APPLICATION OF ULTRASONIC PULSE VELOCITY TO EVALUATE THE HOMOGENEITY OF FOAM CONCRETE

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ABSTRACT

In foam concrete (FC), the distribution of bubbles must be uniform throughout its internal structure, ensuring good performance. This paper, applying the ultrasonic pulse velocity (UPV) technique and statistical tools, presents an evaluation study of the homogeneity of the internal structure of specimens from different FCs, in three stages. In the first, the homogeneity in each specimen; in the second, in samples of 03 specimen from the same FCs; and in the third, the heterogeneity of samples from the various FCs. The results proved that the UPV was efficient in proving that the various samples of the same FC come from the same material (uniform and homogeneous structure) and that the samples of the various FCs were identified as from different materials. The lowest correlation coefficient of th FCs sets, was 91.28%. Thus, UPV proved to be effective in identifying the homogeneity or heterogeneity of the internal structure of the FCs.

KEYWORDS: *Foam Concrete, Ultrasonic Pulse Velocity, Statistical Analysis.*

I. INTRODUCTION

The foam concrete (FC) is composed of cement, fine aggregate, water and an incorporating additive that generates stable foam, besides additions and other additives [1], [2], [3]. Advantages include reduced construction costs, better thermal insulation, fire resistance, and lower self-weight in the hardened state, as well as great fluidity in the fresh state [2], [4], [5], [6]. This has increased interest in the use of FC [7], [8]. Dosing and mixture homogenization methods that are significantly different from conventional ones are needed to get and produce FC [9], [10], [11], [12]. A consistently dispersed macroscopic pore system (0.1 mm to 1 mm) in the cement paste matrix should result from the introduction of preformed foam [13]. Obtaining this uniformity in the structure of the FC ensures a balanced system that meets its main properties. Techniques like photographic microscopy [14], [15], which can be damaging [16], are not easily accessible or handled, and are necessary to verify the homogeneity of pore dispersion.

Certain concrete parameters, including density, the dynamic modulus of elasticity, homogeneity, durability, and the depth of surface cracking, have been measured in recent decades using the ultrasonic pulse velocity (UPV) [7], [17], [18], [19], [20], [21]. It was used in FC to evaluate the UPV and sample porosity as measured by gas permeability [22], demonstrating a strong association. Nonetheless, to guarantee optimal performance, the homogeneity of pore distribution in the FC's structure needs to be assessed.

When used in place of optical approaches, the UPV can be a more accessible and efficient method of verifying the homogeneity of FC without causing structural damage. The technique that finds it easier to relate UPV with porosity in FC—as opposed to conventional concrete, which has a more

heterogeneous structure—benefits from the predominance of voids and the lack of coarse aggregate [7], [22]. It also makes it easier to identify the homogeneity of voids within the structure. Flexible, very sensitive, portable, non-hazardous, with a high sampling rate and low cost, UPV also has outstanding penetration capability [23], [24]. The theory of compression wave propagation in an infinite, homogeneous, isotropic, and elastic material serves as the foundation for the UPV approach [25].
The size, shape, kind, and quantity of aggregates, the kind of cement, the water-to-cement ratio, additives, and the age of the concrete are some of the variables that might impact the UPV in cementitious materials. A few other test-related factors can also cause interference, such as the temperature of the concrete, travel length, and the size and shape of the specimens [15], [19], [25], [26], and [27]. Because ultrasonic energy can pass through liquids, examinations must be conducted on dry samples; if the pores or fissures are filled with water, they will not be detected [15].
All phases of concrete—solid, liquid, or gaseous—can be seen as homogenous. Even in tiny layers of air, an ultrasonic wave can become blocked as it passes through concrete since it propagates better through solids [29]. Part of the initial energy of the compression wave pulse is dispersed from the original wave path by voids, fissures, aggregate particles, and cement pastes [15].
This paper aims to verify the homogeneity of the internal structure of the FC using the UPV technique. Samples of 04 (four) types of FC were used, each varying the foam volume from 0 % to 50 %, totalling 20 FC compositions. First, the research methodology is presented, with the component materials, characterization of the tests, followed by the statistical procedures used. Next, the results of the tests are shown after statistical analysis. Finally, the conclusions show how suitable the VPU test is for determining the homeogeneity of samples.

