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# Investigation of concrete segregation by ultrasonic pulse velocity

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## Abstract.

The segregation is a separation between components of concrete or fresh mortar, which can be caused by an insufficient malaxation or an excessive vibration or a more fluidity. Literature reports many tests to characterize concrete's maniability, slump-test, maniabilimeter LCPC, cylinder's tests, column's tests, ball's tests, pallet's tests, are some examples. It also exists some tests of hardened concrete or at beginning of hardening. These are generally based on the percentage of the coarse aggregates between the top and the bottom of the samples.

This work objective is to study the mechanisms of concrete's segregation, to analyze the correlations between the various indices of segregation and theirs correlations with ultrasonic pulse velocities. The segregation characterization of fresh concrete was carried out by the sieve test and that of the hardened concrete by a counting technique of coarse aggregates on prismatic samples 10x10x50 cm<sup>3</sup>.

Ultrasonic velocities were carried out on the same samples for seventeen concretes compositions to determine an ultrasonic velocity ratio through the sample's top part on that of the bottom part. The six concretes that do not present segregation (sieve stability lower than 15 % and segregation resistance by counting higher than 95 %) have an ultrasonic segregation factor approaching 100%. Thus, this ultrasonic method can be a fast alternative to characterize fresh concrete segregation.

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

## Résumé

La ségrégation est un phénomène de séparation des constituants d'un béton ou d'un mortier frais, qui peut être provoqué par un malaxage insuffisant, par une vibration excessive ou par une fluidité importante. Les essais de caractérisation sont multiples, existe-t-il ou non des relations entre les différents essais d'ouvrabilité actuellement utilisés pour caractériser les bétons en général et les BAP en particulier ? L'utilisation d'une méthode de caractérisation non destructive (la méthode par vitesse de pulsation) peut apporter une réponse et se substituer à ces essais. L'objectif est d'étudier les mécanismes de ségrégation des bétons, d'analyser les corrélations entre les différents indices de ségrégation et essayer de les relier aux vitesses des ultrasons.

Nous sommes parvenu aux résultats des essais selon les techniques existant de caractérisation de la ségrégation des bétons, pour le béton frais- l'essai de stabilité au tamis- et pour celle du béton en cours de durcissement- la technique de comptage des gros granulats prélevés sur des moules prismatiques 10x10x50 cm. Les vitesses des ultrasons ont été réalisées sur les mêmes éprouvettes pour dix sept compositions de bétons pour déterminer un rapport des vitesses à travers la partie supérieure sur celle de la partie inférieure.

Nous montrerons que, Les bétons qui ne présentent pas de ségrégation (stabilité au tamis et résistance à la ségrégation par comptage) ont un indice ultrasonique de ségrégation dépassant les 98 %. Donc cette méthode ultrasonique peut s'avérer une alternative rapide à la caractérisation de la ségrégation du béton frais ou d'auscultation de la ségrégation du béton durci.

**MOTS CLES :** Béton, Ségrégation, , Stabilité, Vitesse ultrasonique, Corrélations.

## 1. Introduction.

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The water is one of the fundamental parameters in the composition of the concrete. If there is an excessive quantity of water then phenomenon of segregation appears (separation between mortar and gravels). The use of chemical additives (plasticizing, expectorant...) conduits also to obtain fluid concretes without excess water but also leads sometimes to segregation. The segregation is thus a phenomenon of separation of the components of a concrete or a fresh mortar, which can be caused by an insufficient malaxation or an excessive vibration or an important fluidity. Literature describes many tests of characterization. Concrete's "L" workability, Slump-test, LCPC maniabilimeter, cylinder's test, column's test, ball's test, pallet's test, etc are some examples. One also finds tests on samples of hardened concrete or at the beginning of hardening. These tests are generally based on counting techniques of the coarse aggregates. It is noticed the multitude of tests used to characterize the segregation, are there relations or not between these various tests of currently used to characterize concretes and self-compacting concretes (SCC) in particular?

The use of non-destructive method can give an answer and replace these tests. Method of ultrasonic pulse velocity is the most used one for inspection and evaluation concrete's structures. It was used successfully as much in-situ or at laboratory.

This method is used to evaluate homogeneity and quality of concrete as to analyze its deterioration. Determination of dynamic modulus of elasticity and Poisson ratio is the most direct use of this method. Many researchers published results on these two properties [1] and indicated that the relation between strength and pulse velocity was not direct and that several parameters intervened in this relation like composition of concrete, its moisture... [1]. the standards RILEM (Europe), ASTM (the United States) and British Standards Association (Great Britain), propose procedures to establish these correlations.

