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Impact of Admixtures on Segregation in Self-compacting concrete: A Comparative Study Between Standardized and Ultrasonic Pulse Velocity (UPV) Methods

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Abstract

Mastering the rheology of self-compacting concrete (SCC) remains a major challenge for researchers. One of the main obstacles is segregation, an undesirable phenomenon where aggregates separate from the matrix, thus compromising the quality and homogeneity of the material. This study aims to use the ultrasonic pulse velocity (UPV) measurement technique to evaluate the variation in the degree of static segregation in self-compacting concretes. To do so, column-type molds of different sizes were fabricated. The first was designed in accordance with the recommendations of standard V1, while the others, of different dimensions, were made according to standards V2 and V3. The latter allowed the study of the scale effect on the segregation of SCC, by comparing the results with those obtained using UPV. Five SCC mixes, containing respectively 1%, 1.2%, 1.4%, 1.6% and 1.8% of admixture, were tested using standard techniques (sieve and column test), then compared to the results obtained with the UPV method. The experimental results of the two methods were analyzed and compared to other tests, such as spread, L-box, and sieve stability. Moreover, the correlation between the results of the ultrasonic tests and those of the standardized tests (V1, V2, and V3) showed a high coefficient of determination R^2: 86% for V1, 92% for V2 and 87% for V3. These results demonstrate that the UPV method is a promising alternative for evaluating segregation of fresh concrete.

Keywords: Self-compacting concrete (SCC). Rheology. Static segregation. Scale effect. Ultrasonic pulse velocity (UPV) test. Superplasticizer.

Nomenclature

SCC : Self-compacting concrete.
I_{SS} , f : Percentage of static segregation.
Isu : Assessment of static segregation using ultrasonic pulse velocity.
G_{inf}, M_α^A et CA_T : Mass of coarse aggregates in the upper section of the column.
G_{Sup}, M_α^B et CA_B : Mass of coarse aggregates in the lower section of the column.
UPV : Ultrasonic pulse velocity.

1. Introduction

Self-compacting concrete (SCC) stands out for its exceptional workability, provided its fluidity is carefully optimized. The addition of admixtures plays a key role in this optimization, directly influencing the rheological properties of the concrete. However, it is essential to find a balance, as excessive fluidity can lead to segregation, a phenomenon where aggregates separate from the matrix, thus compromising the quality of the concrete. By precisely adjusting the dosage of admixtures, it is possible to modulate the performance of SCC while minimizing the risk of segregation, paving the way for more reliable and innovative solutions in the construction industry.

On the other hand, in recent years, several methods have been developed to evaluate the dynamic segregation of SCC (Grini *et al*., 2019; Grini & Benouis, 2017; Shen *et al*., 2014; Yim *et al*., 2020b). For the first time, the use of UPV as a means to detect segregation of self-compacting concrete on a steel mold and the transducers were placed outside the mold without contact with the fresh concrete (Grini *et al*., 2019; Grini & Benouis, 2017). In other studies, an electrode was used to evaluate segregation (Khayat *et al*., 2003; Shen *et al*., 2014; Yim *et al*., 2020b). However, the design of a simple device to represent a probe used to evaluate segregation by penetrating the upper part of the sample (Shen *et al*., 2014), where the penetration of this probe reflects the segregation rate. It should be noted that relative prediction methods based on the fresh-state rheological behavior of concrete, as well as V-funnel, L-box, or JRing tests, remain essential to define the characteristics of self-compacting concrete. To this end, the standardized test method ASTM C 1611-18 (ASTM, 2005) for the flow of self-compacting concrete in an Abrams cone suggests a method for the direct evaluation of dynamic segregation; this method uses a visual stability index (VSI) determined by the visual evaluation of the apparent stability of the flow in the Abrams cone.

In order to study the static segregation of concrete, it was decided to use the column technique to measure the amount of coarse aggregates deposited in a fresh mixture using wet sieving of the upper and lower segments of a concrete column, in accordance with ASTM standard C 1610 (ASTM, 2006). It should be noted that several methods exist in the literature to determine the segregation of fresh concrete. For example, the penetration test (ASTM, 2014) can be mentioned. Moreover, some researchers have attempted to evaluate the penetration depth using innovative methods (Bui *et al*., 2002; Shen *et al*., 2014) such as the hardened visual stability index (HVSI) (AASHTO, 2008), electrical conductivity (Jolicoeur *et al*., 2000; Khayat *et al*., 2003). A metrological study was conducted where repeatability procedures were adopted. In addition, the statistical analysis of aggregates allowed obtaining the results of column tests (Mouret *et al*., 2008), image analysis of hardened concrete (Breul *et al*., 2008; Shen *et al*., 2005), and digital image processing of concrete with aggregates (Breul *et al*., 2008; Han & Yan, 2021; Panesar & Shindman, 2012; Yoon *et al*., 2023). Some techniques have also been developed to evaluate static segregation. Several previously published studies (Grini *et al*., 2019; Grini & Benouis, 2017; Mohammed Krachaï & Bouabdallah, 2020; Mouret *et al*., 2008; Yim *et al*., 2020b) have used column test dimensions different from those of conventional standards (ASTM, 2006).

