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Effects of different viscosity agents on the properties of self-leveling concrete

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Abstract

It has already been reported that a suitable quantity of welan gum, a kind of natural water soluble polysaccharide, is very effective in stabilizing the rheology of self-consolidating concrete. The main problem of this product is its cost. Therefore, new viscosity agents were investigated in the present study: starch, precipitated silica, and a waste from the starch industry. Associated with a sulfonated melamine-formaldehyde superplasticizer, these agents were used to develop self-leveling concrete at low cost (20% higher than that of concrete used in building construction). This paper presents the influence of the type of viscosity agent on various properties of concrete: workability, segregation, bleeding, compressive strength, shrinkage, and permeability. Precipitated silica and starch were found to lead to the best performances.

Keywords: Bleeding; Flowability; Segregation; Self-leveling concrete; Strength; Viscosity agent

A self-compacting concrete (SCC) is defined as a concrete that has excellent deformability and high resistance to segregation, and can be filled in a heavily reinforced area without applying vibration. Most developments and uses of SCC have been in Japan [1–10].

In general, the self-consolidating property of SCC depends on mixture proportion and uneven quality of materials. This causes problems in producing stable SCC. To stabilize fluidity, which greatly affects self-consolidating property, the use of welan gum, a kind of natural polysaccharide, has proved to be very effective [8], but this product is costly and increases the price of usual concrete. An investigation was undertaken to use other lower-cost viscosity agents, especially in the development of self-leveling concrete (SLC). SLC is a SCC that gives a very flat surface without any vibration: the levelness tolerance is 1 mm over a length of 4 m.

Three types of viscosity agents available in different concentrations of aqueous solutions were investigated: starch, precipitated silica, and a by-product from the starch industry [11]. The properties of the latter product were discussed in a previous paper [12]. The scope of the present study was to compare the properties of these agents through various engineering properties of SLC: workability, segregation, bleeding, compressive strength, shrinkage, and permeability.

1. Experimental

1.1. Materials

1.1.1. Cement and aggregates

Normal Portland cement, type CEM I 52.5 R according to the ENV 197/1 European standard, was used. Its Blaine specific surface area was 480 m^2/kg and its Bogue potential composition was as follows:

$$C_3S = 70.8\%$$
$$C_2S = 8.5\%$$
$$C_3A = 8.5\%$$
$$C_4AF = 7.5\%$$

River sand and gravel were used. Their particle size distributions are given in Fig. 1.

Four percent of grains in the sand were larger than 5 mm; the maximum diameter of coarse aggregate was 16 mm.

1.1.2. Additional fine material

Ground limestone of specific gravity 2.70 and Blaine specific surface area 395 m^2/kg was used as additional fine material. It is particularly useful for enhancing the cohesion of concrete [13].

1.1.3. Chemical admixtures

A commercially available sulfonated melamine formaldehyde superplasticizer was used in binary combinations

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Table 1
Mixing proportions of concretes

Concrete reference	Content (kg/m^3)						
	Cement	Powdered limestone	Gravel	Sand	Mixing water	Superplasticizer	Viscosity agent
Control C_0	260	140	700	1040	173	5	0
Starch C_1	260	140	700	1040	172	5	1.3
Precipitated silica C_2	260	140	700	1040	170	5	3.9
By-product C_3	260	140	700	1040	168	5	7.5

with viscosity agents. The dry matter content of the superplasticizer was 30%.

Aqueous solutions of three viscosity agents were investigated: starch, precipitated silica, and a by-product from the starch industry. The concentrations of the solutions were 10% for starch, 20% for precipitated silica, and 32% for the by-product.

1.1.4. Mixture proportions

A test program was formulated to clarify the effects of the viscosity agents on the properties of fresh concrete (flow, segregation, and bleeding) on the following bases:

1. The weight fractions of cement, powdered limestone, sand, coarse aggregate, and superplasticizer were kept constant as listed in Table 1. The water to cementitious material (cement + powdered limestone) ratio was kept constant at 0.44. Therefore, due to the different concentrations of the viscosity agent solutions, the quantity of mixing water varied in the different mixtures.
2. A control concrete without any viscosity agent was studied.
3. The quantities of viscosity agent solutions were adjusted to obtain approximately the same flow (600 mm). The amounts introduced in the different mixtures were as follows:
   - 1.3 kg/m^3 starch solution,
   - 3.9 kg/m^3 precipitated silica solution, and
   - 7.5 kg/m^3 by-product solution.