II. METHODOLOGY

2.1. Characterization of Materials

In the manufacture of the FCs, were used: portland cement composed with pozzolan (CPIIZ-32), in accordance with [29], 2 sands with different grain sizes, superplasticizer additive of 3rd generation (carboxylate ether base), additive incorporating synthetic air for foam generation (salt acid base of sulfated ethoxylated fatty alcohol) and water from the supply company of Maceió/AL.
The two sands have similar morphological characteristics, differing basically in particle size distribution. The thinnest sand was named A1 (Dmax = 1.18 mm and MF = 1.45) and the thickest A2 (Dmax = 2.36 mm and MF = 2.14).

2.2. Composition of Foam Concrete

The FCs, with water/cement ratio of 0.38 (unique), were determined with 5 foam volumes (Ve) - 0%, 20%, 30%, 40% and 50% - in relation to the volume of concrete, and 2 sand/cement ratios (Snd/C) of 0.5 and 1, by mass, for each sand. They were produced in the Laboratory of Structures and Materials (LEMA/CTEC/UFAL) with the participation of the research group Eco-efficient Materials for Construction (MECOEFICON) do CNPq.
Each concrete was identified with the type of sand used (A1 and A2), followed by the Ar/C ratio (0.5 or 1) and the volume of foam used (0%, 20%, 30%, 40% and 50%). For example, sample A2-1-40, represents FC made with A2 sand, Ar/C ratio of 1 and with 40% foam volume.
Three specimens were molded for each FC, in prismatic forms of 40 mm x 40 mm x 160 mm, originating a sample, following the [30]. The specimens remained in the molds for 48 hs and, after the desmolde, conditioned in dry chamber, with control of temperature (23 ± 2 ºC) and relative humidity of the air (50 ± 5 %). At 25 days of age, they were removed from the chamber and placed in an oven, with a temperature of 105 ± 5 ºC. These procedures prevent shrinkage, which could create undesirable cracks, influencing ultrasonic measurements [22].

2.3. Ultrasonic Velocity Determination

At 28 days, the samples were removed from the oven and taken to the Physical Acoustics Laboratory of UFAL. In each specimen, 5 points were marked on the face perpendicular to the direction of formwork filling [15], 30 mm away from the ends (to avoid any edge effect) and 25 mm apart (Figure 1).

Figure 1. Position of the ultrasonic readings on the specimens.

At each point the time for an ultrasonic wave to cross from one face to the other was determined. The test apparatus (schema in Figure 2), consists of a pulse generator, a pair of transducers (transmitter and receiver), an amplifier, a time measurement circuit, a time display unit, and connection cables [31].

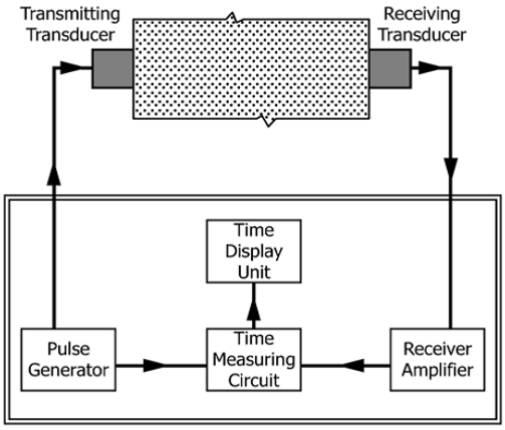

Figure 2. Scheme of the Pulse Velocity Device [32]

For the tests, the recommendations of [32] were used. The transducers were positioned on opposite faces of the specimen (direct transmission and maximum energy transfer), more efficient for reading compression waves [15]. Medicine gel was used as coupling material, because it is easy to clean after the readings [33], [34].