On the other hand, several studies have examined the use of ultrasonic waves to determine the compactness, modulus of elasticity, and compressive strength of hardened materials (Abouhussien & Hassan, 2020; Choudhary *et al*., 2020; Panesar & Shindman, 2011; Sathurshan *et al*., 2021; Ulucan *et al*., 2008). In addition, other research has focused on fresh concrete (Benaicha *et al*., 2015; Zhang *et al*., 2021). Among the applications of ultrasound, there is the detection of internal defects, including air voids, in steel tubes filled with concrete. This detection is carried out using ultrasound immersed in a tank, allowing for in-depth analysis without direct contact of the transducers with the concrete (Callejas *et al*., 2022). Moreover, the use of ultrasound in liquids has also been studied (Lubbers & Graaff, 1998; Nowruzi & Ghassemi, 2016), particularly to determine the velocity of ultrasonic waves in water. More recent research has focused on high-viscosity mixtures (Bampouli *et al*., 2023).

The following equations were employed to determine the segregation rate in self-compacting concrete:

$I_{ss} = \left(G_{inf} - G_{sup}\right) \times 100$ (Bensebti *et al.*, 2007; Mohammed Krachaï & Bouabdallah, 2020) (1)

$f = \frac{M_{\alpha}^{A}}{M_{\alpha}^{B}} \times 100$ (Grini *et al.*, 2019; Grini & Benouis, 2017) (2)

$I_{ss} = 2\left[\frac{CA_B - CA_T}{CA_B + CA_T}\right] \times 100, \quad if\ CA_B > CA_T$ (Nili *et al.*, 2017; Panesar & Shindman, 2012; Yim *et al.*, 2020a; Zhang *et al.*, 2021) (3)

The presented studies demonstrate that ultrasonic pulse velocity (UPV) is significantly influenced by the viscosity of the liquid medium. Variations in viscosity result in corresponding changes in UPV, emphasizing the importance of accounting for viscosity in ultrasonic measurements. Consequently, the obtained UPV values are dependent on both the viscosity of the test liquid and the granular density, necessitating a thorough understanding and interpretation of the results. This study aims to measure the static segregation of self-compacting concrete as a function of admixture dosage, in accordance with ASTM standards, and to correlate these measurements with UPV. Additionally, a scale effect study on concrete segregation was conducted using both methods presented herein.

2. Experimental Study

Concrete samples were prepared using Portland cement of class 42.5, as shown in Table 1. Sand with a maximum size of 5 mm was used as fine aggregate. Crushed gravel with a maximum size of 15 mm was used as coarse aggregate. It is worth noting that the aggregates used in all concrete samples were prepared under similar conditions.

Furthermore, the particle size distribution of the aggregates (Figure 1) was carefully studied to ensure the same proportions for each class, as clearly indicated in Tables 2 and 3.

It is important to specify that polycarboxylate ether (PCE) was used as a superplasticizer, as shown in Table 4.

2.1. Material Analysis

The cement class used in this study is CEM II/A 42.5 N. It fully complies with the European standard EN 197-1 (BS EN British Standard, 2000). The physicochemical properties of the cement used are presented in Table 1 according to the standard EN 197-1 (BS EN British Standard, 2000), EN 196-2 (BS EN British Standard, 1995), EN 196-6 (BS EN British Standard, 1989), and EN 196-3 (BS EN British Standard, 1987).

Table 1 - Physico-chemical characteristics of cement.

Constituent	Unit	CEM II/B 42,5 N	Requirements EN 197-1	Standard
SiO2	[%]	16,46	/	EN 196-2
Al2O3	[%]	3,89	/	EN 196-2
Fe2O3	[%]	2,51	/	EN 196-2
CaO	[%]	61,70	/	EN 196-2
K2O	[%]	0,64	/	EN 196-2
Na2O	[%]	0,20	/	EN 196-2
Na2O-Equ	[%]	0,62	/	EN 196-2
Perte au feu	[%]	9,60	/	EN 196-2
Teneur en MgO	[%]	3,41	/	EN 196-2
Teneur en SO3	[%]	2,15	≤ 3,5 %	EN 196-2
Chlorure (Cl-)	[%]	0,04	≤ 0,10 %	EN 196-2
SSB	[cm^2/g]	4107	/	EN 196-6
I S T	[min]	163	≥ 75	EN 196-3
F S T	[min]	229	/	
Expansion	[mm]	1,00	≤ 10	EN 196-3

The physical and mechanical properties of the aggregates and limestone fines were evaluated through a series of laboratory tests. Tables 2 and 3 summarize the results of all tests conducted on the aggregates and limestone fines.