1.2. Measurements

1.2.1. Fluidity of concrete

The fluidity of concrete was assessed by measuring the static spread of a truncated cone having upper and lower diameters of 170 and 225 mm, respectively, and 120 mm height. The time necessary to obtain this spread was measured. Field applications showed that concrete is self-leveling when the following conditions are both fulfilled: spread higher than 600 mm and time to obtain this spread is lower than 30 seconds.

1.2.2. Resistance to segregation

Segregation of self-leveling concrete means separation into mortar and coarse aggregate caused by settlement of

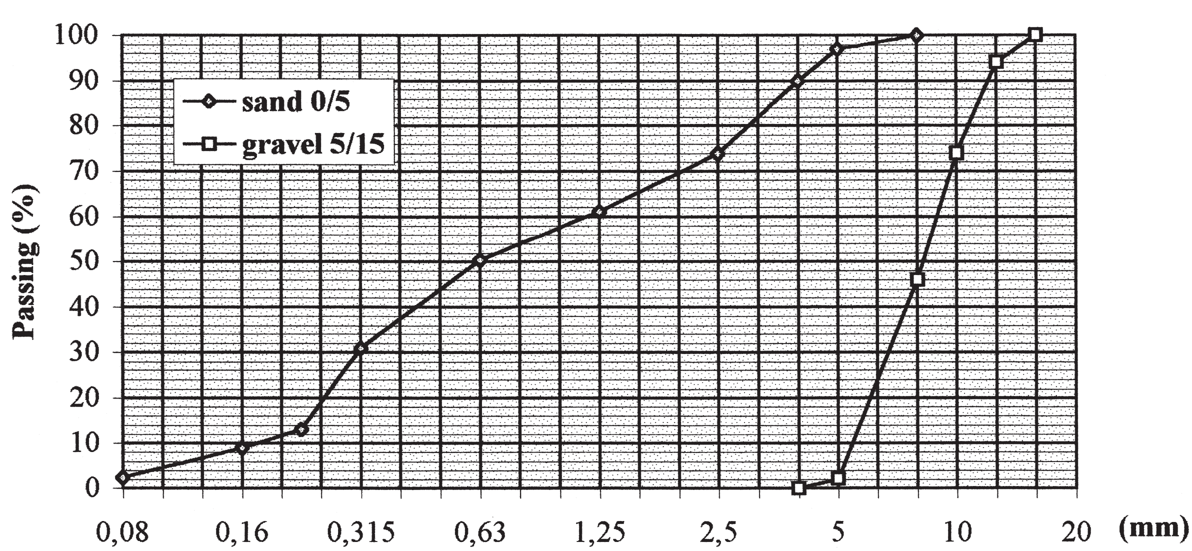

Fig. 1. Particle size distribution of sand and gravel.

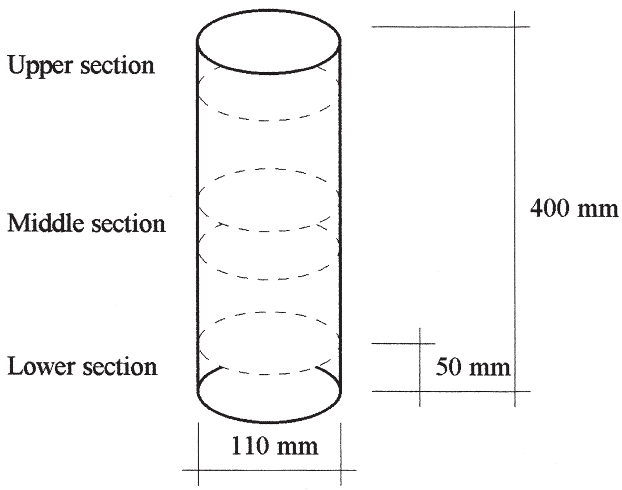

Fig. 2. Form used to measure segregation.

