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SCLEROMETRY TEST ON CONCRETE USING RIGID POLYURETHANE FOAM RESIDUES TREATED WITH CONDUCTIVE GRAPHENE PAINT

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Abstract: In order to guarantee the characteristics of concrete, one of the most used materials in civil construction, technological control is fundamental, making it necessary to search for adequate tools and methods to verify the properties of concrete structures. The most used methodologies to analyze and confirm the compressive strength of concrete are the destructive tests, whose purpose is to obtain parameters that confirm its strength, quality and durability. Currently, there are other methodologies, such as non-destructive tests, which are becoming increasingly attractive due to the ease of collecting data in loco, with the advantage of quick results and not causing damage to structures. The present study was carried out on a sample of concrete with rigid polyurethane treated with conductive graphene paint (PURP) with the application of non-destructive testing of concrete, using a Schmidt type sclerometer to estimate the compressive strength. The methodology used was based on the definitions of NBR 7584:2012, which determines the minimum of nine impacts in each area, it was decided to carry out 9 impacts for 50% of PURP and 9 impacts for 25% of PURP, which obtained if the sclerometric index per point, then the correlation was performed to estimate the characteristic resistance. Therefore, the sclerometry test is capable of indicating the compressive strength of PURP concrete, obtaining data that contribute to the reliability of the technological control, without causing damage to the analyzed element.

Keywords: Concrete. Characteristic resistance. Non-destructive rehearsal. Sclerometry.

INTRODUCTION

The civil construction industry has large rates of solid waste generation. Aiming at taking actions that reduce the impacts generated on the environment, it is important to carry out studies aimed at the reuse of materials (TINOCO AND KRAEMER, 2011).

The durability of concrete is related to its ability to perform the functions assigned to it. However, it is worth mentioning that durability does not mean an infinite useful life, in addition to that, it is known that in many situations it is necessary to intervene either through repairs or periodic maintenance (NEVILLE, 2016).

In Brazil, the method of controlling the compressive strength of concrete is standardized by ABNT NBR 5738: 2015, and consists of molding and breaking specimens. However, these tests tend to cause damage to structures, compromising their structural integrity. Therefore, seeking the best performance and durability, the technological control of concrete is necessary in the search for parameters that guarantee its quality during and after execution.

As a viable alternative, non-destructive testing (NDT) is gaining ground in the civil construction industry as it is a method capable of estimating the compressive strength of concrete, causing little or no damage to structures quickly, facilitating the diagnosis, as well as helping in the Inspection process of concrete structures, being performed in the stages of manufacture, construction, assembly and maintenance. Therefore, this tool is of paramount importance in controlling the quality and safety of materials and equipment, in order to guarantee quality, as well as reduce costs and increase credibility in inspection. (CASTILLO PERREDA, 2010).

LITERATURE REVIEW

SCLEROMETRY

The test is based on the principle that the reflection of an elastic mass depends on the rigidity of the surface against which it was launched (NEVILLE, 2016).The sclerometry test is a simple, easy and relatively low-cost method when compared to other non-destructive methods, making it possible to estimate the compressive strength of concrete without causing damage to the analyzed structural element.

The test method is standardized by ABNT NBR 7584 (2012) with the use of equipment known as a reflection sclerometer, which is a type of hammer that, driven by a spring, collides, by means of a rod with a tip in the shape of a spherical cap, with the test area, aiming to measure the return of the force driven on a concrete surface, as shown in Figure 1.

Schmidt's reflection sclerometer emerges as an innovative tool that aims to estimate the compressive strength of concrete through a non-destructive test, known as sclerometry, which becomes attractive because it does not cause damage to the analyzed structure, as well as its applicability where the tests with core extraction become unfeasible and can be performed in the field.

The main advantage of the method is the speed of execution and the collection of information, as well as the ease of operating the equipment used, causing little or no damage to the tested surface. It is noteworthy that in monitoring the development of resistance over the years, the method is well accepted to assess the uniformity of concrete, as well as to estimate its resistance in situations where destructive tests are inadequate.

The fact of reaching only a depth of about 30 mm limits the results to a surface area of concrete, and after 3 months the influence of concrete carbonation occurs (BS 1881: Part 202, 1986). With the use of this method, it is possible to evaluate structures both in the execution phase and ready, aiming to estimate the characteristic resistance of the concrete without damaging the structures, as well as to compare the quality of the concrete in different areas.