The device used was a generator/ receiver, with gain controls, selection of frequency, energy and pulse amplitude, impedance of the pulsator, which has a fast recovery receiver, protected from noise and electromagnetic interference (high signal/noise ratio), controlled by the computer, through a software for selection and reading of wave properties. A photo of the equipment appears in Figure 3.

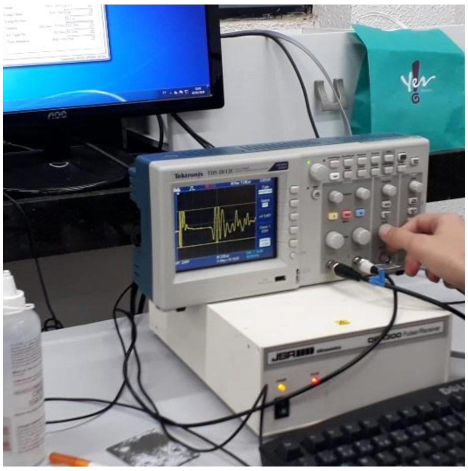

Figure 3. Equipment used for the UPV reading (pulse generator/receiver and oscilloscope).

Depending on the dimensions of the specimen s and the maximum dimension of the aggregate, the frequency of 1 MHz was used. Thus, maximum pulse energy is transmitted and received, making it highly sensitive and precise [15], [31].
The equipment reads the flight time (t) - or transit time - which is the time elapsed between the emission and the reception of the wave, crossing the specimen. To calculate the UPV, the Equation is used (1).

$$UPV = L/t \quad (1)$$

Where: UPV is the propagation speed of the longitudinal wave; L is the distance between the transducers (width of the specimen); t is the flight time.

2.4. Statistical Analysis

Statistical analysis was performed in 3 steps. The 1st analyzed the UPV readings in each specimen separately. In the 2nd, statistical similarities were analyzed between the specimen of the same sample, composed of 3 specimens. In the 3rd, statistical comparisons were performed between samples of the same FC dosage (varying the foam volume). The statistical analyses were performed with JASP software.

2.4.1. Verification of Homogeneity of UPV in each Specimen

Firstly, in order to analyze the homogeneity of UPV readings in each specimen of FC, with 05 reading points, a statistical analysis was performed by calculating the statistical data of position (mean) and dispersion (coefficient of variation – CV). Since there are no parameters for discarding the CV for this type of material in the literature, outliers were discarded, considered those that are 1.5 times the interquartile range above the upper quartile and those that are 1.5 times the interquartile range below the lower quartile of the respective sample, methodology used by JASP itself.

2.4.2. Verification of UPV in Each Sample

Then, in a second analysis, it was statistically determined if the 3 specimen s of each sample belonged to the same concrete. The anomalous values (outliers), following the same procedure of the previous item, were discarded. This time, the outliers were determined in the 15 UPVs of the 3 specimen s of each concrete, using the JASP.
After the discard, the statistical analysis of the UPV results of each sample followed the flowchart shown in Figure 4, according to the recommendations of [35]. Because the data were taken from specimen s of the same concrete, paired data were considered.

Initially, for each concrete specimen, it was determined whether the residuals of the results obtained presented a normal distribution. To determine the residuals, Equation (2) was used, according to [36].

$$e_i = y_i - \hat{y}_i \quad (2)$$

Where: e_i is the residue from the UPV reading; y_i is the UPV reading; $\hat{y}_i$ is the average of UPV readings.
Once the residuals for each sample were calculated, the Shapiro-Wilk test was used to determine whether the UPV readings of the specimen s had a normal distribution, using the residuals. After the normality tests for each specimen, if the 3 specimens presented normality, the values were submitted to Mauchly's parametric test, to determine if the specimens had equal variances. If the 3 specimens did not present normality, or if their variances were not equal (Mauchly test), the UPV values of the 3 specimens were submitted to non-parametric tests. If the residuals presented normal distribution and the UPV values presented equal variances, the UPV values of the 3 specimens were submitted to parametric tests. The Friedman test (non-parametric) was used in non-normal samples with paired data to determine whether the means were equal. If the 3 specimens had the same mean, it was proved that they belonged to the same sample. Otherwise, Conover's non-parametric post hoc test was performed, indicating which specimen (s) did not belong to the same concrete.
If they were normal and presented equal variances, they were submitted to a parametric variance analysis (ANOVA) to verify the equality of the means. If the 3 specimens had the same mean, it was verified that they belonged to the same sample. Otherwise, the Bonferroni post hoc parametric test was performed, indicating which specimen (s) did not belong to the same specimen. All the above tests were performed at a 5% significance level.

