Contribution to the study of concrete segregation

A. Grini1[1,2], A. Benouiss[2]
1: Faculty of Architecture & urbanism, University of Constantine 3, Algeria, email: abdelouahab.grini @yahoo.fr
2: Civil Engineering & Hydraulic Laboratory, University of Guelma, Algeria.

Abstract

Segregation is the unintentional separation of the fresh components of concrete or mortar, which can be caused by bad proportioning, insufficient mixing, or excessive vibration. Segregation can have negative impacts on the mechanical, transport, and durability properties of the cured product. While there are several tests that can measure concrete at the beginning of hardening or in its fully hardened state, these are generally based on the percentage of the coarse aggregates between the top and the bottom of the samples. Consequently, the results do not provide a full description of the state of the material or a basis for its long-term performance. To begin to address this deficit, this paper investigates the potential of using ultrasonic pulse velocity (UPV) as a means to identify and characterize segregation in traditional and self-compacting concrete (SCC), which is known to be particularly prone to segregation, because of its high fluidity level..

Keywords: *Concrete, Segregation, Stability, Ultrasonic pulse velocity, Correlations.*

I. Introduction

Segregation is a separation of the constituents of a concrete mix or a fresh mortar, which can be caused by insufficient mixing, excessive vibration or major fluidity. In addition, water content is one of the fundamental parameters in the composition of concrete.

Water quantity and quantity can influence the separation between mortar and gravels [1]. Water-reducing admixtures are used to reduce the quantity of mixing water required to produce concrete of a certain slump. These admixtures (plasticizers, fluidizers, among others) are added to concrete to make high-slump flowing but are not free of excessive bleeding or segregation [2]. On the other hand, in the case of highly cohesive concrete mixtures [3], [4], such as those containing limestone filler, even in the absence of external bleed water, static segregation can still take place [5], [6] and [7]. The mixing method proposed by [8] for SCC is based on equivalent mortars. The literature describes many tests to characterize the segregation, including the sieve segregation index test, cylinder test, column test, ball test, pale test, etc. Shindoh and Matsuokahave evaluated self-compacting concrete test methods [9].

We also know of tests performed on samples of hardened concrete or at the beginning of hardening. These tests are generally based on the technique of counting the coarse aggregates or non-destructive testing. Some studies discuss non-destructive testing [10, [11] to estimate segregation in concrete. Breul et al. use image analysis [12] to estimate on-site concrete segregation. Schwendenmann et al., Li et al and tribikram discuss segregation in self-compacting concrete walls using gamma densitometry [13], [14] and [15]. Geoendoscopy and video-compaction are used by Idanez et al. to evaluate concrete segregation [16].

Given the multitude of tests used to characterize segregation, are there any relationships between all these methods, particularly in the case of self-compacting concretes (SCC)? The use of a non-destructive method [10], [17] could be a replacement solution. The ultrasonic pulse velocity method is the most widely used test for the inspection and evaluation of concrete structures. It is successful in situ as well as in the laboratory. This method can also be used to evaluate the homogeneity and the quality of concrete as well as to analyze its deterioration. This method is mainly used for the determination of the dynamic modulus of elasticity and Poisson's ratio. Many researchers have published results on these two properties, including Naik and Malhotra

[18], [19] and indicated that the relationship between strength and pulse velocity was not linear and that several parameters intervene in this relationship, such as the composition of concrete and its moisture content [18], [19]. The standards of RILEM (Europe), ASTM (the United States) and the British Standards Institution propose procedures to establish these correlations [20, 21 and 22]. Heterogeneity in concrete creates dispersions of the pulsations [23]. These dispersions are caused by indirect factors such as the origin of the concrete mixture and the problems of consolidation (vibration) during the casting of concrete on site. It is possible to make qualitative concrete comparisons in situ. The objective of this experimental study is to analyze correlations between the various indices of segregation and to try to correlate them with the ultrasonic pulse velocity. This work aims to propose a non-destructive and quick method of characterizing the segregation of fresh concretes.

