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EFFECTS OF LOADING ON CONCRETE QUALITY THROUGH ULTRASOUND TESTING

EFEITOS DO CARREGAMENTO NA QUALIDADE DO CONCRETO ATRAVÉS DO ENSAIO DE ULTRASSOM

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Abstract: Considering the importance of non-destructive testing in inspecting existing structures, this study aims to analyze the effects of external loading on the quality of concrete using the ultrasonic pulse velocity (UPV) test. To this end, a multidirectional UPV measurement is proposed on concrete samples under compressive stresses, considering their porosity and anisotropy. Twenty cylindrical specimens measuring 10 × 20 cm (diameter × height) were made from low-strength concrete (< 20 MPa). Compressive strength (f_c), tensile strength (f_{ct}), porosity (P), and UPV were then measured in the direction of the height of the specimen and also radially, under increasing compressive stresses in this case. Scanning electron microscopy (SEM) was also carried out. The results (UPV = 3716.20 m/s) made it possible to classify the quality of the low-strength concrete (f_c = 17.48 MPa, f_{ct} = 1.65 MPa) as "good", which is attributed, among other things, to its high porosity (P = 6.73%) and quantity of macropores, confirmed via SEM. However, under increasing compressive loads, the curve fitting the data (R^2 = 79.42%) revealed a reduction in the UPV in the radial direction, significantly reducing the quality of the concrete.

Keywords: Non-destructive testing, Concrete structures, Ultrasonic pulse velocity.

Resumo: *Considerando a importância dos ensaios não destrutivos na inspeção de estruturas existentes, este trabalho tem por objetivo analisar os efeitos do carregamento externo na qualidade do concreto por meio do ensaio de velocidade de pulso ultrassônico (VPU). Para isso, propõe-se a medição multidirecional da VPU em amostras de concreto sob tensões de compressão, considerando sua porosidade e anisotropia. Vinte corpos de prova cilíndricos medindo 10 × 20 cm (diâmetro × altura) foram moldados com concreto de baixa resistência (< 20 MPa). Então, foram medidas a resistência à compressão (f_c), a resistência à tração (f_{ct}), a porosidade (P), a VPU na direção da altura do corpo de prova e também radialmente, sob tensões de compressão crescentes, neste caso. Também foi realizada a microscopia eletrônica de varredura (MEV). Os resultados (VPU = 3716,20 m/s) permitiram classificar a qualidade do concreto de baixa resistência (f_c = 17,48 MPa, f_{ct} = 1,65 MPa) como "boa", o que se atribui, entre outros aspectos, à sua elevada porosidade (P = 6,73%) e quantidade de macroporos, confirmada via MEV. Entretanto, sob carga de compressão crescente, a curva de ajuste dos dados (R^2 = 79,42%) revelou a redução da VPU na direção radial, reduzindo significativamente a qualidade do concreto.*

Palavras-chave: *Ensaios não destrutivos, Estruturas de concreto, Velocidade de pulso ultrassônico.*

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1 Introduction

Non-destructive testing plays a crucial role in assessing the quality of concrete, offering the means to inspect and evaluate material properties without compromising its structural integrity (BREYSSE et al., 2008). These techniques are essential for preventive maintenance and ensuring the safety of civil constructions, allowing early detection of potential defects or deterioration that could adversely affect the durability and functionality of structures (RASHID; WAQAS, 2017).

Among the various non-destructive testing methods, ultrasonic pulse velocity (UPV) testing stands out for its effectiveness and reliability in assessing the condition of concrete. This method is based on the propagation of high-frequency sound waves through the material, whose propagation speed is affected by the presence of voids and porosity. This propagation allows internal discontinuities to be identified, making ultrasound an essential tool for monitoring the integrity of concrete structures (LORENZI FILHO et al., 2009).