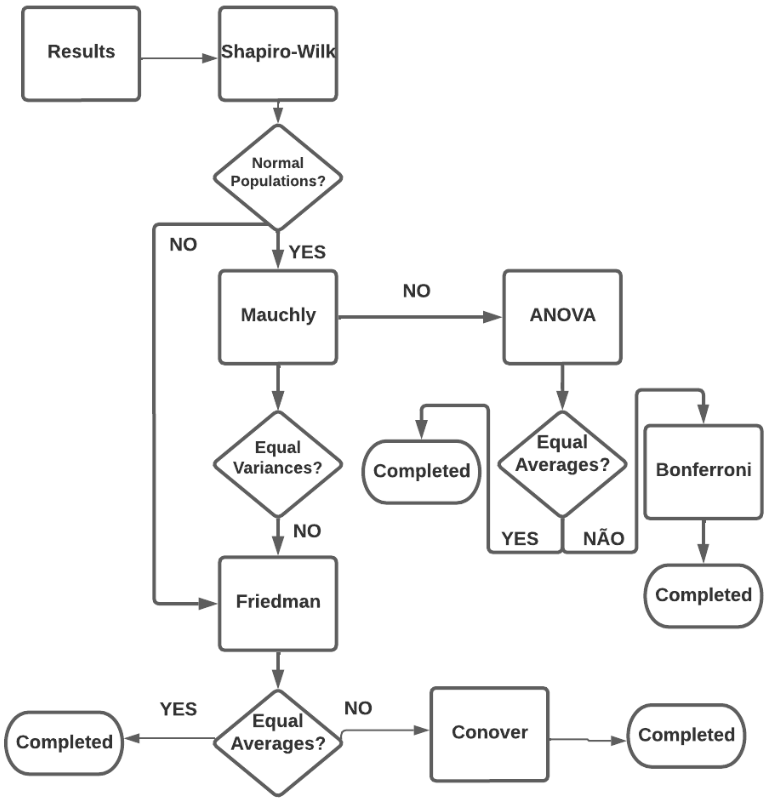

Figure 4. Flowchart of the statistical analysis of the UPVs from the second analysis.

2.4.3. Verification of heterogeneity of FC, varying the volume of foam

In the third stage, the same previous statistical tests were performed for each type of concrete with the same sand and Snd/C ratio, varying the volume of foam in 05 (five) dosages, considering that each sample of a concrete was formed by 03 (three) specimens with 15 (fifteen) reading points, per concrete, totaling 75 readings. The objective is to prove that the concretes, varying the dosage of foam, belong to different samples. The flowchart adopted was very similar to the one used in the second stage.
Again, the outliers were discarded for the 15 readings of the 3 specimens of each sample, and the normality tests on the residues (Shapiro-Wilk) were performed to determine whether the samples were normal or not. If all samples were normal, they passed the Mauchly sphericity test. Confirmed the sphericity, the samples were submitted to ANOVA, if the sphericity was not confirmed, the samples were submitted to the non-parametric Friedman test. Proof of equality of the means (ANOVA or Friedman) then indicated that the samples were statistically similar. Otherwise, the samples were subjected to post hoc Bonferroni (parametric) or Conover (non-parametric) tests, respectively, to indicate which samples were statistically different. All statistical tests were performed at a 5% (0.05) significance level.

III. Results and Discussions

The results of the statistical study for the 3 indicated steps are presented.

3.1. Verification of Homogeneity of UPV in Each Specimen

Tables 2 and 3 show the results for each combination of sand type and Snd/C ratio, varying the foam content, both before and after discarding the outliers.