Table 2 - Material properties

	Unit	Sand 0/3	Gravel 3/8	Gravel 8/15
Absorption coefficient	[%]	2,8	0,3	0,4
Density		2,62	2,62	2,63
Fines content	[%]	3,1	0,3	0,5
Sand equivalent	[%]	80	-	-
Methylene blue value		1	-	-
Fineness modulus		1,76	-	-
Los Angeles abrasion test	[%]	-	-	26
Micro-Deval test		-	-	16
Cleanliness		-	0,20	0,20
Flatness coefficient		-	-	13,02
Moisture content	[%]	1,20	0,30	0,20

Table 3 - Chemical characteristics of limestone fines.

	CaO	SiO2	MgO	Al_2O_3	Fe_2O_3	Cl-	Na_2O	K_2O	P_2O_5	Perte au feu
Limestone fines	56,03	0,04	0,17	0,03	0,02	0,003	0,05	0,02	0,008	43

The high-performance water-reducing admixture employed is a polycarboxylate-based superplasticizer. This additive enables the production of highly flowable concretes with significantly reduced water-cement ratios (w/c), as demonstrated in Table 4.

Table 4 - Admixture properties

Aspect	Appearance	Density at 25°C	Cl-	PH	Dry extract
Liquid	Brown	1,13 (± 0,03)	< 0,1%	5,5 ± 1	38 ± 2 %

2.2. *Particle Size Analysis*

Figure 1 presents the results of the particle size analysis, including the grading curve of the granular mixture used in our study.

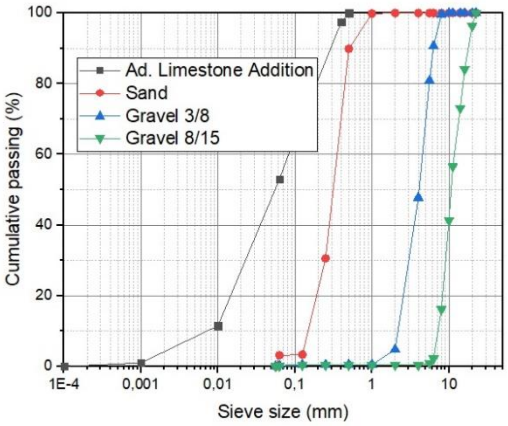

Figure 1 – Particle size distribution curves of the materials used.

2.3. Concrete Mix Design

A total of five concrete samples were prepared and labeled: SCC1, SCC2, SCC3, SCC4, and SCC5. In the initial stage, the mix proportions were identical, except for the dosage of superplasticizer, as indicated in Table 5. All samples had a water-cement ratio (w/c) of 0.46. The percentages of admixture by mass of cement used were 1.0%, 1.2%, 1.4%, 1.6%, and 1.8%, respectively. The cement class used was CEM I 42.5. The samples were prepared using a concrete mixer in a well-defined three-cycle process, for a total duration of 5 minutes. The first cycle, lasting 2 minutes, consisted of a dry mixing of the components. In the second cycle, 70% of the mixing water was added, followed by 30 seconds of mixing. Finally, the third cycle introduced the remaining 30% of the water, along with the admixtures, and the mixing lasted for 2 minutes and 30 seconds. Once the process was complete, the samples were cast into column-type molds. Table 5 summarizes the characteristics obtained for the different self-compacting concretes (SCC) that were tested in both fresh.

Table 5 - Mix design of self-compacting concrete.

BAP	Unit	SCC1	SCC2	SCC3	SCC4	SCC5
Gravel 8/15	[kg/m3]	387	387	387	387	387
Gravel 3/8	[kg/m3]	510	510	510	510	510
Sand 0/3	[kg/m3]	861	861	861	861	861
Limestone fines	[kg/m3]	50	50	50	50	50
Ciment	[kg/m3]	400	400	400	400	400
Admixture	[%]	1,00	1,20	1,40	1,60	1,80
Superplasticizer	[l/m3]	4,0	4,8	5,6	6,4	7,2
Water	[l/m3]	205,0	205,0	205,0	205,0	205,0
W/C	Rapport	0,51	0,51	0,51	0,51	0,51

2.4. Self-Compacting Concrete Testing

A comprehensive testing program was carried out in strict adherence to the guidelines provided by the European Federation of Specialized Concrete and Construction Chemicals (EFNARC, 2005). The specific tests conducted were: the Abrams flow cone test (Figure 2-A, ASTM C 161118 (ASTM, 2005)), the L-box test (Figure 2-B, (BS EN British Standard, 2010a)), the sieve stability test (Figure 2-C, (BS EN British Standard, 2010b)), the determination of fresh density (Figure 2-D, (ASTM, 2013)), the column test (Figure 4, (ASTM, 2006)), and ultrasonic velocity measurements (Figure 5, (ASTM, 2010)).

A **B**

C D

Figure 2 - (A) Abrams' cone flow test, (B) L-box test, (C) Sieve stability test and (D) Concrete density tests.