In this sense, the influence of loading, internal stresses, and anisotropy on UPV measurements is a critical aspect that deserves attention. Internal stresses can alter the propagation speed of ultrasonic waves, while the anisotropy of concrete – variation in mechanical and acoustic properties in different directions – can lead to variable UPV measurements (BROŽOVSKÝ, 2016). This variability highlights the complexity of concrete as a material and the need to interpret UPV results carefully, considering the factors that can affect the speed of ultrasonic waves (SURSHETWAR et al., 2020).

Therefore, the multidirectional UPV test is crucial for accurately assessing concrete quality, considering the influence of anisotropy and porosity. These factors can significantly alter the results, hiding flaws or indicating false diagnoses. Therefore, this paper aims to analyze the UPV under different compressive stresses, elucidating the relationship between the strength and compactness of the material. This approach contributes to developing test methodologies that consider the complexity of concrete, promoting the safety and longevity of the useful life of the structures in use.

2 Materials and Methods

Low-strength concrete samples (< 20 MPa) were produced with the following materials: Portland cement type CPV-ARI RS (ABNT, 2018a), medium natural sand (fineness modulus of 2.75 and maximum diameter of 2.4 mm, specific density of 2.632 g/cm^3) and

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gneiss crushed stone (fineness modulus of 4.92, maximum diameter of 9.5 mm, and specific density of 2.646 g/cm^3), following the standards that address the determination of specific mass and apparent specific mass of fine aggregates, as well as particle size composition (ABNT, 2002; 2003). The mixing proportion was 270 kg/m^3 of cement with a cement:sand:gravel:water ratio of 1:2.31;2.07;0.60.

The mixing was carried out in a 120-liter concrete mixer in two stages: initially, aggregates and 50% of the water were mixed for 3 minutes; then, the cement and the remaining 50% of the water were added, mixing for another 3 minutes. Consistency was checked by the slump test, resulting in 150 mm (ABNT, 1998). Twenty 10 × 20 cm (diameter × height) cylindrical specimens were prepared with manual compaction in two stages, demolded after 24 hours, and cured in a saturated calcium hydroxide solution at 23 ± 2 °C for 28 days (ABNT, 2015).

After this period, the following properties were measured:

(i) compressive strength (f_c): using a universal testing machine (model EMIC DL 30000), the compressive strength was measured in five test specimens (ABNT, 2018b). These tests provided an average estimate of concrete strength, assisting in UPV measurements in the radial direction.

(ii) ultrasonic pulse velocity: UPV was measured in two orientations. Initially, five specimens were used to determine the UPV in the direction of the cylinder height (ABNT, 2019), using a Proceq brand device (Pundit Lab(+) model) for measurements. Then, another five specimens were used to measure the UPV in the radial direction during the application of the load in the same hydraulic press as the compression test, as illustrated in Figure 1. The loading was interrupted every 30 kN of force (approximately) to measure UPV safely and then restart. This process was repeated until rupture when the last reading was taken.

(iii) porosity (P): porosity was measured according to the method of Rabbani et al. (2014), using the specimens initially employed for UPV measurements in the height direction. Additionally, a scanning electron microscopy (SEM) analysis was carried out on broken concrete samples to identify the distribution and approximate size of the pores in the material.

(iv) tensile strength (f_{ct}): tensile strength was evaluated in five specimens using the diametral compression test (ABNT, 2011).

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Figure 1. Measurement of UPV in the radial direction of the specimen

3 Results and Discussions

Figure 2 presents the results of compressive strength (f_c), tensile strength (f_{ct}), porosity (P), and ultrasonic pulse velocity (UPV) in the height direction of the concrete specimen, with the horizontal line in each boxplot referring to the average value. There were no spurious values (outliers) in any property.