II. Experimental tests

To understand the potential applicability and reliability of UPV to establish segregation problems in concrete mixes, an experimental program was devised. The scope of that work involved the following: Sieve stability tests, described by [24], Column stability tests as [25; 26], inspired by [27] and UPV testing (newly developed) as described below.
Sieve stability test- according to [EN 12350-11, 2010] for segregation resistance. An index π (the mass percentage of the sample passing through the sieve) is determined using equation (1):

$$\pi = \frac{W_{cs}}{W_c}\, x\, 100 \quad (1)$$

W_{cs}; Weight of the sieved materials.
W_c ; Weight of the sample poured onto the sieve.
Column stability test, an index f is determined, (i.e. equation 2)

$$f = \frac{M_a{}^A}{M_a{}^B}\, x\, 100 \quad (2)$$

$M_a{}^i$; Mass of aggregate contained in each section of concrete ("i=A" top, or "i=B" bottom)
Proceedings Ultrasonic test, ultrasonic pulse velocities [28] can be used to determine an ultrasonic segregation index f_u,as per equation 3.

$$f_u = \frac{V_A}{V_B}\, x100 \quad (3)$$

Where:
$V_A = V_{fA}$- V_{eA}: Propagation velocity ratio in the top section [A] between the filled sample and the empty sample.
$V_B = V_{fB}$- V_{eB}: Propagation velocity ratio in the bottom section [B] between the filled sample and the empty sample, respectively (Fig. 1).
V_f is the propagation velocity in a zone, filled sample.
V_e is the propagation velocity in a zone, empty sample.
Correlations between the last index, the sieve segregation index π, and the segregation resistance *f* are established.

A. Materials

The experimental materials were sourced locally in Algeria including an ordinary Portland cement (CEM II-A, 42.50), a limestone filler (a 0/80 μm) to modify the viscosity, and a superplasticizer (Médaplast SP40). Crushed sand with a maximum grain size of 5 mm and gravel with a maximum size of 15 mm are used.

B. Mixture proportions

The concrete formulations were based on Japanese method requirements as described by Okamura and Ouchi [8] and [29], as the technique originated there. In the research herein, the proportion of coarse aggregate was fixed at 50% in each mixture's compactness and that of the sand as 40% of the total volume of the mixture (cement, sand, filler and water). The compositions of 7 mixtures tested are presented in Table 1 In all of the mixes, the binder quantity was held constant and the ratio of the other constituents was varied: filler (0% to 20%), super plasticizer result (1.7% to 2%) and water (32% to 48%).
The experimental work conducted on the 7 mixes in Table 2 involved the following

- The sieving method using equation (1)

- The column method using equation (2)
- The ultrasonic velocities method proposed using equation (3)

Table 1. Mixture proportion

Concrete	Proportions in kg/m³								
	Gravel	**Sand**	**Cement**	**Fillers**	**Water**	**Super-**	a^*=	b^*=	d^*=
	(5-15mm)	(0-5mm)	(*C*)	(*F*)	(*W*)	**Plasticizer(S_p)**	*F/B* (%)	S_p/B (%)	*W/B* (%)
C01	775	736	495	0.0	237.8	9.91	0.00	2.00	48
C03	775	736	460	46	232.5	9.50	9.09	1.88	46
C05	775	736	454	64	227.8	9.48	12.28	1.83	44
C07	775	736	450	81	222.8	9.46	15.25	1.78	42
C09	775	736	618	0.0	198.0	12.35	0.00	2.00	32
C12	775	736	528	84	196.0	11.06	13.79	1.81	32
C13	775	736	509	102	195.0	10.75	16.67	1.76	32

* B; binder, ($a = F/B$); limestone filler-to-binder ratio, ($b = S_p/B$); superplasticizer-to-binder ratio, ($d = W/B$); water-to-binder ratio.

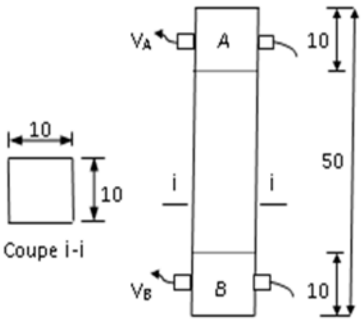

Figure1. Velocity propagation on side [A] and [B]: Direct transmission mode.

III. Results and discussion

The amalgamated results for each of the three samples for the 7 mixes are presented in Tab.2. Results of the segregation ultrasonic index are expressed as the ultrasonic velocity ratio of the upper part A to that of the lower part B. Figures 1 clearly show a sharp division between the unstable and stable mixes (C1-C4 vs C5-C7). The results of the UPV can be used to assess the segregation resistance and to control the quality of concrete products, as will be further discussed in the subsequent section.