2.5. Measurement of Concrete Segregation Using Column Tests

A widely used method for evaluating the static segregation of fresh self-compacting concrete is that proposed by ASTM C 1610, which measures the coarse aggregate content (ASTM, 2006). Three column-type molds with different dimensions were fabricated for the segregation resistance test, as illustrated in Figure 03. It is important to note that the base of these molds is made of polyvinyl chloride (PVC), a non-conductive material. The dimensions of the first mold, conforming to the ASTM C 1610 test equipment (ASTM, 2006), are V1 (D = 200 mm, H = 660 mm, h = 165 mm), while the other two molds have the following dimensions respectively: V2 (D = 160 mm, H = 528 mm, h = 132 mm) and V3 (D = 100 mm, H = 330 mm, h = 82.5 mm). Coarse aggregates were separated by wet sieving with a 5 mm sieve, and then the percentage of their distribution between the upper and lower parts of the cylindrical mold was determined to evaluate static segregation. This mold was also used for the UPV test (ultrasonic pulse velocity), where transducers were fixed to the outside of the column, coupled to the surface with a suitable medium (e.g., grease) at each end, as shown in Figures 4, 5, and 6 (Kumavat *et al.*, 2014). The ambient temperature during mixing and testing varied between 18°C and 22°C.

The percentage of static segregation was calculated using the following equation:

$$I_{ss} = 2\left[\frac{CA_B - CA_T}{CA_B + CA_T}\right] \times 100 \qquad (3)$$

Where I_{SS} is the static segregation [%], CA_T is the mass of coarse aggregate in the upper section of the column [kg], and CA_B is the mass of coarse aggregate in the lower section of the column [kg].

Figure 3 - Test results for columns with varying concrete volumes (V1, V2, and V3).

2.6. Ultrasonic Pulse Velocity (UPV) Measurement

An ultrasonic pulse velocity (UPV) meter was used to measure the propagation velocity of ultrasonic pulses according to ASTM C 597 (ASTM, 2003). This technique is commonly used for testing and quality control of concrete. The velocity of ultrasonic waves is determined by measuring the time taken for longitudinal vibrations at ultrasonic frequencies to travel a known distance through the material. It can be calculated using the following expression:

$$V_i\ (l,t) = \frac{L}{T} \tag{4}$$

In this equation, V represents the velocity of the ultrasonic pulses expressed in kilometers per second. The index i denotes the transducer position, which can be either upper (U) or lower (L). The distance traveled by the pulse is represented by L, while T signifies the corresponding travel time. To measure the time taken for the pulsed wave to traverse the length of the prism, transducers with a frequency of 54 kHz and a diameter of 49.7 mm were employed.

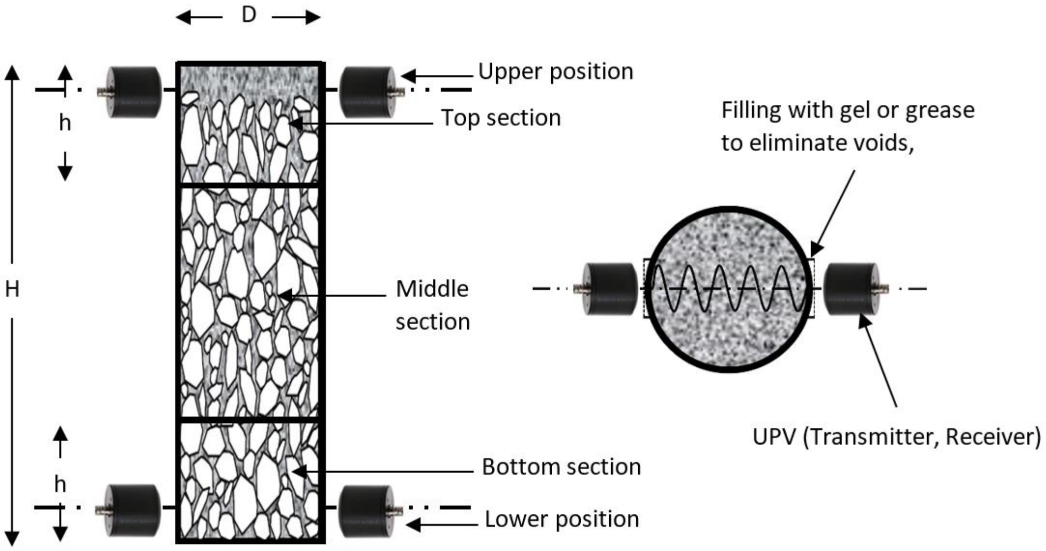

Figure 4 - Ultrasonic pulse velocity test for segregation assessment in a concrete column.