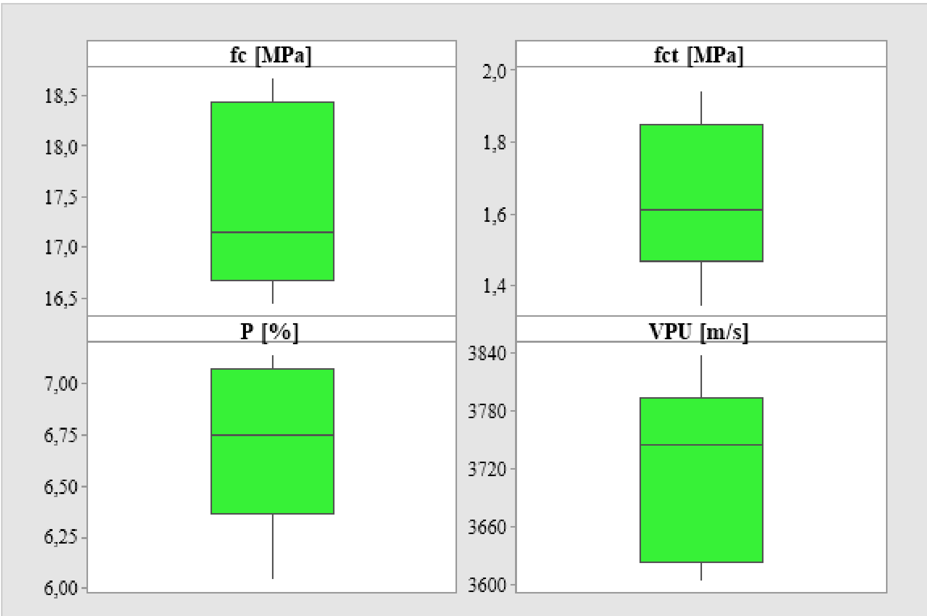

Figure 2. Boxplot of compressive strength (f_c), tensile strength (f_{ct}), porosity (P), and ultrasonic pulse velocity (UPV) in the height direction of the concrete specimen

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As expected, the concrete had low compressive strength (f_c = 17.48 MPa; coefficient of variation – CV = 5.30%) and tensile strength (f_{ct} = 1.65 MPa; CV = 13.26%), which is related to its high porosity (P = 6.73%; CV = 6.27%), which, in turn, is due to the water/cement ratio (w/c) of 0.60 used in the mixture. Consequently, the result of the UPV in the direction of the cylinder height (UPV = 3716.20 m/s; CV = 2.48%) allows the categorization of this concrete's quality as "good", as it is between 3500 and 4500 m/s (an "excellent" quality is attributed when there is a UPV greater than 4500 m/s) (IAEA, 2002).

Figure 3 shows an SEM image at 100x magnification. The concrete is porous and has many macropores, negatively interfering with UPV. In other words, when flaws and/or voids exist, the ultrasonic pulse must go around them, taking more time to travel through the material.