Table 2. Summary of Test Results- ultrasonic, column and sieve coefficient's

				UPV coefficient	Column coefficient	Sieve coefficient
Concrete	***a***=*F/B* **(%)**	***b***=*SP/B* **(%)**	***d*** =*W/B*(%)	$f_u = V_A/V_B$	$f = A/B$	π^* (*sieve*)
C1	0.00	2.00	48	90.80 ± 3,5	58.30 ± 0,1	24.08
C2	9.09	1.88	46	88.20 ± 1,8	53.60 ± 5,1	16.84
C3	12.28	1.83	44	89.50 ± 0,0	46.10 ± 4.6	16.08
C4	15.25	1.78	42	87.20 ± 2,3	57.40 ± 1,8	16.23
C5	0.00	2.00	32	99.80 ± 0,0	95.30 ± 0,7	06.60
C6	13.79	1.81	32	99.90 ± 0,2	95.10 ± 2,2	10.98
C7	16.67	1.76	32	99.90 ± 0,1	96.40 ± 1,6	04.67

By analyzing the results presented in Fig.2, we can see that the risk of instability becomes important when the W/B ratio exceeds 0.40 but that the instability risk decreases when the W/B ratio increases.

Table 2 shows that the coefficients of segregation resistance remain almost constant in the case of C5 – C7. The variation between their values does not exceed 0.1%, 10.1% and 2.35% for the UPV test method, column test method and sieve test method, respectively.

Based on the stability test results, we can conclude that the concretes C5, C6, and C7 present a very satisfactory stability compared to other concretes.

We noticed that the first four concrete mixes (C1–C4) were not stable, with a sieve segregation index higher than 15%. The last three concretes (C5–C7) are stable and present sieve segregation index lower than 15% and their resistance index stability is higher than 95%.

These concretes presented an ultrasonic index of segregation approaching 100% (Table 2).

The effect of the water quantity is illustrated in Figure3, from which we can see an important influence of this parameter on the segregation of the concretes.

The segregation appears, by the three indicators, for W/B ratios higher than 0.32. A decrease of this ratio by 16% causes a decrease in the indicators of the segregation π of 17.48% and an increase of f and f_u of 37% and 9% respectively for the concretes (C1, C9).

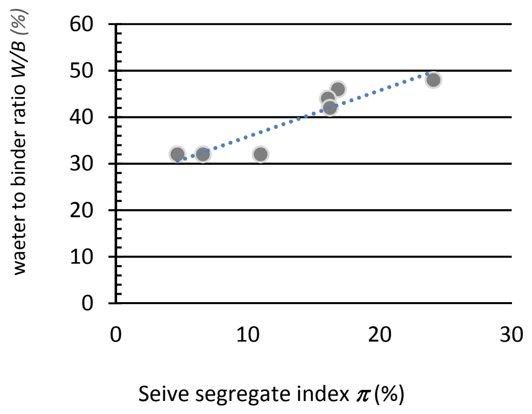

Figure 2. Relationship between the sieve segregation index test and the ratio of water-to-binder W/B (based on Table.6)

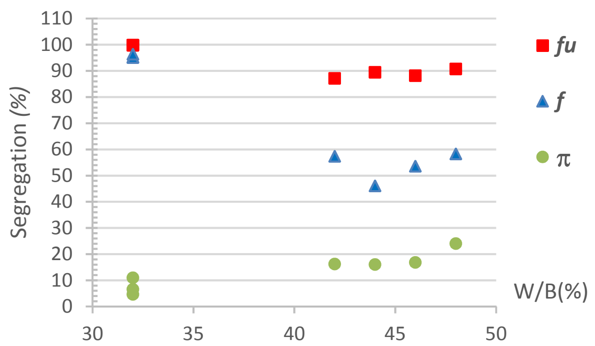

Figure 3. Evolution of the segregation index (f_u,f and π) with W/B ratio

Figure 4 shows the evolution of the two indicators of segregation (f_u *and f*), with the F/B ratio similar in both cases. The ultrasonic coefficient fu is less sensitive to the variation of the fines quantity in the concrete, especially for unstable concretes, than the coefficient of resistance *f*. This is because ultrasonic velocities are determined through the concrete (mortar and gravel), whereas for the resistance segregation index *f*, it relates only to gravel.