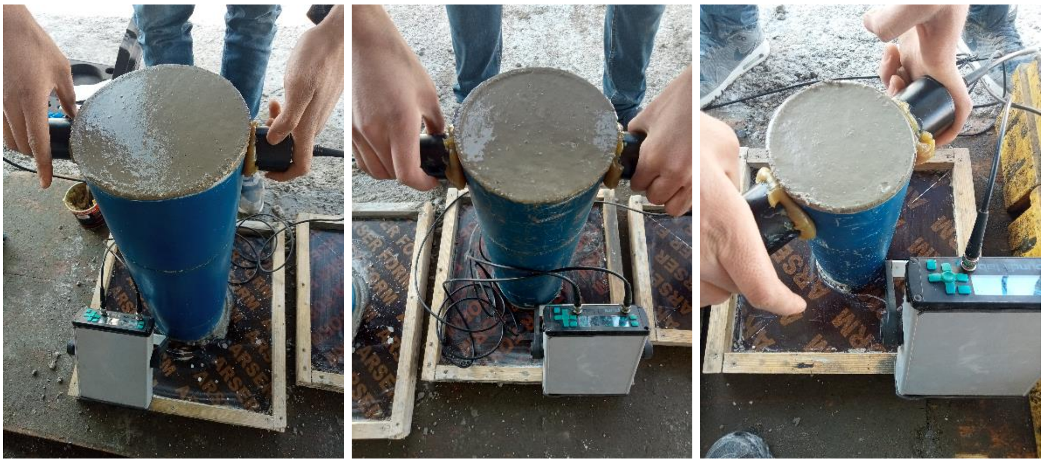

Figure 5 - Application of the ultrasonic pulse velocity (UPV) method to assess segregation (V1, V2 and V3).

Ultrasonic measurements were taken 60 minutes after placing the concrete mixture in the plastic cylindrical mold. The transducers were positioned on the mold surface, not directly in contact with the fresh concrete (Grini *et al*., 2019; Grini & Benouis, 2017). This setup does not affect segregation results as the only variable between the upper and lower sections is the aggregate content (Grini *et al*., 2019; Grini & Benouis, 2017). This method is analogous to Crosshole Sonic Logging, where continuous measurements are taken between two nested tubes placed in the pile prior to concrete placement, conforming to ASTM D6760-16 (ASTM, 2017).

The Ultrasonic Segregation Index (I_{SU}) is defined as follows:

$$I_{SU} = 2\left(\frac{V_L - V_U}{V_L + V_U}\right) \times 100 \tag{5}$$

Where I_{SU} represents the static segregation ratio (%), V_U and V_L correspond to the UPV tests in the upper and lower sections of the column, respectively.

Figure 6 - Effect of sample size on concrete segregation index measured by ultrasonic pulse velocity (UPV).

3. Results and Discussion

Figure 7 presents the results of the spread test in relation to the segregation level measured during column tests for all mixtures, obtained both by standard Iss tests and ultrasonic Isu tests. It also includes a study on the scale effect according to the volume of self-compacting concrete with different percentages of admixture. The results of the Abrams cone test are also presented. The results of these tests are satisfactory, as they fall within the acceptable range for different classes of SCC. According to EFNARC recommendations (EFNARC, 2005), a concrete is considered self compacting (SCC) when the spread is between 550 and 650 mm, which corresponds in our study to an admixture of 1%, or 4 L, and to the SF1 class. For a spread between 660 and 750 mm, the concrete is also classified as SCC, which corresponds in our study to an admixture of 1.2%, or 4.8 L, corresponding to the SF2 class. Beyond 750 mm, and up to 850 mm, the concrete is classified as SCC with an admixture equal to or greater than 1.4%, or 5.6 L, and up to 1.8%, or 7.2 L, corresponding to the SF3 class. In general, according to the results obtained, we have noticed that the increase in admixture led to an increase in the percentage of segregation for different volumes, and this, with both the standardized method and the ultrasonic method.

The correlation between the results of the segregation index Isu obtained by the UPV method and those obtained by conventional Iss tests of self-compacting concrete, as a function of the spread results, shows that with the standard Iss test, we obtained a coefficient of determination R² of 85.20% for volume V1. For V2 and V3, the coefficients of determination were 86.93% and 90.69%, respectively. For the segregation results Isu obtained by the UPV method, the coefficient of determination R² was 94.04% for volume V1, while for V2 and V3, the results were 72.21% and 56.30%, respectively, the latter representing a weak correlation.

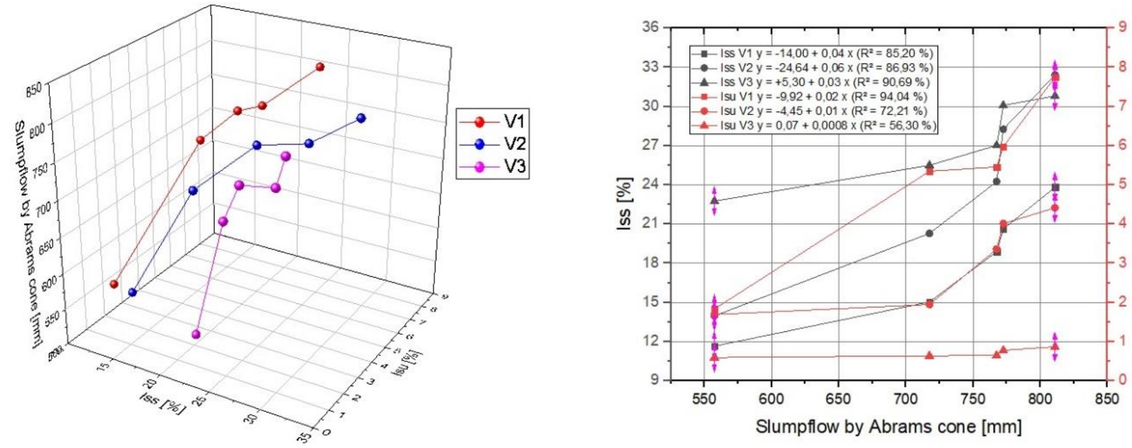

Figure 7 - Correlation between slump flow test results and segregation indices (Iss and Isu).