Table 2. Statistical data of FC S1-0.5 and S1-1.0 specimens.

FC	Specimen	After discards			Outliers	FC	Specimen	After discards			Outliers
		Readings	UPV Average (m/s)	CV (%)				Readings	UPV Average (m/s)	CV (%)	
S1-0.5-0	1	4	3510.8	0.07	1	S1-1.0-0	1	3	3523.6	0.31	2
	2	4	3450.8	0.49	1		2	5	3528.5	0.38	0
	3	4	3552.0	0.11	1		3	5	3508.1	0.73	0
S1-0.5-20	1	4	2898,9	0.27	1	S1-1.0-20	1	5	3204.7	0.94	0
	2	5	2710.0	2.61	0		2	5	3170.0	1.51	0
	3	3	2904.0	0.18	2		3	3	3219.2	0.30	2
S1-0.5-30	1	5	2677.7	0.61	0	S1-1.0-30	1	5	2959.1	0.51	0
	2	5	2629.2	0.50	0		2	4	2962.4	0.21	1
	3	5	2685.5	1.87	0		3	5	3162.9	0.55	0
S1-0.5-40	1	5	2547.5	1.26	0	S1-1.0-40	1	5	2959.1	1.60	0
	2	4*	2660.1	5.55	0		2	5	2962.4	3.47	0
	3	5	2504,8	6.52	0		3	5	3162.9	0.76	0
S1-0.5-50	1	4	2275.5	1.29	1	S1-1.0-50	1	5	2521.6	2.91	0
	2	4	2267.8	0.22	1		2	4	2658.2	1.31	1
	3	5	2350.1	2.04	0		3	4	2749.3	1.35	1

* Only 4 readings were possible due to a defect in the specimen.

By table 2, 18 specimens (60%) did not present outliers, 9 (30%) presented 1 outlier and only 3 (10.0%) presented 2 outliers. The highest CV was 6.52%.

Table 3: Statistical data of FC S2-0.5 and S2-1.0 specimens.

FC	Specimen	After discards			Outliers	FC	Specimen	After discards			Outliers
		Readings	UPV Average (m/s)	CV (%)				Readings	UPV Average (m/s)	CV (%)	
S2-0.5-0	1	4	3179.9	0.26	1	S2-1.0-0	1	5	3563.4	0.48	0
	2	4	3166.1	0.14	1		2	5	3514.6	0.64	0
	3	4	3179.8	0.43	1		3	5	3590.7	0.41	0
S2-0.5-20	1	5	2991.9	1.93	0	S2-1.0-20	1	4	3401.3	0.42	1
	2	5	3181.3	0.63	0		2	5	3477.5	1.04	0
	3	5	2853.3	2.25	0		3	5	3533.3	0.77	0
S2-0.5-30	1	5	2752.5	2.06	0	S2-1.0-30	1	5	3277.6	1.33	0
	2	5	2676.4	0.42	0		2	5	3461.5	0.33	0
	3	5	2791.4	5.33	0		3	5	3321.5	1.14	0
S2-0.5-40	1	4	2607.2	1.75	1	S2-1.0-40	1	3	3230.8	0.11	2
	2	3	2498.3	0.25	2		2	5	3123.8	0.90	0
	3	5	2618.7	0.15	0		3	5	3315.3	2.81	0
S2-0.5-50	1	4	2269.1	0.64	1	S2-1.0-50	1	5	3231.4	2.52	0
	2	3	2253.3	3.09	2		2	5	3072.1	1.72	0
	3	4	2127.2	0.42	1		3	5	2889.5	0.56	0

As seen in table 3, 20 specimens (66.7%) showed no outliers, only 7 (23.3%) showed 1 outlier, and only 3 (10%) showed 2 outliers, while the highest CV was 5.33%.

In summary, due to the small number of outliers and the low coefficients of variation, it can be stated that the results indicate that the UPV readings belong to the same specimens in all FCs. In these analyses, the UPV technique proved to be very sensitive to the variations of the samples, showing that it can be considered suitable for determining the homogeneity of concrete.