Heterogeneity in concrete creates dispersions of pulsations. These dispersions are caused by indirect factors such as source concrete, ingredients of the mixture and the problems of consolidation (vibration) during the installation of concrete in building site. It is possible to make qualitative in situ concrete comparisons.

The objective of this experimental study is to analyze correlations between various indices of segregation and trying to correlate them to ultrasonic pulse velocity. This work study to propose a nondestructive and fast method for segregation characterization of the fresh concretes.

## **2. Methodology and experimentation.**

### **2.2. Materials and mixtures**

The parameters of study are proportioning out of calcareous filler expressed by "Fillers/Binder" and water proportioning expressed by (Water/Binder). While fixing proportioning super-plasticizer with its saturation, formulation was led according to the recommendations of the Japanese method suggested by Okamura [2] and that of the approach followed by Bensebti [3].

A wholesale proportioning aggregate is fixed at 50% of its compactness and that of sand with 40% of the total volume of mortar. The volume of SCC paste must support concrete's flow while reducing the raw material cost of this formulation [4]. Then materials used are coarse aggregate 5/15 mm, a sand crushed 0/5 mm, cement type CEM/II42.5, a superplasticizer Médaplast SP40 of Granitex and fillers limestones 0/80  $\mu\text{m}$ .

### **2.3. Tests procedure**

#### **2.3.1. Workability of Concretes**

The characterization in a fresh state of ordinary concretes is limited to workability with Abrams cone and that of self-compacting concretes (SCC) to tests recommended by French Association of Civil Engineering [5]. That is to have spreading out with the cone, flow with the "L" box and stability with the sieve. The use of a SCC requires to validate these three tests (when for "ordinary" concrete it is required only one). A spreading out ranging between 64cm and 72cm, a ratio  $H_2/H_1$  higher than 0.80 for "L" box is necessary and a stability with the sieve  $\pi$  ranging between 0% and 15.

#### **2.3.2. Characterization of the segregation**

Several techniques are related in literature and which are based on the same principle of the methods, [6, 7]. The freshly mixed concrete is put in a cylinder of 20 cm diameter and 50 cm height. After one hour, 10cm is taken of each end of the cylinder. The special design of test samples facilitates this operation. Taken con-

crete is washed to separate aggregates from mortar. The aggregates are then dried, and weighed. A coefficient of segregation resistance of the concrete is calculated using following formula:

$$f = A/B \quad (\text{Eq.1})$$

Where A: dry aggregate mass of the higher section

B: dry aggregate mass of the lower section

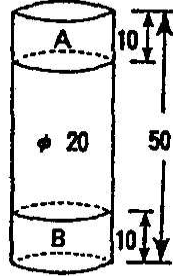


Fig.1. Cylinder sample for measurement of segregation resistance "f". [6]

According to Lowke and al. [6], a concrete having a good segregation resistance will present a coefficient  $f$  higher than 95%. Like same principle, we use a square metal samples form with 100 cm<sup>2</sup> area and 50 cm height for our study to determine a similar coefficient based on ultrasonic pulse velocity.

### 2.3.3. Characterization of the segregation by ultrasonic pulse velocity

Ultrasonic pulse velocity method can also be very useful for the study of concrete segregation. Concrete heterogeneity creates dispersions of pulsations. These dispersions are caused by indirect factors such as origin of aggregates, mixture's ingredients and problems of consolidation (vibration) during the installation of the concrete.

Thus, based on the previous techniques of segregation's characterization, we can use ultrasonic pulse velocities (in fresh states or at beginning of hardening) to establish correlations between these velocities and sieve stability  $\pi$  and segregation  $f$ . The ultrasonic coefficient of segregation resistance proposed will be thus:

$$f_u = f_{uA} / f_{uB} \quad (\text{Eq.2})$$

Where:  $f_{uA} = V_{fA} - V_{eA}$ : ultrasonic velocity ratio through the higher section of full sample to empty sample

$f_{uB} = V_{fB} - V_{eB}$ : ultrasonic velocity ratio through the lower section of full sample to empty sample

$V_f$ : ultrasonic velocity through the higher section of empty sample.

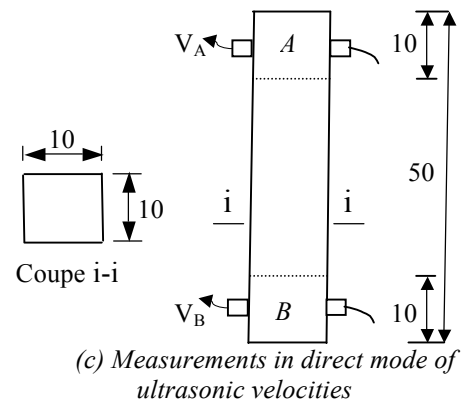
$V_e$ : ultrasonic velocity through the higher section of full sample.