Figure 8 displays the data collected from the Abrams cone test, focusing on the time it takes for the concrete to spread 500 mm (T500). The results obtained align with the acceptable standards for the VS2 category of self-compacting concrete. EFNARC (EFNARC, 2005) suggests that a T500 value exceeding 2 seconds is suitable for the type of concrete used in this study. Our findings indicate that increasing the amount of admixture used in the concrete mix reduces the time it takes for the concrete to spread. For example, SCC1 concrete with a 1% admixture has a spread time of 3.7 seconds, whereas with 1.8% admixture, the time is reduced to 2 seconds. This clearly demonstrates that the admixture accelerates the flow of the self-compacting concrete.

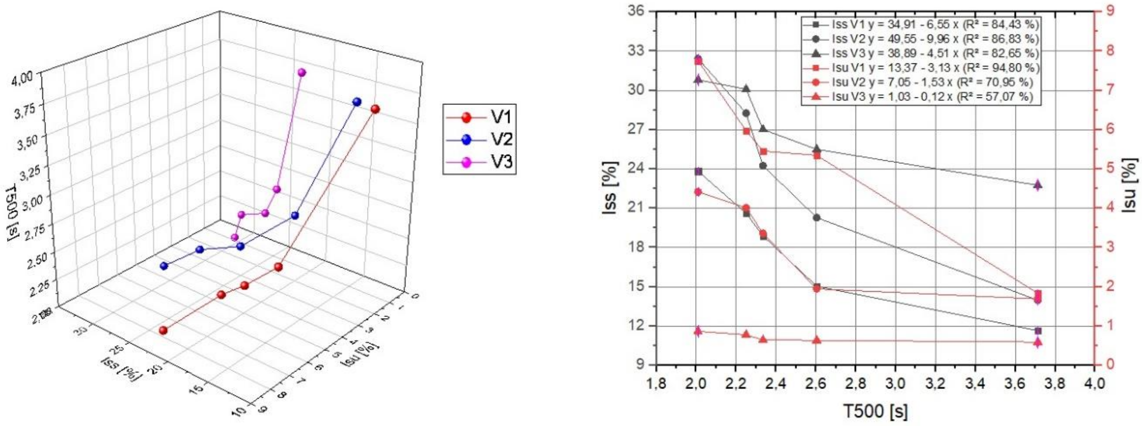

Figure 8 - Correlation between T500 slump flow time and segregation indices (Iss and Isu).

When comparing the segregation index (ISU) obtained from the ultrasonic pulse velocity (UPV) method to the conventional Iss test results for self-compacting concrete, based on the time taken for the concrete to spread, a significant correlation was found. The standard Iss test exhibited a strong correlation with an R² value of 84.43% for volume V1, and similarly high values for volumes V2 and V3. However, while the UPV method also showed a strong correlation for volume V1 (R² = 94.80%), the correlation was notably weaker for volumes V2 and V3, with R² values of 70.95% and 57.07%, respectively. This suggests that the UPV method may be more sensitive to variations in segregation for smaller volumes.

Figure 9 presents a graphical representation of the relationship between segregation in self-compacting concrete (measured by both the standard Iss test and the ultrasonic Isu test) and its plastic viscosity (μ). Plastic viscosity, a critical parameter for characterizing the fluidity of concrete, is calculated using equation (6):

$$\mu = \frac{\rho}{1000} \times (0{,}0268 \times Sf - 2{,}39) \times T_{500} \tag{6}$$

In this equation, μ represents the plastic viscosity expressed in pascal-seconds (Pa.s), ρ corresponds to the concrete density in kilograms per cubic meter (kg/m³), SF denotes the spread of the concrete in millimeters (mm), and T500 represents the time required for the concrete to spread over a distance of 500 millimeters, expressed in seconds. This figure provides a better understanding of how variations in plastic viscosity, influenced by different admixture dosages, affect the tendency of the concrete to segregate.

Our findings indicate that increasing the dosage of admixtures resulted in a decrease in the viscosity of the self-compacting concrete. Correlation analysis between the segregation indices Iss and Isu of the self-compacting concrete, as a function of the concrete's viscosity, was performed. The standard Iss test exhibited a strong correlation with the concrete's viscosity, with determination coefficients (R²) of 95.67%, 94.12%, and 86.29% for volumes V1, V2, and V3, respectively. The ultrasonic pulse velocity (UPV) method, employed to obtain the Isu results, also demonstrated a strong correlation, with R² values of 85.53%, 86.44%, and 85.83% for volumes V1, V2, and V3. These results suggest that both the Iss and Isu tests can effectively quantify the relationship between segregation and viscosity in self-compacting concrete.