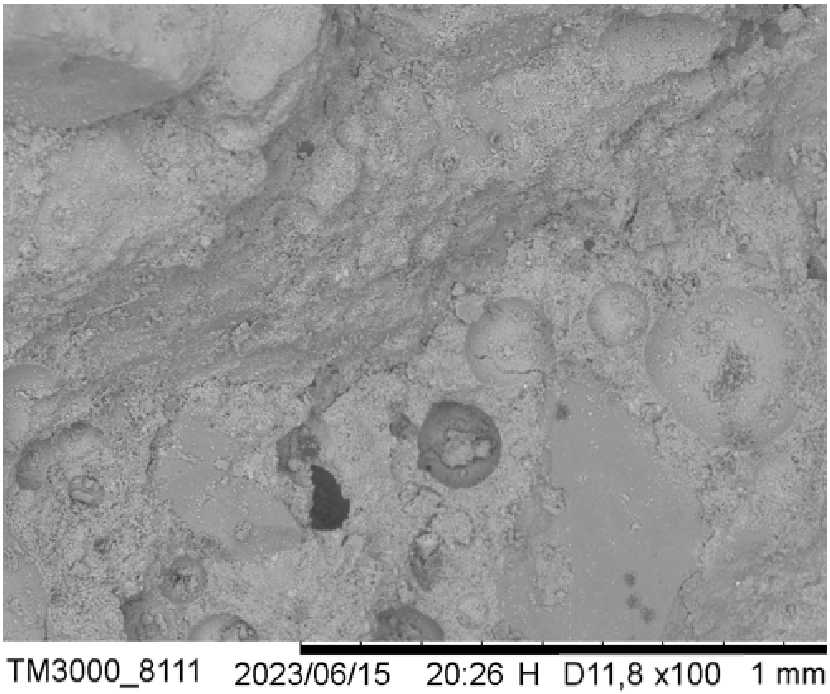

Figure 3. SEM image with 100x magnification of the broken concrete sample

It must also be considered that the internal structure of the concrete can undergo changes resulting from external loads, altering its quality in different directions. Therefore, UPV measurements were also carried out in the radial direction of the cylindrical specimens during the compression test, with the results given as a function of the stress applied from the decompressed state (zero force) until after rupture (maximum f_c) (Figure 4).

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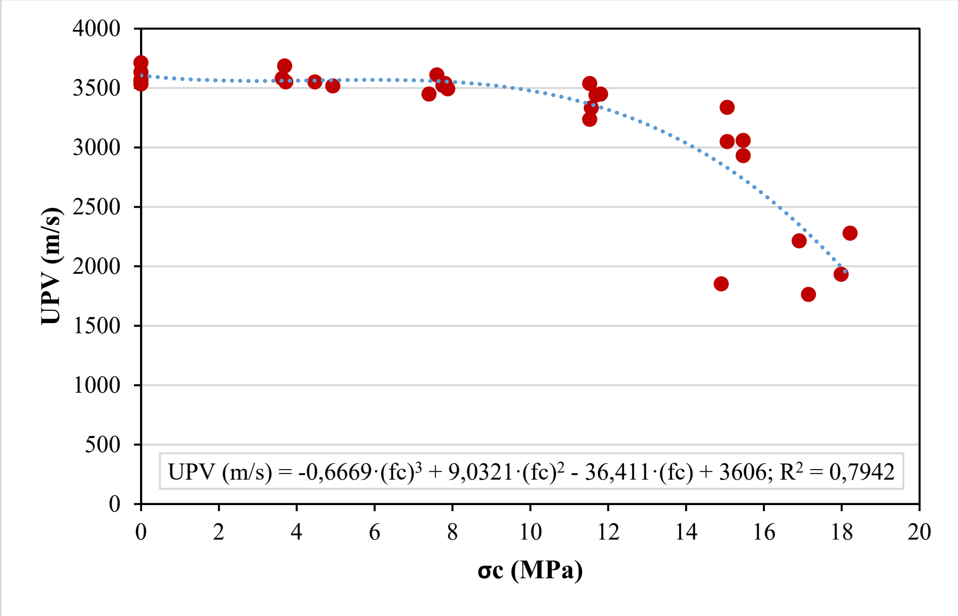

Figure 4. Evolution of the UPV during the compression test

It can be seen in Figure 4 that the curve fitted to the experimental data presented a coefficient of determination (R^2) of 79.42%, indicating a considerable adjustment. Therefore, it is inferred that it satisfactorily explains the reduction in UPV with the increase in compressive stress (σ_c). From the results in this figure, it is also noted that the quality of the concrete is classified as "doubtful" (between 3,000 and 3,500 m/s) after 7 MPa of compression, as "poor" (between 2,000 and 3,000 m/s) between 16 MPa and 18 MPa and as "very poor" (less than 2,000 m/s) from approximately 18 MPa (IAEA, 2002).

Due to the Poisson effect, the axially compressed specimen (in its height direction) tends to elongate transversely (in this case, in the radius direction), which also occurs with its internal structure, especially in the weakest phases of the structure (interfacial transition zone and paste). Consequently, the rounded pores tend to elongate in the unconfined (radial) direction, increasing the time and distance to be covered by the ultrasonic pulse in the cylindrical specimen.