(a) Transducers used



(b) Ultrasonic device



(c) Measurements in direct mode of ultrasonic velocities

Fig. 2. Procedure to measure segregation resistance by ultrasounds " $f_u$ "

## 3. Experimental tests and discussion.

Prismatic steel moulds were used for making samples of 100 cm<sup>2</sup> section and 5000 cm<sup>3</sup> volume (a=10cm, h=50cm). The variation in mixture concerns fillers proportioning " $a=F/L$ " varying from 0% to 20% of binder,

superplasticizer “ $b=S_p/L$ ” 1.70 to 2.00% and water “ $d=E/L$ ” varying from 32 to 48% (binder contains cement and fillers). Seventeen (17) compositions were used for this study (tab. 1).

Concrete	Proportions in Kg/m <sup>3</sup>								
	Gravel	Sand	Cement	fillers	Water	Superplasticizer	a=F/L (%)	b=S <sub>p</sub> /L (%)	d= E/L (%)
C01	775	736	495	0	237.8	9.91	0.00	2.00	48
C02	775	736	477	24	235.2	9.71	4.76	1.94	47
C03	775	736	460	46	232.5	9.50	9.09	1.88	46
C04	775	736	457	55	230.2	9.49	10.71	1.86	45
C05	775	736	454	64	227.8	9.48	12.28	1.83	44
C06	775	736	452	72	225.3	9.47	13.79	1.81	43
C07	775	736	450	81	222.8	9.46	15.25	1.78	42
C08	775	736	448	90	220.2	9.45	16.67	1.76	41
C09	775	736	440	97	220.1	9.32	18.03	1.74	41
C10	775	736	433	104	219.9	9.18	19.35	1.71	41
C11	775	736	429	107	219.8	9.11	20.00	1.70	41
C12	775	736	618	0	198	12.35	0.00	2.00	32
C13	775	736	577	29	200	11.76	4.76	1.94	33
C14	775	736	550	55	200	11.37	9.09	1.88	33
C15	775	736	528	84	196	11.06	13.79	1.81	33
C16	775	736	509	102	195	10.75	16.67	1.76	32
C17	775	736	488	122	195	10.36	20.00	1.70	32

Tab.1. Proportions of concretes mixtures

The experimental study carried out on these concretes mixtures related to characterize segregation by sieve stability, segregation resistance index ( $f$ ) and segregation ultrasonic index ( $f_u$ ).

### 3.1. Determination of the segregation ultrasonic index

Density variation through element height can be determined by ultrasonic velocity. Mortar and aggregates do not transmit sound with a same velocity. These differences can thus be used to evaluate quantity of aggregates through element height. The experimental procedure consists to measure ultrasonic pulse velocities through the freshly mixed concrete in the upper and lower parts of samples (fig. 2-c) using transducers with a frequency of 54 hertz (fig.2-a). Results of segregation ultrasonic index are expressed by ultrasonic velocity ratio in upper part  $A$  on that of lower part  $B$ . Thus, for all mixtures, it has proceeded to determine stability by sieve ( $\pi$ ), by resistance index ( $f$ ) and of cause by ultrasonic index ( $f_u$ ). These tests have concerned three samples for each concrete mixture.

### 3.2. Results and discussion

The results of all tests are summarized in the following table :

Concrete	a=F/L (%)	b= S <sub>p</sub> /L (%)	d =E/L (%)	$\pi$ (%)	$f$ (%)	$f_u$ (%)
C01	0.00	2.00	48	24,08	58,30	65,50
C02	4.76	1.94	47	16,49	64,30	57,80
C03	9.09	1.88	46	16,84	53,60	46,80
C04	10.71	1.86	45	16,12	52,00	45,90
C05	12.28	1.83	44	16,08	46,10	53,30
C06	13.79	1.81	43	16,91	58,50	41,20
C07	15.25	1.78	42	16,23	57,40	49,30
C08	16.67	1.76	41	15,45	47,10	38,80
C09	18.03	1.74	41	23,2	62,90	43,60
C10	19.35	1.71	41	25,87	44,00	38,50
C11	20.00	1.70	41	23,53	47,70	35,20
C12	0.00	2.00	32	6,60	95,3	99,10
C13	4.76	1.94	33	6,35	95,2	98,00
C14	9.09	1.88	33	3,30	95,1	98,70
C15	13.79	1.81	33	10,98	95,1	99,90
C16	16.67	1.76	32	4,67	96,4	99,60
C17	20.00	1.70	32	11,45	95,3	97,40