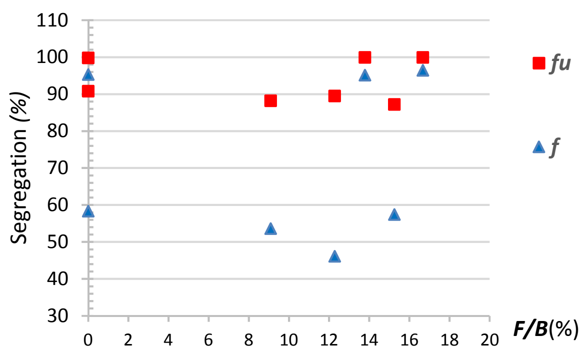

Figure 4. Evolution of the segregation index (f_u and *f*) with F/B ratio

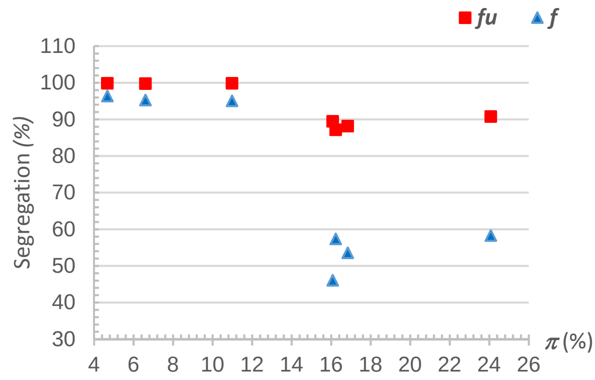

Figure 5. Evolution of the segregation index (f_u and f) with π (sieve)

The stable concretes (C5, - C7) are those having a sieve segregation index lower than 15%, and it is proved that all these concretes presented an ultrasonic index fu higher than 99.80% (Figure.5). It can be seen that when the difference of aggregates content in the column f does not vary by more than 5%, the segregation ultrasonic index fu does not vary more than 0.2% for stable concretes. For fresh concrete, the ultrasonic pulse velocity method can thus be used for segregation characterization.

IV. CONCLUSION

In this experimental study, a non-destructive method was tested to diagnose the homogeneity of the concrete in terms of segregation. It is proved through the tested concrete mixes that the proportion of water is a determinant parameter in the manifestation of the segregation.

A decrease in the W/B ratio leads to very different increases of the segregation indices f_u, *f* and π but with the same tendency. The segregation ultrasonic index f_u is less sensitive to the variation of the fines ratio, especially for unstable concretes, than the segregation resistance index *f*. The effect of F/B has the same result.

This is because the ultrasonic velocities are determined through the cement paste and granular skeleton, whereas the f index concerns gravels only.

The stable concretes are those having a sieve segregation index lower than 15%, and it is proved that all these concretes presented a resistance index f higher than 95% and an ultrasonic index fu higher than 99.80%.

In this study, the stable concretes (C5 –C7) were highly identifiable from the others regardless of the measuring methods and the water proportions used, but this was especially true for the ultrasonic velocities, which remained almost constant. The results found by ultrasonic velocity and those found by empirical testing were similar. As such, this study showed the possibility to characterize concrete segregation with a novel, rapid, and easy to use non-destructive method at an acceptable precision level

References

[1] Li, L., Kwan, G. and Kh, A., "Concrete mix design based on water film thickness and paste film thickness", Cement and Concrete Composite, 39, 33–42. 2013

[2] Uysal, M., Yilmaz K. and Ipek, A. M., "The effect of mineral admixtures on mechanical properties, chloride ion permeability and impermeability of self-compacting concrete", Construction and Building Materials, 27, 263–270.2012

[3] Ghafoori, N. and Diawara, H., "Evaluation of fresh properties of self-consolidating concrete under long transportation time and extreme temperature", Proceeding of SCC 2010, Design, Production and Placement of Self-consolidation concrete (Ed. by Khayat, K.H. and Feys, D.), Canada, 139-152.

[4] Job T.and Harilal B. "Fresh and hardened properties of concrete containing cold bonded aggregates"Advances in Concrete Construction, 2 (2), 77-89. 2014

[5] Khayat. H.K. and Guizani. Z., "Use of viscosity-modifying admixtures en enhance stability of fluid concrete", ACI Mater. J. 94 (4) 332–340. 1997

[6] Bauchkar S.D. and Chore H.S. "Rheological properties of self-consolidating concrete with various mineral admixtures", Structural Engineering and Mechanics, An Int'l Journal, 51(1).2014

[7] Vakhshouri B. and Nejadi S., "Self-compacting light-weight concrete; mix design and proportions", Structural Engineering and Mechanics, An Int'l Journal 58 (1).2016

[8]Okamura, H. Masahiro, O., "Self-compacting concrete", Journal of Advanced Concrete Technology, 1 (1), 5-15. 2003