coarse aggregate. To evaluate resistance to segregation, concrete was placed in a column (Fig. 2) and left until it started to set, after which samples were taken from the upper, middle, and lower sections. Coarse aggregates of each sample were washed out through a 5-mm mesh screen and weighed. There is no segregation and uniform distribution of coarse aggregates if the percentage of coarse aggregates retained on the screen, in each section, is close to Eq. (1):

$$(700 + 0.04 \times 1040) / 2320 = 32\% \quad (1)$$

↓ Coarse aggregates; ↓ Coarse aggregates contained in sand; ↓ Specific gravity of concrete

1.2.3. Rate of bleeding

Six liters of concrete was poured in a basin 245 mm long, 245 mm wide, and 100 mm high, and left for 5 h. The quantity of bleeding water that appeared at the surface of the sample was measured. The bleeding rate (BR) was calculated using Eq. (2):

$$BR = \frac{M_w}{W} \times 100(\%) \quad (2)$$

where M_w = weight of bleeding water in the basin, and W = weight of water contained in the concrete placed in the basin.

1.2.4. Properties of hardened concrete

The compressive strengths at 1, 7, 28, and 90 days were measured on six cylinders 110 mm in diameter and 220 mm high; the rate of loading was 5 kN/s. The stress-strain relationship was recorded during these tests and the Young's modulus was calculated from these curves.

The unrestrained drying shrinkage was measured on prismatic samples (70 × 70 × 280 mm) according to the French standard NFP 15-433. The specimens were demolded at 24 h and kept in the testing room at 20 ± 2°C and 50 ± 10% relative humidity.

The water permeability of concrete was measured at 90 days on discs 110 mm in diameter and 50 mm high, according to Darcy's relationship.

2. Results and discussion

2.1. Properties of fresh concrete

The flow and rate of bleeding of the different mixtures are listed in Table 2. Their resistance to segregation is presented in Fig. 3. When the total amount of fine particles is limited to 400 kg/m^3, self-leveling concrete cannot be developed without any viscosity agent: its flow is very good but it presents high segregation (Fig. 3). A better concrete is obtained using the by-product of the starch industry, but some segregation still occurs. From the results shown in Table 2 and Fig. 3, starch and precipitated silica appear to be the most effective viscosity agents. In addition, precipitated silica limits the bleeding of concrete. Starch seems to improve the resistance to segregation of self-leveling concrete, whereas precipitated silica enhances the resistance to segregation and limits the rate of bleeding.

2.2. Properties of hardened concrete

The properties of hardened concrete were only investigated for mixes C_1 (starch) and C_2 (precipitated silica), those presenting the best resistance to segregation.

The compressive strengths at different times of hydration are listed in Table 3. The level of strength is the same for mixes C_1 and C_2. Early-age strength is relatively high, whereas long-term performance is very close to that obtained after 28 days of hydration. This may be explained by the use of a cement rich in C_3S and very reactive at an early age, and by the presence of powdered limestone, which influences early-age hydration of cement and does not possess any pozzolanic activity. Husson [14] showed that finely divided limestone reacted with C_3S to form calcium carbosilicates.

The typical stress-strain relationships of these concretes are shown in Fig. 4. If f_{cj} (MPa) is the 28-day compressive strength of concrete, the following relations may be proposed to describe the stress-strain relationships in Eq. (3):

Table 2
Properties of fresh concrete

Concrete reference	Flow (mm)	Time needed to obtain the flow (s)	Specific gravity	Rate of bleeding (%)
Control C_0	640	20	2.35	ND*
Starch C_1	610	20	2.30	1.4
Precipitated silica C_2	600	20	2.33	0.8
By-product C_3	620	25	2.35	1.0

* Bleeding is difficult to measure. The water present at the surface is not very clear; it is a suspension of cement and fine particles.