COMPOSITE

Composite is interpreted as a multiphase element, artificially developed and "engineered". That is, a substance can be acquired that contains a mixture of chemically varied phases, in a very specific way and with the presence of a different interface. Coming from the emergence of the combined action or rule of mixtures, the composite element shows a significant intensity of both constituent stages. Therefore, it is possible to reach a practically infinite range of combinations of characteristics, which would be unlikely to be acquired, in isolation, in monolithic materials (CALLISTER AND RETHWISCH, 2020).

GRAPHENE

From the 60s H.P.Bohen and other scientists split some carbon nanosheets from the minimization and heating of graphite oxide. However, graphene was known as a nanomaterial for theoretical purposes only because of the acquired leaves, when divided, a thermodynamically unstable behavior at room temperature is observed (BOEHM et al., 1962).

Graphene nanosheets were separated in 2004 from various mechanical exfoliation of graphite and characteristically analyzed by researchers from the University of Manchester A. Geim and K. Novoselov (NOVOSELOV et al, 2004).

CONDUCTIVE GRAPHENE INK

Conductive graphene ink is a material with high surface tension (Figure 2), excellent stability, good adhesion, high conductivity, high resolution and fast drying. It was formulated to dry at room temperature. When applying, it is spread with a brush and it dries for around 15 minutes at room temperature (±25°C). Indicated for use directly or through a brush. Its composition makes this ink capable of being used on several classes of substrates,

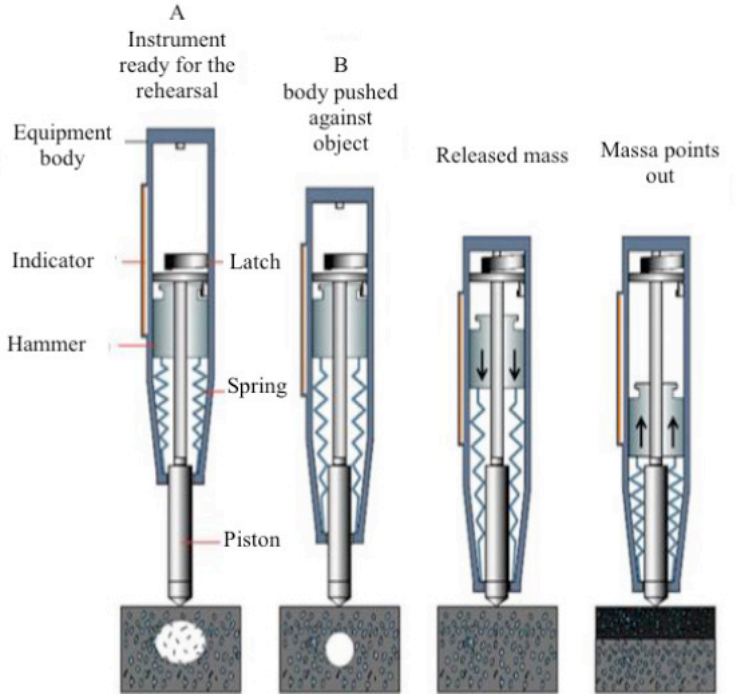


Figure1:Illustration of the execution sequence of the sclerometry test, adapted by Rogerio Alves based on Mehta and Monteiro, 2014.

Figure 2: Conductive graphene ink (CARBONEXPLORE,2021)

such as paper, cardboard, wood, metal, polymers, natural fibers, synthetic fibers, electronic boards, components, walls, fabrics, plastics, etc. Excellent for performing repairs on cell phone boards, notebooks, remote control, circuit board tracks, transistors, photovoltaic devices, diodes, cables in general, etc. (CARBONEXPLORE, 2021).

CONCRETE

During the execution stages of civil construction projects, it is possible to verify the presence of a global material in all works, which is concrete. This input has been used for several decades for the construction of structures, coatings and laying ceramic materials. The concrete is established (ABNT12655, 2015; BOTELHO AND MARCHETTI, 2002; CARVALHO AND FILHO, 2014; DIAS et al.,2017) fundamentally as a homogeneous element made of cement, water, sand and gravel (stone), chemical additives and minerals that forms a mass adherent to other types of materials, being simply manipulated, elaborated and carried out by a large part of the population, exhibiting application versatility, prolonged durability, low production cost, resistance to shocks and vibrations, thermal and atmospheric effects and mechanical wear.

METHODOLOGY

The analyzed element was the cylindrical sample of 20 x 10 cm, with a 0º inclination and for carrying out the test, the guidelines of NBR 7584 (2012) were followed, which determines the cleaning of the test surface, as well as the minimum number of impacts to be carried out by area and the mesh that must be drawn on the contact surface, in addition to the minimum distances that must be considered in relation to elements such as beams and pillars.