It is noticed that the first eleven concretes (C01-C11) are not self-compacting with a stability to sieve higher than

15%. The last six concretes (C12-C17) are self-compacting and present stabilities to sieve lower than 15% and their resistance stability index higher than 95%. These concretes present segregation ultrasonic index approaching 100%. The effect of water proportioning is illustrated by figure 3; it's noticed an important influence of this parameter on the segregation of the concretes. The segregation appears, by the three indicators, for ratios  $E/L$  higher than 0.32. An increase of this ratio of 28% causes an increase in the indicators of the segregation  $\pi$  of 105% and a decrease of  $f$  and  $f_u$  of respectively 100% and 15% for the concretes with 20% of fillers.

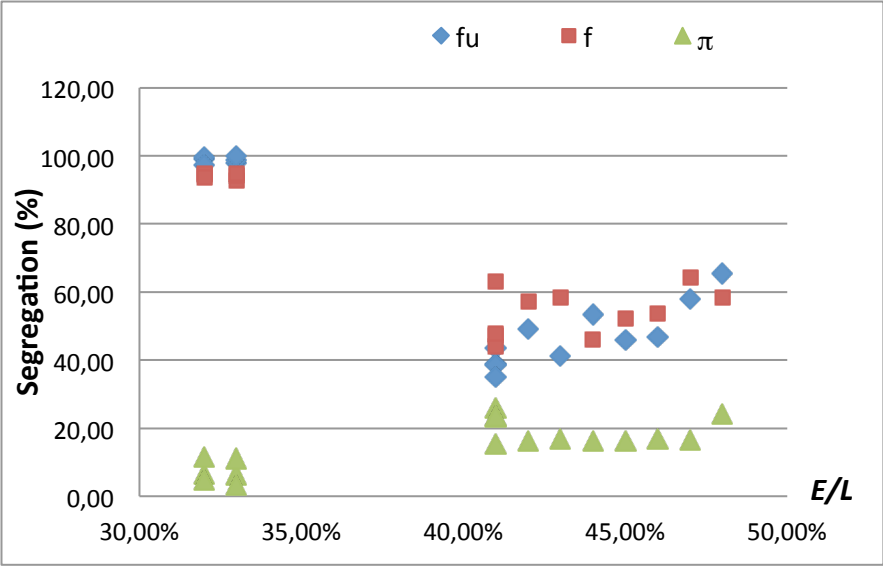


Fig.3 : Evolution of the segregation indices ( $f_u$ ,  $f$  and  $\pi$ ) with ratio  $E/L$

Figure 4 shows the evolutions of two indicators of the segregation ( $f_u$  and  $f$ ) with ratio  $F/L$  which are similar in both cases. The ultrasonic coefficient  $f_u$  is less sensitive than the coefficient of resistance  $f$  to the variation of the fines quantity in the concrete especially for unstable concretes. This variation is respectively 8% and 22% for 20% variation of  $F/L$  ratio. This is due to that ultrasonic velocities are determined through concrete (mortar and gravel) where for resistance segregation index  $f$ , it relates only gravels.