3.2. Verification of Homogeneity of UPV in Each Fc's sample

Tables 4 through 7 shows the results of the UPVs for each specimen (average readings after discarding outliers) from different FCs and the statistical study of the homogeneity among the specimens from the same sample of a given FC.

Table 4: Statistical tests for samples A1-0.5 of each FC.

FC	Specimen	Readings *	UPV Average (m/s)	Normality (value-p)	Mauchly (value-p)	ANOVA/ Friedman (value-p)	Bonferroni/ Conover
A1-0.5-0	1	4	3510.8	0.024	-	0.018	Specimen 2 statistically different from 3
	2	4	3450.8	0.024			
	3	4	3552.0	0.024			
A1-0.5-20	1	4	2898.9	0.024	-	0.097	-
	2	5	2710.0	0.788			
	3	4	2904,0	<0.001			
A1-0.5-30	1	5	2677.7	0.419	0.190	0.068	-
	2	5	2629.2	0.774			
	3	5	2685.5	0.774			
A1-0.5-40	1	5	2547.5	0.250	0.843	0.095	-
	2	4	2660.1	0.838			
	3	5	2504.8	0.287			
A1-0.5-50	1	4	2275.5	0.413	0.489	0.018	Specimens 2 statistically different from 3
	2	4	2267.8	0.264			
	3	5	2350.1	0.308			

* After exclusion of outliers

As observed in table 4, only FCs A1-0.5-0 and A1-0.5-50 showed statistical difference in some combination of the specimens, indicating that they do not belong to the same sample.

Table 5: Statistical tests for samples A1-1 of each FC.

FC	Specimen	Readings *	UPV Average (m/s)	Normality (value-p)	Mauchly (value-p)	ANOVA/ Friedman (value-p)	Bonferroni/ Conover
A1-1.0-0	1	3	3523.6	0.303	0.668	<0.001	Specimen 3 statistically different from 1 and 2
	2	5	3528.5	0.302			
	3	5	3508.1	0.551			
A1-1.0-20	1	5	3204.7	0.279	0.630	0.313	-
	2	5	3170.0	0.385			
	3	3	3219.2	0.156			
A1-1.0-30	1	5	2977.8	0.713	0.672	<0.001	All specimens statistically different
	2	4	3073.0	0.809			
	3	5	3028.4	0.903			
A1-1.0-40	1	5	2959.1	0.250	0.843	0.095	-
	2	5	2962.4	0.838			
	3	5	3162.9	0.287			
A1-1.0-50	1	5	2521.6	0.837	0.001	0.018	Specimen 3 statistically different from 1
	2	4	2658.2	0.927			
	3	4	2749.3	0.999			

* After exclusion of outliers

Table 5 indicates that FCs A1-1.0-0, A1-1.0-3 and A1-1.0-50 showed statistical difference in some combination, indicating that they do not belong to the same sample.

Table 6: Statistical tests for sample A2-0.5 from each FC.

FC	Specimen	Readings *	UPV Average (m/s)	Normality (valor-p)	Mauchly (valor-p)	ANOVA/ Friedman (valor-p)	Bonferroni/ Conover
A2-0.5-0	1	4	3179.9	0.455	0.362	0.090	-
	2	4	3166.1	0.344			
	3	4	3179.8	0.891			
A2-0.5-20	1	5	2991.9	0.170	-	0.007	Specimen 3 statistically different from 2
	2	5	3181.3	0.607			
	3	5	2853.5	0.017			
A2-0.5-30	1	5	2752.5	0.419	<0.001	0.091	-
	2	5	2676.4	0.774			
	3	5	2791.4	0.994			
A2-0.5-40	1	4	2607.2	0.768	0.329	<0.001	Specimen 2 statistically different from 1 and 3
	2	3	2498.3	0.459			
	3	5	2618.7	0.391			
A2-0.5-50	1	4	2269.1	0.544	0.447	0.387	-
	2	3	2253.3	0.100			
	3	4	2127.6	0.846			

* After exclusion of outliers

In Table 6, FCCs A2-0.5-20 and A2-0.5-40 showed a statistical difference in some combination of the specimens, indicating that they do not belong to the same sample.