In this test, equipment called a reflection sclerometer, also known as Schmidt's Hammer, is used. The equipment consists of a hammer mass system driven by a spring, which collides with the surface of the concrete from an impact piston that has a spherical tip. After being released, the hammer mass is reflected by the piston still in contact with the surface of the material. The impact energy is, in part, used in the permanent deformation caused in the test area and, in part, preserved elastically by providing the return of the hammer mass. The distance covered in the return by the mass is called the sclerometric index (SI) as shown in Figure 3.

The test was carried out point by point, respecting a minimum distance of 50 mm from the edges of the elements, then a grid was demarcated to guide the impact blows of the sclerometer in each different location of the test. Each mesh was demarcated by composing a 90x90 mm matrix, with 9 impact points each, and all points had a minimum distance of 30 mm between them.

A template (Figure 4) will be used to mark the points where the test will take place, thus acquiring the IE (sclerometric index) of each point, and after acquiring the values, the calculation of the arithmetic mean of the 9 impacts will be performed for 50% of PURP and 9 impacts for 25% PURP, and any individual EI that is more than 10% of the median value obtained will be discarded and a new arithmetic mean will be calculated with at least 5 values.

According to Zanardo (2015) the deformation is directly linked to the surface of the tested concrete, the harder the region, the smaller the change caused in the test area, increasing the reflection portion, offering higher reflection rates.

RESULTS

The 9 readings of sclerometric indices performed in each analyzed sample were

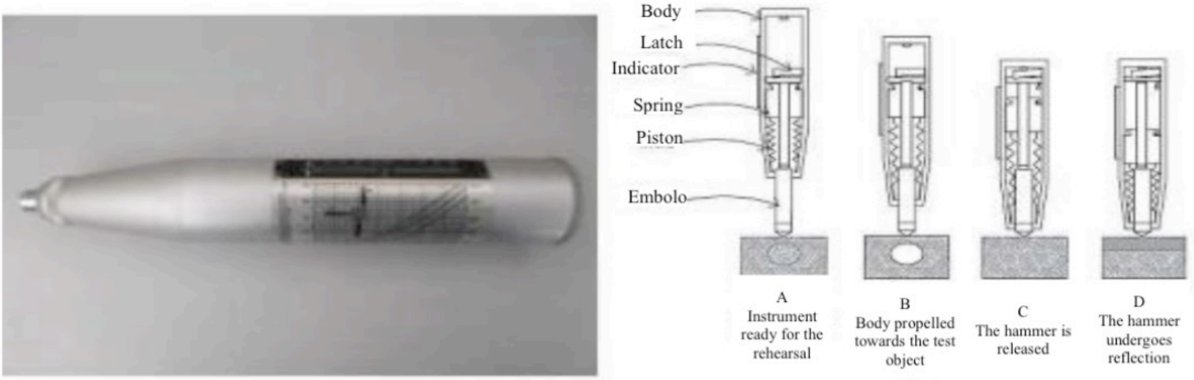
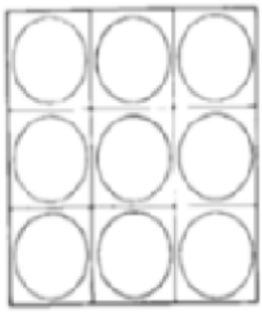


Figure3: Reflection sclerometer: (a) Schmidt sclerometer, (b) Execution sequence (TÉCHNE, 2009)



9 Impact

Figure 4: Template (Source: NBR 7584: 2012)

SCLEROMETRIC TESTING			**Nº** 001/21 DATE :09/09/21
		BRAND **:Sadt**	
		TYPE : N	**Nº**SERIE:**1805048**
		MODEL :HT-225ª-ANALOG	**FCK:35** MPA
		NºCALIBRATION: 2018082702	
CONCENTRATION		25%	50%
AGE (DAYS)		28	28
TESTING ANGLE		0°	0°
TESTED PIECE (CM)		CYCLINDER 20X10	
DEVICE REBOUND INDEX	1	20	20
	2	19	19
	3	19	19
	4	22	19
	5	23	21
	6	23	23
	7	19	24
	8	23	26
	9	23	21

Table1:Sclerometric Index Values Obtained in the Test

shown in Table 1, and it presents the total value of the indices obtained in each of the analyzed points, which will be used to obtain the mean and effective sclerometric indices.