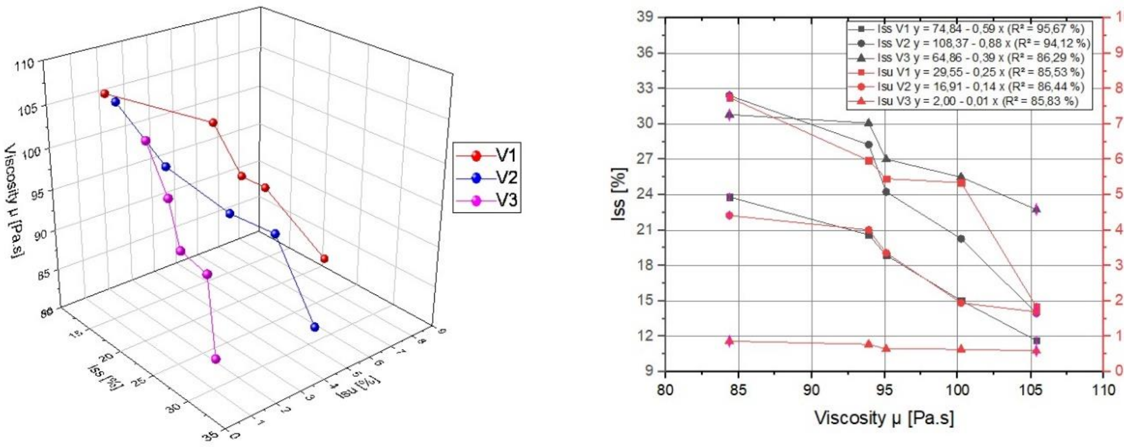

Figure 9 - Correlations between viscosity (µ) and segregation indices (Iss and Isu).

Figure 10 presents a visual representation of the sieve stability classification for the investigated self-compacting concrete mixtures. The results indicate that the mixtures fall within the SR1 and SR2 classes, with sieve stability values below 15% for mixtures containing 1% to 1.6% of admixture and below 20% for mixtures with a 1.8% admixture dosage. These findings align with the recommended sieve stability limit of π < 30% as outlined in the literature (AFGC, 2008; CUSSIGH *et al*., 2005). Furthermore, correlation analysis between the segregation indices Iss and Isu and the sieve stability π was conducted. The standard Iss test exhibited a strong correlation with sieve stability, with determination coefficients (R²) of 93.05%, 93.66%, and 85.29% for volumes V1, V2, and V3, respectively. The ultrasonic pulse velocity (UPV) method, employed to obtain the Isu results, also demonstrated a correlation with sieve stability, although with slightly lower R² values of 96.65%, 78.10%, and 76.02% for volumes V1, V2, and V3. These results highlight the relationship between sieve stability and segregation in self-compacting concrete and support the use of both the Iss and Isu tests for assessing segregation.

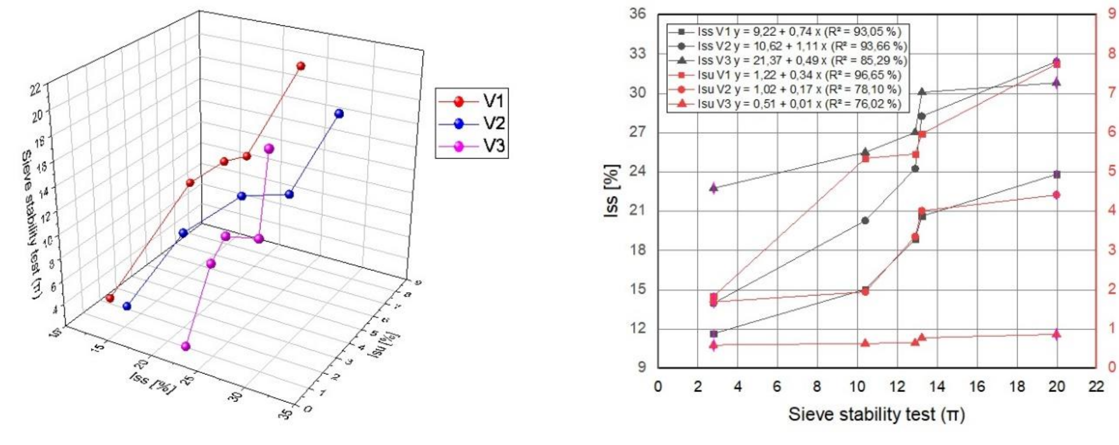

Figure 10 - Correlation between sieve stability segregation index (π) and resistance to segregation indices (Iss and Isu).

Figure 11 visually represents the positive impact of admixtures on the mobility of self-compacting concrete within confined spaces, effectively mitigating the occurrence of blockages, especially under conditions where the h2/h1 ratio exceeded 0.8. Correlation analysis between the segregation indices Isu, obtained using the ultrasonic pulse velocity (UPV) method, and those of the conventional Iss tests, as a function of the L-box test results, was conducted. The standard Iss test exhibited a strong correlation with the UPV method, with determination coefficients (R^2) of 84.43%, 86.83%, and 82.65% for volumes V1, V2, and V3, respectively. However, while the UPV method demonstrated an excellent correlation for volume V1 ($R^2 = 94.80\%$), the correlation weakened for smaller volumes V2 and V3, with R^2 values of 70.95% and 57.07%, respectively. These findings highlight the effectiveness of admixtures in improving the mobility of self-compacting concrete and underscore the overall good correlation between the Iss and Isu tests, particularly for larger volumes.