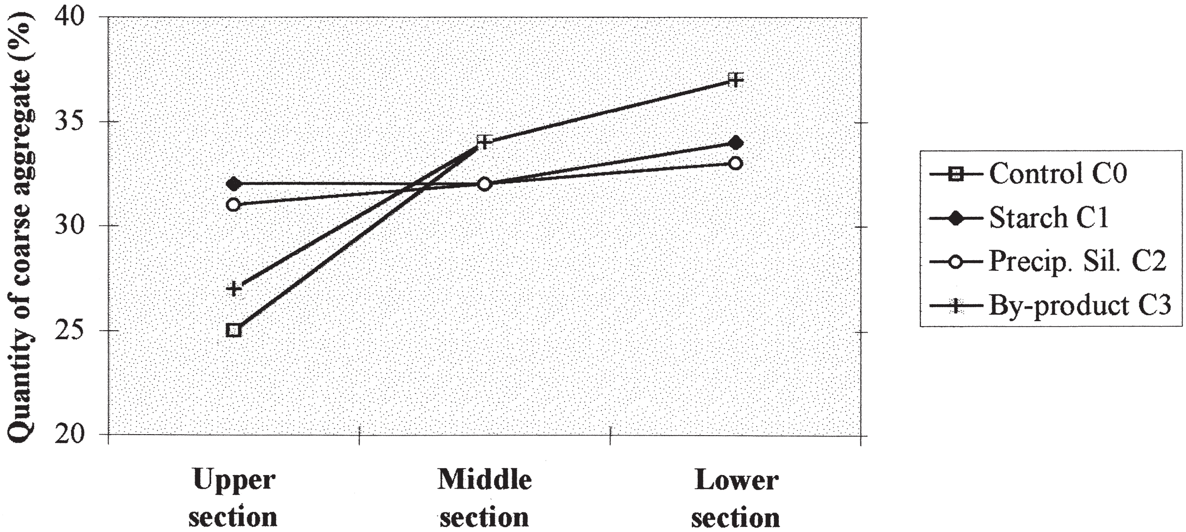

Fig. 3. Quantity of coarse aggregate by sampling position.

$$* \sigma_{bc} = 0.18 f_{cj} \varepsilon_{bc} \times 10^{-3}(4.6 - \varepsilon_{bc} \times 10^{-3}), \text{ for } C_1(\text{starch})$$

$$* \sigma_{bc} = 0.19 f_{cj} \varepsilon_{bc} \times 10^{-3}(4.7 - \varepsilon_{bc} \times 10^{-3}), \text{ for } C_2 \text{ (precipitated silica)}, \quad (3)$$

with ε_{bc} in 0/00.

The elastic modulus of self-leveling concrete ranged from 34.2 ± 0.8 GPa (C_1) to 36.2 ± 2.4 GPa (C_2). It was calculated from the recorded stress-strain curves.

The unrestrained drying shrinkage of these concretes is shown in Fig. 5, until 90 days of hydration. It can be predicted using the ACI model in Eq. (4):

$$\varepsilon(t) = \varepsilon_{\infty}\left(\frac{t}{b+t}\right)^{n} \quad (4)$$

where ε = shrinkage at t days; ε_{∞} = final shrinkage; and b and n = material parameters that must be considered as random variables.

For C_1 (starch), the relationship is given in Eq. (5):

$$\varepsilon(t) = 770 \times 10^{-6}\left(\frac{t}{47+t}\right)^{0.55}. \quad (5)$$

For C_2 (precipitated silica), it becomes as given in Eq. (6):

$$\varepsilon(t) = 730 \times 10^{-6}\left(\frac{t}{36+t}\right)^{0.61}. \quad (6)$$

The final shrinkage of self-leveling concrete (730 to 770 × 10^{-6} m/m) is 50% higher than that of an ordinary concrete containing the same cement content (450 to 500 × 10^{-6} m/m) because self-leveling concrete contains more mortar and less coarse aggregate than ordinary concrete. Such concrete needs to be cured properly so that it can develop its potential strength and durability.

The water permeability of concretes C_1 and C_2 is listed in Table 4. Precipitated silica leads to the lowest permeability, and the deviation in experimental values is less important.

3. Conclusions

From the investigations carried out in this study, the following conclusions can be drawn.

1. Precipitated silica and, to a less extent, starch could be good alternatives for welan gum as viscosity agents for self-leveling concrete.
2. These products allow the development of concretes with limited bleeding after 5 h and high resistance to segregation.