Based on these results, the approach proposed in this work, as it is a non-destructive test that is simple to apply, proves to be valuable for detecting damage and deterioration and monitoring the integrity of existing structures. It makes it possible, for example, to identify areas that present potential problems, helping to plan maintenance interventions, repairs, or structural reinforcements effectively.

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It is essential to mention that this research does not propose a new assay but the improvement of the traditional method, or, in other words, a recommendation for a more appropriate use of the UPV approach. Therefore, its application is expected to contribute significantly to assessing structural safety and the diagnosis necessary to rehabilitate structures, ensuring their durability and functionality over time.

4 Conclusions

This study evaluated the concrete's compressive strength (f_c), tensile strength (f_{ct}), porosity (P), and ultrasonic pulse velocity (UPV) in both the vertical and radial directions of the cylindrical specimen, especially under conditions of increasing compressive stress. In addition, analysis was carried out using scanning electron microscopy (SEM).

Based on the results (UP = 3716.20 m/s), it was possible to determine the quality of the low-strength concrete (f_c = 17.48 MPa, f_{ct} = 1.65 MPa) as "good". This judgment was influenced by several factors, including the high porosity (P = 6.73%) and the marked presence of macropores, verified via SEM. However, as the compression load increased, the curve fitting the data (R^2 = 79.42%) indicated a decrease in UPV in the radial direction, which compromised the quality of the concrete.

Therefore, the proposed way of using the ultrasound test in this research, considering its simple execution and the anisotropy of concrete, is recommended to improve the assessment of the safety of structures and provide more accurate diagnoses of their integrity.

References

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR 16697: Cimento Portland - Requisitos.** Rio de Janeiro, 2018a.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR 5738: Concreto - Procedimento para moldagem e cura de corpos de prova.** Rio de Janeiro, 2015.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR 5739: Concreto - Ensaio de compressão de corpos de prova cilíndricos.** Rio de Janeiro, 2018b.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR 7222: Concreto e argamassa - Determinação da resistência à tração por compressão diametral de corpos de prova cilíndricos.** Rio de Janeiro, 2011.

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DOI: 10.4025/revtecnol.v33i1.72037

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR 8802: Concreto endurecido – Determinação da velocidade de propagação de onda ultrassônica.** Rio de Janeiro, 2019.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR NM 248: Agregados – Determinação da composição granulométrica.** Rio de Janeiro , 2003.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR NM 52: Agregado miúdo - Determinação de massa específica e massa específica aparente.** Rio de Janeiro, 2002.

BREYSSE, D. *et al*. How to combine several non-destructive techniques for a better assessment of concrete structures. **Cement and Concrete Research**, v. 38, p. 783-793, 2008.

BROŽOVSKÝ, J. (2016). Ultrasonic Pulse Method - Influence of Internal Compressive Stress on Results of Testing Calcium Silicate Bricks. **Key Engineering Materials**, v. 722, p. 260-266, 2016.

INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA). **Guidebook on non-destructive testing of concrete structures**. Industrial Applications and Chemistry Section, 2002.

LORENZI FILHO, A. *et al*. Monitoramento de Estruturas de Concreto através de Ensaios de Velocidade de Propagação do Pulso Ultra-sônico. *51º Congressso Brasileiro do Concreto, Instituto Brasileiro do Concreto*, Curitiba (Brasil), 2009.

RABBANI, A.; JAMSHIDI, S.; SALEHI, S. An automated simple algorithm for realistic pore network extraction from micro-tomography images. **Journal of Petroleum Science and Engineering**, v. 123, p. 164-171, 2014.

RASHID, K.; WAQAS, R. Compressive strength evaluation by non-destructive techniques: An automated approach in construction industry. **Journal of Building Engineering**, v. 12, p. 147-154, 2017.

SURSHETWAR, V. *et al.* Effect of Compressive Stress on Ultrasonic Pulse Velocity. **International Journal of Engineering Research and Technology**, v. 9, p. 1055-1061, 2020.