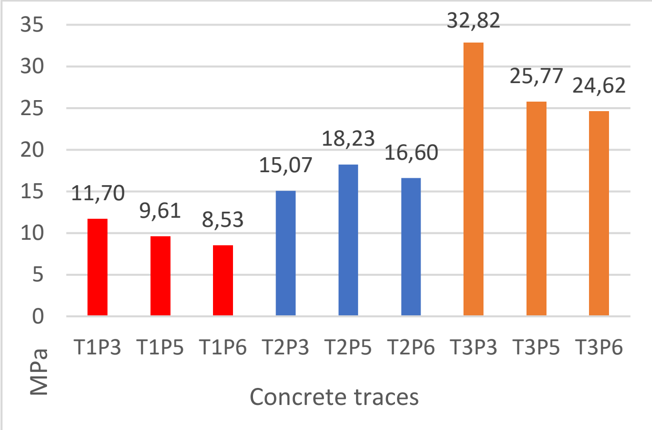

Figure 13 – Results of the compressive strength of colored concrete at 7 days.

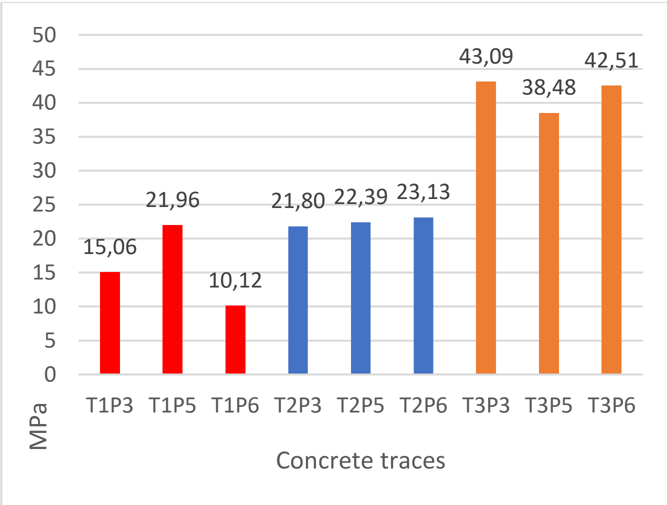

Figure 14 - Results of the compressive strength of colored concrete at 14 days

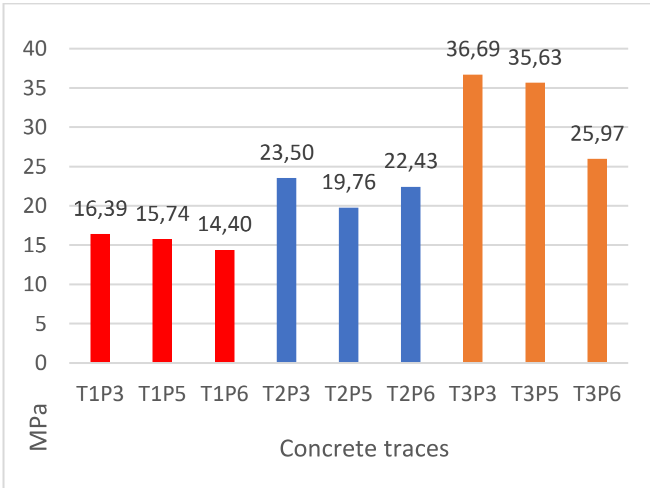

Figura 15 – Results of the compressive strength of colored concrete at 28 days.

According to Figure (15), none of the colored mixes reached their theoretical strengths at 28 days. The mixes with fck values closest to the theoretical ones were T1P3, achieving 16.39 MPa out of 18 MPa; T2P3, achieving 23.50 MPa out of 25 MPa; and T3P3, reaching 36.69 MPa out of 40 MPa. These results corresponded to over 90% of the theoretical fck for each mix.

Mix T2P6 showed a gain of approximately 12% compared to T2P5, while T1P6 exhibited a reduction of around 9% compared to T1P5. T3P6 showed an even more significant reduction, approximately 27% compared to T3P5.

The results obtained from the slump test for determining the consistency of the concrete mixes are presented in Table (5).

NBR NM 67/1998 specifies that for the concrete slump test, a hollow truncated cone mold with predefined dimensions must be used. These dimensions include a base diameter of 200 mm ± 2 mm, a top diameter of 100 mm ± 2 mm, and a height of 300 mm ± 2 mm. The test also requires a circular-section compacting rod with a diameter of 16 mm and a length of 600 mm to consolidate the mix inside the mold.

The consistency of the concrete is measured as the difference between the height of the mold and the height of the concrete mix after the mold is removed. This result indicates the workability of the mix (NBR NM 67, 1998).

Table 5 – Results of slump tests on fresh concrete mixes.

Composition	Temp. (°C)	Reduction (cm)
T1P3	30.2	4.5
T2P3	30.2	4.2
T3P3	30.2	8.3
T1P5	28.3	3.4
T2P5	29.9	3
T3P5	28.5	4.5
T1P6	28.6	1.5
T2P6	27.4	2
T3P6	29.3	1.7

According to the results in Table (5), a reduction in the workability of the concrete was observed as the pigment content in the mixture increased.

The mixes with the most significant results were those of mix design 3, possibly because it has the highest cement consumption in its composition, mitigating the effect of the pigment. It was noted that the slump measurement for this mix decreased by approximately 46% from T3P3 to T3P5 and by 80% from T3P3 to T3P6.

The optimal pigment addition level was observed in mixes with 3% pigment addition (T1P3, T2P3, and T3P3), with slump values of 4.5, 4.2, and 8.3, respectively. The lowest slump values were recorded for mixes with 6% pigment addition (T1P6, T2P6, and T3P6), at 1.5, 2, and 1.7, respectively.

Aguiar (2006) explains that the addition of pigment to the concrete mix hinders the interaction between the pigment and cement particles, contributing to the formation of voids in the concrete, which consequently reduces its strength.

5. Conclusion

Based on the results of this study, it was possible to verify that the addition of materials containing iron oxide, the main component of the pigment, can influence the compressive strength of concrete.

The strengths obtained at 7 days with 3% pigment addition corresponded to more than half of the theoretical fck values for each mix, reaching approximately 65% for T1P3, 60% for T2P3, and 82% for T3P3.

The colored mix that showed the greatest strength gain was T3P3, reaching an fck of 43.09 MPa at 14 days, surpassing the theoretical fck of 40 MPa at 28 days. Conversely, the mix with the greatest reduction in the same period was T1P6, achieving a strength of 10.12 MPa compared to a theoretical fck of 18 MPa at 28 days.

The best results were observed in colored mixes with a 3% pigment addition, making this percentage the most recommended for the application of colored concrete.

An increase in the percentage of pigment addition in the mix also contributed to reduced workability and decreased concrete strength.

For greater reliability and precision of the results, it is necessary to develop mixes that reflect the characteristics and peculiarities of the aggregates used for concrete production in the city of Teófilo Otoni.

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