Table 3
Compressive strength of self-leveling concretes

	Compressive strength (MPa)			
Concrete reference	1 day	7 days	28 days	90 days
Starch C_1	18.1 ± 1.1	36.1 ± 0.6	42.8 ± 0.5	43.0 ± 0.5
Precipitated silica C_2	17.2 ± 1.3	37.6 ± 2.3	44.1 ± 0.8	44.5 ± 2.0

Table 4
Water permeability of self-leveling concrete

	Water permeability (10^{-12} m/s)		
Concrete reference	Average	Minimum	Maximum
Starch C_1	1.9	0.9	3.4
Precipitated Silica C_2	0.4	0.2	0.9

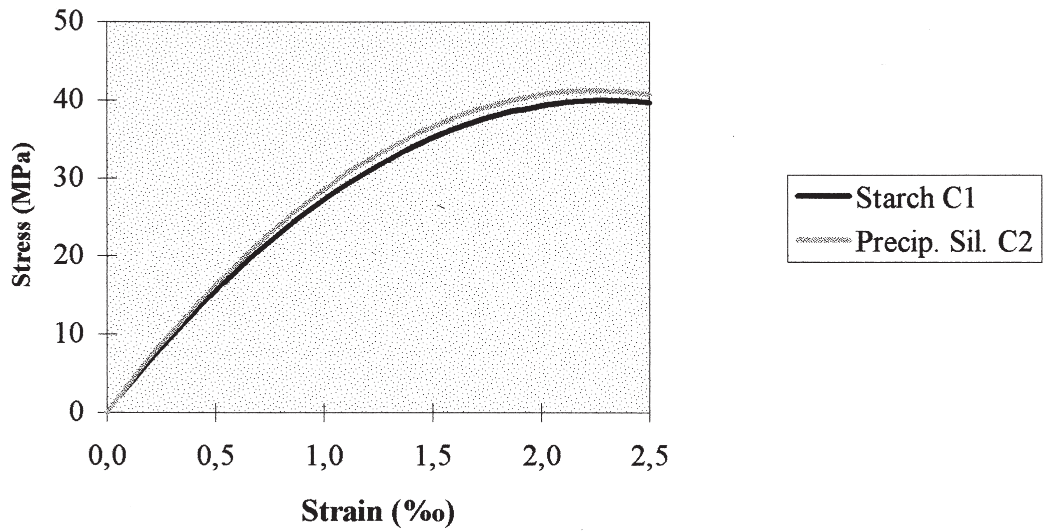

Fig. 4. Stress-strain relationships of self-leveling concretes.

3. The mechanical performance of self-leveling concrete is high (more than 40 MPa at 28 days) despite a cement content limited at 260 kg/m^3 and a water-to-cement ratio of 0.68.
4. The drying shrinkage strains of self-leveling concrete are about 50% greater than those of ordinary concrete containing the same amount of cement. To prevent cracking, it is necessary to cure self-leveling concrete in field applications.
5. The water permeability of self-leveling concrete is limited to 2×10^{-12} m/s and allows expectation of good durability.

References

[1] K. Ozawa, K. Mackawa, H. Okmura, High performance concrete based on t he durability of concrete, Proceedings of the 2nd East Asia-Pacific Conference on Structural Egineering and Construction, Volume 1, 1989, pp. 445–456.
[2] T. Shindoh, Fundamental study on properties of super workable concrete, Proceedings of the Japan Concrete Institute 13 (1) (1991) 179–184.
[3] S. Tanaka, The application of super workable concrete and polymer impregnated concrete form to PC cable-stayed bridge, Proceedings of FIP Symposium 92, 1992, pp. 729–735.
[4] Y. Matsuoka, T. Shindoh, H. Akatsuka, Application of super workable concrete to construction of actual structure, Concrete Journal 30 (2) (1992).