For each test sample, 9 sclerometric indices were collected, which were added and divided by the number of impacts, where the first sum was obtained. Subsequently, the yellow and red flagged values were discarded, as they were more or less than 10% away from the sclerometric index obtained in the first average. Based on the remaining values, a second sum was obtained, as well as the second average, which is the mean EI value at each analyzed point, as shown in Table 2.

The values referring to the second average are the average sclerometric indices for each of the five evaluated points that will be corrected using the correction coefficient value provided by the equipment manufacturer, which in this case is k= 0.996 to determine the effective sclerometric index. The effective sclerometric index (IEi) was determined, performing the product between the correction coefficient (k) and the mean sclerometric index (IE), according to table 3. The values relevant to the IEi are represented in the line that refers to to the corrected index.

The results of the effective sclerometric indices were used to determine the characteristic resistance of the material based on the conversion table of sclerometric index into resistance (MPa) provided by the equipment manufacturer as a function of the test performance angle, as shown in the table 4.

To estimate the resistance values at each of the points, a linear interpolation was performed between the values found in the manufacturer's conversion table 5 and the IEi value obtained in the test.

With the resistance values obtained in each tested sample, the graph of figure 5 was plotted, referring to the IEi value, to better demonstrate the behavior of the concrete resistance.

The compressive strength of concrete is a determining factor in assessing the quality of concrete, the performance of a structure, as well as its useful life and safety. For each specific project, it is necessary to guarantee the durability of the construction with the use of quality concrete and with fck that meets the requests to which it will be submitted, according to the pre-defined dimensioning in the project.

The fck adopted from the project sample was 35 MPa and with the sclerometric test it was possible to verify that there was a loss of resistance, because according to the graph in figure 5, the method carried out demonstrated at 28 days with a percentage of PURP increment with 25 and 50 %, and their respective fck of 11.5 MPa and 12.6 MPa, are below the design fck.

CONCLUSION

Due to the need to guarantee a standard of quality and durability of concrete structures, the technological control of concrete is of paramount importance due to the parameters that are analyzed that tend to verify the resistant capacity, homogeneity, permeability, etc.

The sclerometric results linked to the resistance of the samples, an average of 12.05 MPa was observed. However, the characteristic resistance obtained is lower than that estimated in the project, being recommended for concrete without structural purposes.

Therefore, concrete with increased PURP is designated for filling and sealing walls, partitions and panels, as established (ABNT NBR, 6118: 2014).

SCLEROMETRIC TESTING			Nº 001/21 DATE :09/09/21
		BRAND :Sadt	
		TYPE : N	NºSERIE:1805048
		MODEL :HT-225ª-ANALOG	FCK:35 MPA
		NºCALIBRATION: 2018082702	
CONCENTRATION		25%	50%
AGE (DAYS)		28	28
TESTING ANGLE		0°	0°
TESTED PIECE (CM)		CYCLINDER 20X10	
DEVICE REBOUND INDEX	1	20	20
	2	19	19
	3	19	19
	4	22	19
	5	23	21
	6	23	23
	7	19	24
	8	23	26
	9	23	21
FIRST SUM		191	192
FIRST AVERAGE		21,22	21,33
-10%		19,09	19,19
+10%		23,34	23,46
SECOND SUM		134	85
SECOND AVERAGE		22,33	21,25

Table 2: Procedure for Obtaining the IE Value

SCLEROMETRIC TESTING			Nº 001/21 DATE :09/09/21
		BRAND :Sadt	
		TYPE : N	NºSERIE:1805048
		MODEL :HT-225ª-ANALOG	FCK:35 MPA
		NºCALIBRATION: 2018082702	
CONCENTRATION		25%	50%
AGE (DAYS)		28	28
TESTING ANGLE		0°	0°
TESTED PIECE (CM)		CYCLINDER 20X10	
DEVICE REBOUND INDEX	1	20	20
	2	19	19
	3	19	19
	4	22	19
	5	23	21
	6	23	23
	7	19	24
	8	23	26
	9	23	21
FIRST SUM		191	192
FIRST AVERAGE		21,22	21,33
-10%		19,09	19,19
+10%		23,34	23,46
SECOND SUM		134	85
SECOND AVERAGE		22,33	21,25
CORRECTION FACTOR		0,996	0,996
CORRECTED INDEX		22,24	21,16

Table 3: Procedure for correcting the IE value and obtaining the IEi value

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CONCENTRATION	IEi	RESISTENCE ESTIMATED(MPA)
25%	22,24	12,6
50%	21,16	11,5