[9] Shindoh, T. Matsuoka, Y., "Development of combination-type self-compating, concrete and evaluation test methods". Advanced Concrete Technology, 1 (1), 26-36. 2003

[10]Kumavat H. R., Tapkire G., Patil P. S., Chitte C. J., "Condition assessment of concrete with ndt International Journal of Research in Engineering and Technology e ISSN: 2319-1163 p ISSN: 2321-7308,JUNE. 2014

[11] Silva, P. and Brito, J., "Electrical resistivity and capillarity of self-compacting concrete with incorporation of fly ash and limestone filler", Adv. Concrete Constr., 1(1), 65-84.2013

[12] Breul, P., Geoffray, J. M. and Haddani, Y. "On Site Concrete Segregation Estimation Using Image Analysis", Advanced Concrete Technology, 6 (1), 171-180. 2008

[13] Schwhdenmann, G. and al., Study of segregation in self-compacting concrete walls using gamma densitometry, 2nd North American Conference on the design and use of self-consolidating concrete and the 4th RILEM symposium on self-compacting concrete, Chicago, USA. vol 2. Hanley Wood Publication, Addison, p 793.2005

[14] Li, B., Duan, Y., Zhang, Y. and Liu, S., "Electromagnetic wave absorption properties of cement-based composites filled with porous materials", Mater. Design. , 32(5), 3017-3020. 2011

[15] Tribikram K. "Ultrasonic and Electromagnetic Waves for Nondestructive Evaluation and Structural Health Monitoring", 1st International Conference on Structural Integrity, Dep. of Civil Engineering and Engineering Mechanics, Dep. of Aerospace and Mechanical Engineering University of Arizona, Tucson, Arizona 85721, USA. 2014

[16] Idanez, D. Geoffray, J. M. Haddani, Y., "Etude de la ségrégation des bétons basée sur la géo-endoscopie et du vidéo compatage", Rapport de fin d'étude CUST, p80. 2004

[17] Benouis A/H. and Grini A. "Estimation of concrete's porosity by ultrasounds", S.D., Physics Procedia, 21, 53-58.2011

[18] Naik, T. R., Malhotra, V. M. “Chapter 7: the ultrasonic pulse velocity method, in: V.M. Malhotra, N.J. Carino, (Eds.), CRC Handbook on Nondestructive Testing of Concrete, CRC Press, 1991, pp. 169–188. 1991

[19] Malhotra, V.M., Carino, N.J., “Handbook on Non Destructive Testing of Concrete”, CRC Press LLC. 1991

[20] Tests on the concrete by the method of the ultrasonic testing: recommendation of RILEM, Annals of the Technical Institute of the Building and Public Works, Series: Test and Measurements, No. 142, 1973.

[21] ASTM 1998, Standard Test Method for Pulse Velocity through Concrete, ASTM C 597, USA.

[22] British Testing Concrete. Part 4. Determination of Ultrasonic Pulse Velocity, Standards Institution BS EN 12504-4, London.2004.

[23] Guoxuan, X., Min, D., Haiqing, H. and Mingshu, T. “Absorbing and mechanical properties of cement-based composites with nano-titanic oxide absorbent”, Adv. Mater. Res., 177, 558-561.2011

[24] AFGC, Association Française de Génie Civil, Self-compacting concrete, interim recommendations, Collection des documents scientifiques et techniques, Paris, French.2000

[25] Cussigh, F. et al., “Project testing SCC-segregation test methods.” In: Wallevik O, Nielsson I (eds) Self-Compacting Concrete. 3rd international RILEM symposium on self-compacting concrete, Reykjavik. RILEM Publications SARL, Bagneux, p 311. 2003

[26] Sonebi, M., “Medium strength self-compacting concrete containing fly ash: modeling using factorial experiment plans”. Cement and Concrete Research34(7):1199–1208.2004

[27] Rooney, M.J. et al., “Development of the settlement column segregation test for fresh self-compacting concrete”. In: Ozawa K, Ouchi M (eds) Self-Compacting Concrete.2nd international symposium on self-compacting concrete, Tokyo. COMS Engineering Corporation, Fukui Kochi, p109.2001

[28] Hamidian M., et al., “Application of Schmidt rebound hammer and ultrasonic pulse velocity techniques for structural health monitoring” Scientific Research and Essays, 7(21), pp. 1997-2001. 2012

[29] Bensebti S.,Aggoune S., Houari H. , “Essai de caractérisation expérimentale de la ségrégation verticale des bétons autoplacants”, Sciences & Technologie B – 25, 59-64.2007