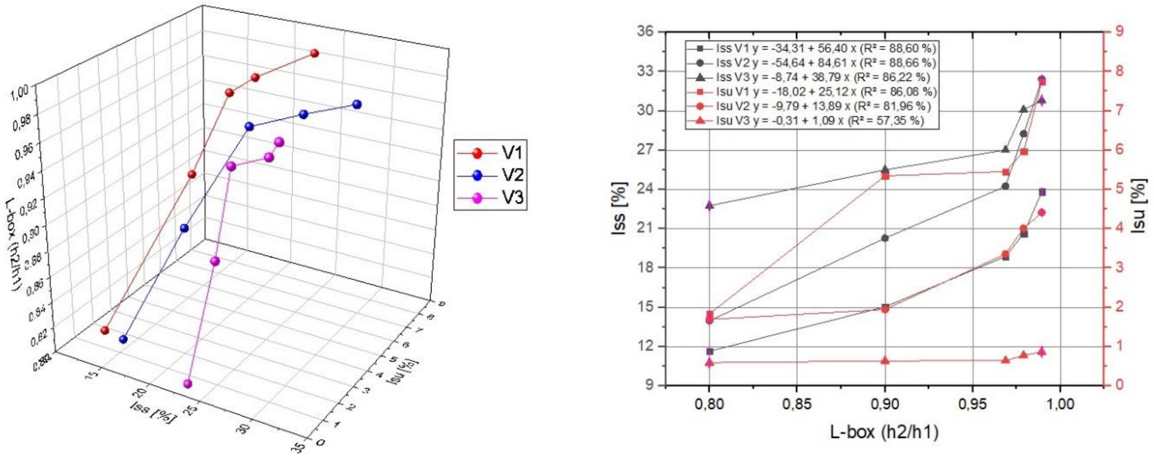

Figure 11 - Correlations between L-box flow test (h2/h1 ratio) and segregation indices (Iss and Isu).

Figure 12 presents a graphical representation of the correlation between segregation indices determined by the ultrasonic pulse velocity (UPV) method and those obtained through conventional self-compacting concrete tests. The results demonstrate a strong linear correlation between the standard test results and the UPV-derived results. Furthermore, the segregation ratio, as defined by ASTM C 1610 (ASTM, 2006), exhibits a linear relationship with the UPV-derived ratio across different concrete volumes, as visually represented in Figure 12. The high coefficients of determination (R^2) obtained for the three correlations, ranging from 86% to 92%, provide compelling evidence that the UPV technique can serve as a reliable and efficient alternative to conventional methods for assessing segregation in self-compacting concrete.

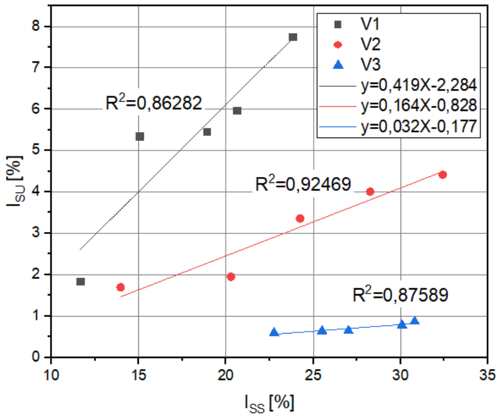

Figure 12 - Correlation between segregation indices determined according to ASTM C1610 and UPV standards.

4. Conclusion

In this experimental study, we compared two methods: the standardized method and the ultrasonic testing method for diagnosing concrete homogeneity in terms of segregation. By investigating the influence of admixture dosage on the segregation indices Iss, Isu, spread, T500, μ, and π in self-compacting concrete (SCC), we found that the ultrasonic segregation index Tsu can effectively replace the standardized Iss test for assessing segregation. As expected, the admixture dosage was a significant factor influencing segregation in SCC. An increase in admixture dosage led to a higher risk of segregation at various volumes, as determined by both methods. This can be attributed to the fact that ultrasonic pulse velocities (UPVs) are influenced by both the cement paste and the granular skeleton, whereas the Iss index is solely based on the gravel mass.

The results obtained from UPV testing were comparable to those from traditional sieve and column tests. This study demonstrated the feasibility of using non-destructive testing methods to evaluate concrete segregation, particularly for volumes V1 and V2.

The UPV method offers a clean, rapid, and user-friendly approach for characterizing concrete segregation with acceptable accuracy across different volumes. The correlation between the segregation indices Iss and Isu, as indicated by the coefficient of determination R^2, ranged from 86% for V1 to 92% for V2, and 87% for V3. Future research should focus on expanding the investigation to larger volumes and exploring the impact of ultrasonic transducer frequency and size on the results.

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