Table 7: Statistical tests for sample A2-1 of each FC.

FC	Specimen	Readings *	UPV Average (m/s)	Normality (valor-p)	Mauchly (valor-p)	ANOVA/ Friedman (valor-p)	Bonferroni/ Conover
A2-1.0-0	1	5	3563.4	0.999	0.425	<0.001	Specimen 2 statistically different from 1 and 3
	2	5	3514.6	0.398			
	3	5	3590.7	0.398			
A2-1.0-20	1	4	3401.3	0.045	-	0.018	Specimen 3 statistically different from 1 and 2
	2	5	3477.5	0.474			
	3	5	3533.3	0.643			
A2-1.0-30	1	5	3277.6	0.159	0.712	<0.001	Specimen 2 statistically different from 1 and 3
	2	5	3471.8	0.451			
	3	5	3321.5	0.821			
A2-1.0-40	1	3	3230.8	0.053	-	0.097	-
	2	5	3123.8	0.205			
	3	5	3315.3	0.013			
A2-1.0-50	1	5	3231.4	0.060	0.417	<0.001	All specimens are statistically different
	2	5	3072.1	0.057			
	3	5	2889.5	0.554			

* After exclusion of outliers

From Table 7, only FC A2-1.0-40 showed no statistical difference in any combination of the specimens (belong to the same sample).

The tables above showed at least 2 statistically different samples, which may have occurred due to the fresh state tests performed on part of the sample, before molding the specimens. Nevertheless, we can indicate that this difference, pointed out by the UPV technique, indicates that it is sensitive to the differences between the specimens of the same sample, appropriate for the analysis of its homogeneity.

3.3. Verification of Heterogeneity of the Concretes UPV, as a Function of the Variation in Foam Volume.

Table 10 shows the results of the comparisons between the samples of different concretes, considering all the values of the UPV readings of the specimens of each FC, varying the foam volume. As table 8 shows, in all concretes there is statistical similarity only in samples with closer foam volumes. Consequently, it can be stated that the use of the UPV technique was effective in proving the heterogeneity of the FCs with different foam volumes.

Table 8: Statistical tests for the FCs samples, varying the foam content.

FC	Ve (%)	Readings *	UPV Average (m/s)	Normality (valor-p)	Mauchly (valor-p)	ANOVA/ Friedman (valor-p)	Bonferroni/ Conover
A1-0.5	0	15	3507.7	0.050	-	<0.001	Statistical similarities between the samples with Ve 0% and 20%; Ve 20% and 30%; Ve 30% and 40% and Ve 40% and Ve 50%
	20	15	2833.9	0.002			
	30	15	2664.1	0.592			
	40	14	2545.2	0.880			
	50	15	2300.8	0.265			
A1-1.0	0	15	3520.3	0.453	<0.001	<0.001	Statistical similarities between the samples with Ve 20% and 30% and with Ve 30% and 40%
	20	15	3175.3	0.367			
	30	15	3025.2	0.363			
	40	15	3028.1	0.363			
	50	15	2666.2	0.363			
A2-0.5	0	14	3171.6	0.992	-	<0.001	Statistical similarities between the samples with Ve 0% and 20%; Ve 20% and 30%; Ve 30% and 40% and Ve 40% and 50%
	20	15	3002.3	0.144			
	30	14	2722.4	0.425			
	40	15	2565.3	0.108			
	50	13	2210.9	0.045			
A2-1.0	0	15	3556.2	0.556	<0.001	<0.001	Statistical similarities between the samples with Ve 0% and 20%; Ve 30% and 40% and Ve 40% and 50%
	20	14	3475.7	0.277			
	30	15	3357.0	0.050			
	40	15	3227.8	0.145			
	50	15	3064.3	0.166			

* After exclusion of outliers

Figure 5 shows the results for the four FCs, by the average UPV x Ve (%) curves, considering the average values of the UPV. It shows that it decreases with increasing foam content because the voids left after hardening and drying of the specimens reduce the speed of the ultrasonic waves. Also, it is observed that there is influence of both the fine aggregate grain size and the Snd/C ratio.