Table 4: Resistance Value (MPa) according to IEi

Rebound value	**MPa**								
	Impact direction				**Horizontal**	**Impact direction**			
	90°	**60°**	**45°**	**30°**	**0°**	**-30°**	**-45°**	**-60°**	**-90°**
20	10.3	10.3	10.3	10.3	**10.3**	13.1	13.7	14.3	14.9
21	10.3	10.3	10.3	10.3	**11.4**	14.3	14.9	15.5	16.2
22	10.3	10.3	10.3	10.3	**12.5**	15.4	16.0	16.7	17.4
23	10.3	10.3	10.3	10.4	**13.7**	16.7	17.4	18.0	18.8
24	10.3	10.3	10.5	11.6	**14.9**	17.9	18.6	19.3	20.0
25	10.3	10.8	11.6	12.7	**16.2**	19.2	20.0	20.8	21.5
26	11.0	12.0	12.8	14.0	**17.5**	20.6	21.4	22.1	22.8
27	11.9	13.3	14.0	15.3	**18.9**	22.1	22.8	23.6	24.5
28	13.4	14.6	15.4	16.7	**20.3**	23.5	24.3	25.0	25.9
29	14.8	16.0	16.7	18.0	**21.8**	25.0	25.9	26.7	27.6
30	16.2	17.5	18.2	19.6	**23.3**	26.5	27.4	28.2	29.1
31	17.6	18.9	19.6	21.0	**24.9**	28.2	29.1	30.0	30.9
32	19.1	20.8	21.2	22.7	**26.5**	29.8	30.7	31.6	32.5
33	20.8	22.0	22.7	24.3	**28.2**	31.6	32.5	33.5	34.4
34	22.4	23.6	24.5	26.0	**30.0**	33.3	34.2	35.2	36.1
35	24.1	25.2	26.0	27.8	**31.8**	35.2	36.1	37.1	38.2
36	25.9	27.1	27.9	29.6	**33.6**	36.9	37.9	38.9	39.9
37	27.8	28.8	29.6	31.4	**35.5**	38.9	39.9	41.0	42.0
38	29.6	30.7	31.6	33.5	**37.5**	40.7	41.8	42.8	43.9
39	31.6	32.5	33.5	35.4	**39.5**	42.8	43.9	45.0	46.1
40	33.6	34.6	35.5	37.5	**41.6**	44.8	45.9	47.0	48.1
41	35.5	36.5	37.5	39.5	**43.7**	47.0	48.1	49.2	50.4
42	37.7	38.7	39.7	41.8	**45.9**	49.0	50.2	51.3	52.5
43	39.7	40.7	41.8	43.9	**48.1**	51.3	52.5	53.6	52.5
44	42.0	43.0	44.1	46.3	**50.4**	53.4	54.6	55.8	57.0
45	44.1	45.2	46.3	48.5	**52.7**	55.8	57.0	58.2	59.5
46	46.5	47.6	48.7	51.0	**55.0**	58.0	59.2	60.0	
47	48.7	49.9	51.0	53.4	**57.5**				
48	51.3	52.5	53.6	56.0	**60.0**				
49	53.6	54.8	56.0	58.5					
50	56.8	57.5	58.8	60.0					

Table 5: Conversion Table of Mean Sclerometric Index into Resistance

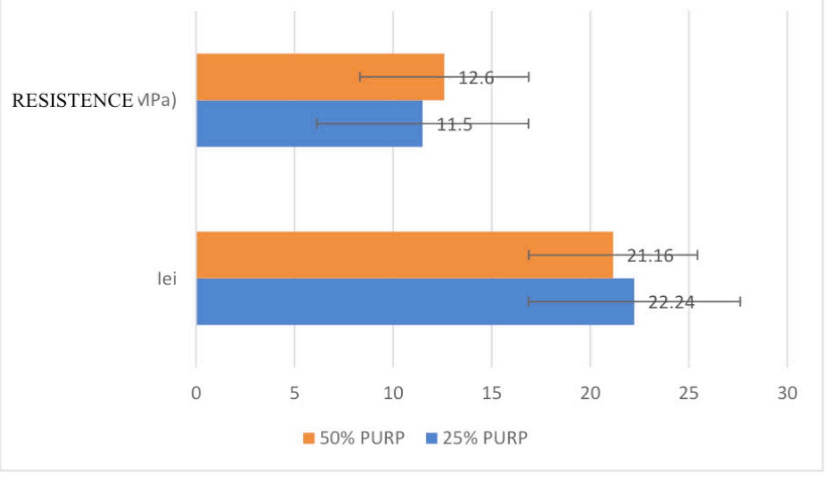

Figure 5: Comparison graph between the IEi and the Estimated Resistance in the Sclerometric Test.

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