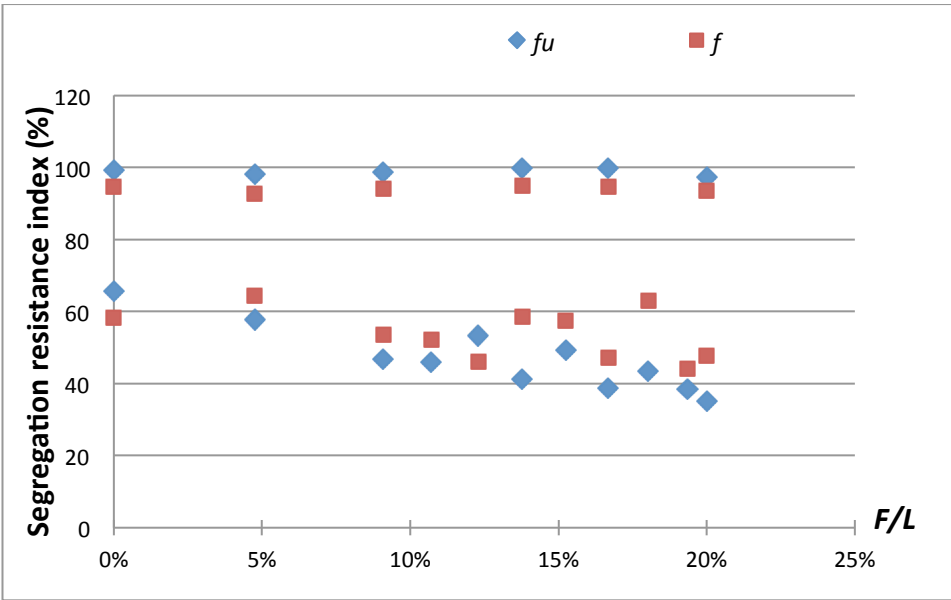


Fig.4 : Evolution of the segregation indices ( $f_u$ ,  $f$  and  $\pi$ ) with ratio  $F/L$

The presence of a significant quantity of fillers as addition in self-compacting concrete (SCC) can have a positive action on their compactness's. Indeed, it is considered that mortar reaches its maximum compactness when critical filler ratio is reached. Beyond this ratio, frictions between particles increase [9].

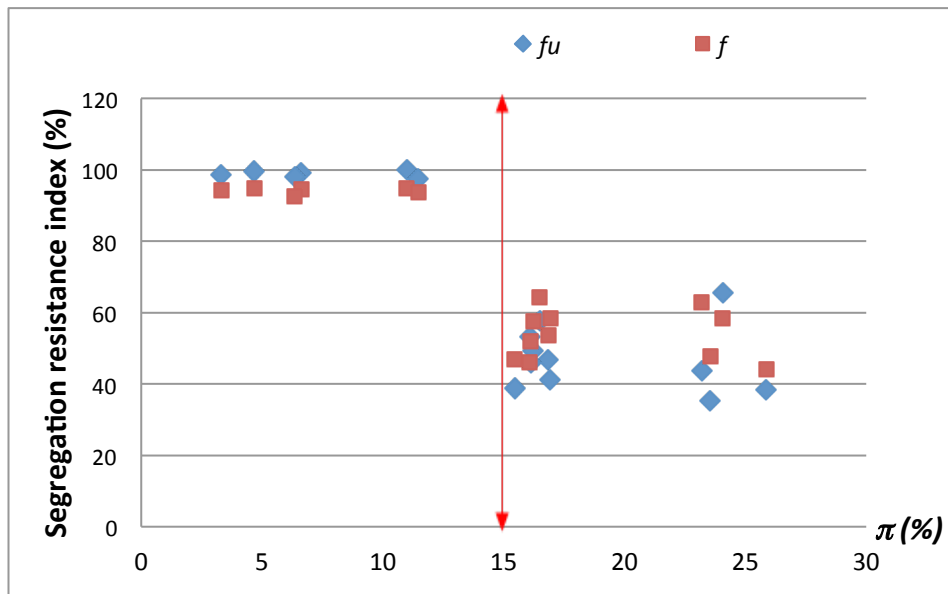


Fig. 5 : Relations between sieve stability ( $\pi$ ) and segregation resistances indices ( $f_u$  and  $f$ )

The stable concretes are those having sieve stability lower than 15%, it is proved that all these concretes presented an ultrasonic index  $f_u$  higher than 98% (fig.5). It can be noticed, that when difference of aggregates content in the column ( $f$ ) does not vary more than 5%, segregation ultrasonic index  $f_u$  does not vary more than 2% for stable concretes. For the reception of fresh concrete, ultrasonic pulse velocity method can thus used for segregation characterization.

#### 4. Conclusion.

In this experimental study, a nondestructive method was tested to diagnose homogeneity of the concrete in terms of segregation. It is proved through the tested concretes that water proportioning is a determinant parameter in the manifestation of the segregation. An increase in  $E/L$  ratio of 28% causes increases very different from segregation indices  $f_u$ ,  $f$  and  $\pi$  but in the same tendency. The segregation ultrasonic index  $f_u$  is less sensitive than the segregation resistance index  $f$  to the variation of fines ratio especially for unstable concretes. This variation is respectively 8% and 22% for a variation of  $F/L$  of 20%. This is due to that the ultrasonic velocities are determined through cement paste and granular skeleton whereas for  $f$  index, it considers only gravels. The stable concretes are those having sieve stability lower than 15%, it is proved that all these concretes presented an resistance index  $f$  higher than 95% and an ultrasonic index  $f_u$  higher than 98%. Thus, this ultrasonic method can prove to be a fast alternative to characterize fresh concrete segregation or in-situ segregation testing of hardened concrete.

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