The correlation coefficients (R2) of the curves are: 96.6% for curve A1-05, 93.03% for curve A1-1, 93.34% for curve A2-05 and 91.28% for curve A2-1. This indicates an excellent correlation between the foam volume and the UPV reading. Once again, it proves the sensitivity of the technique for studying the properties of FCs.

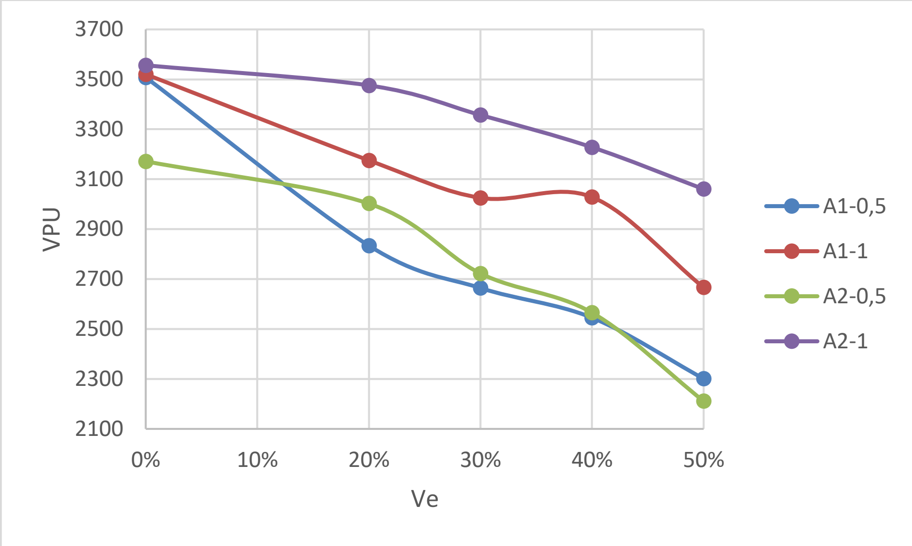

Figure 5: Graph with the UPV results (m/s) of the 4 concretes together.

IV. Conclusions

The use of ultrasonic pulse velocity in the analysis of the specimens of the same sample proved to be effective in proving the homogeneity of each sample. Furthermore, the statistical analysis showed, in most cases, that specimens of the same concrete belong to the same sample in the four combinations of sand type and sand/cement ratio. In some cases, statistical analysis showed that specimens from the same sample could be considered statistically different, which is explained by the influence of other tests on the sample in the fresh state, before molding and hardening of the specimens.

The analysis also proved that UPV can be used to determine the heterogeneity of concrete samples with different foam volumes, indicating that UPV is sensitive to increasing foam volume. This is observed for all concrete dosages. The statistical analysis pointed out that in some cases, it was determined that concrete samples with different amounts of foam could be considered statistically equal, but only when they had close foam volumes.

The lowest correlation coefficient between the UPV reading and the foam volume was 91.28%, indicating an optimal correlation between the properties. As a fundamental data, it can be stated that the use of the ultrasonic pulse velocity (UPV) technique determined, in all combinations, that the pulse velocity depends on the amount of foam applied to the concrete in the fresh state. All graphs showed that the greater the amount of foam, the lower the UPV.

Thus, we can conclude that the UPV test can be used to determine the homogeneity of the FC both in laboratory tests with specimens and to analyze the homogeneity of concrete pieces in situ, when this study is important. It should be noted that in this study, the FC specimens did not contain any type of reinforcement, unlike what can happen in situ, which can influence the UPV.

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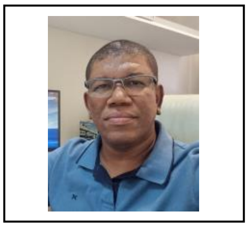

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