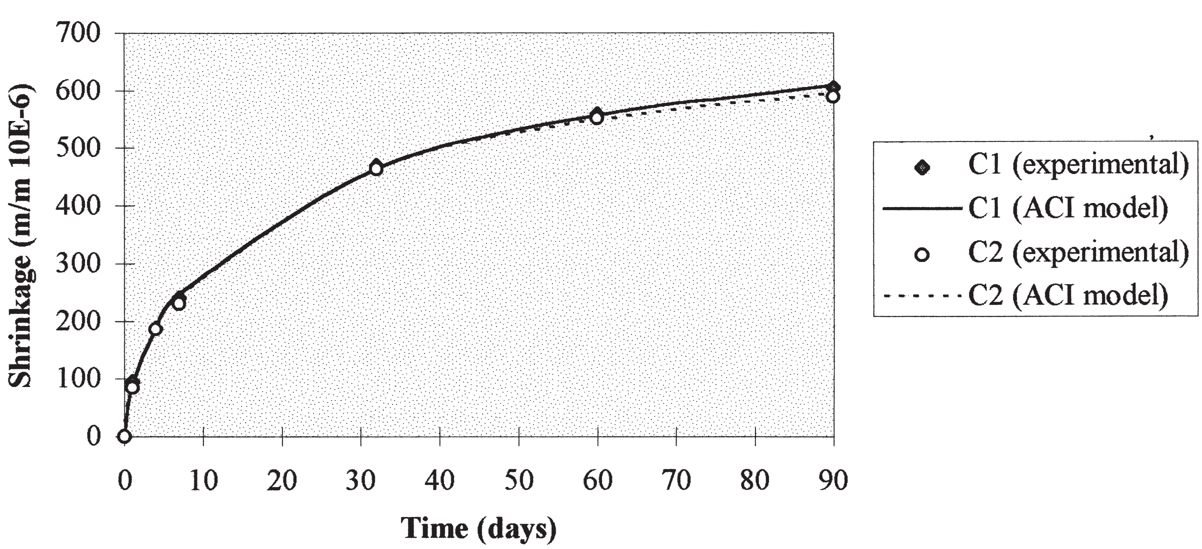

Fig. 5. Drying shrinkage of hardened concrete.

[5] J. Kamoto, Y. Matsukoa, T. Shindoh, S. Tangtermsirikul, Application of super workable concrete to actual construction, In: R.K. Dhir, M.R. Jones (Eds.), Proceedings of Concrete 2000, Economic and Durable Construction through Excellence, Dundee (1993), Volume 1, 1993, pp. 891–902.
[6] M. Hayakawa, Y. Matsuoka, T. Shindoh, Development and application of super-workable concrete, In: P.J.M. Bartos (Ed.), International RILEM Workshop Special Concretes—Workability and Mixing, Paisley, March 2–3, 1993, E & FN Spon, London, 1994, pp. 183–190.
[7] S. Nagataki, H. Fujiwara, Self compacting property of highly flowable concrete, Second CANMET/ACI International Symposium on Advances in Concrete Technology, Las Vegas, ACI SP 154-16, 1995, pp. 301–314.
[8] N. Sakata, K. Maruyama, K. Minami, Basic properties and effects of welan gum on self-consolidating concrete, in: P.J.M. Bartos, D.L. Marrs (Eds.), Proceedings of the International RILEM Conference Production Methods and Workability of Concrete, Paisley, Scotland, June 3–5, 1996, E & FN Spon, London, 1996, pp. 237–253.
[9] S. Nishibayashi, A. Yoshino, S. Inoue, T. Kuroda, Effect of properties of mix constituents on rheological constants of self-compacting concrete, In: P.J.M. Bartos, D.L. Marrs, D.J. Cleland (Eds.), Proceedings of the International RILEM Conference Production Methods and Workability of Concrete, Paisley, Scotland, June 3–5, 1996, E & FN Spon, London, 1996, pp. 256–262.
[10] T. Shindoh, K. Yokota, K. Yokoi, Effect of mix constituents on rheological properties of super workable concrete, In: P.J.M. Bartos, D.L. Marrs, D.J. Cleland (Eds.), Proceedings of the International RILEM Conference Production Methods and Workability of Concrete, Paisley, Scotland, June 3–5, 1996, E & FN Spon, London, 1996, pp. 263–270.
[11] French Patent FR2693719-A1-(16/07/92).
[12] S. Rols, J. Ambroise, J. Péra, Development of an admixture for self-leveling concrete, In: V.M. Malhotra (Ed.), Proceedings of the Fifth CANMET/ACI International Conference on Superplasticizers and Other Chemical Admixtures in Concrete, Rome, Italy, October 7-010, 1997, ACI SP 173, 1997, pp. 493–510.
[13] P.L. Domone, H.W. Chai, Design and testing of self-compacting concrete, In: P.J.M. Bartos, D.L. Marrs, D.J. Cleland (Eds.), Proceedings of the International RILEM Conference Production Methods and Workability of Concrete, Paisley, Scotland, June 3-05, 1996, E & FN Spon, London, 1996, pp. 223–236.
[14] S. Husson, Etude physico-chimique et mécanique des interactions ciment-fillers, Thesis, Institut National Polytechnique de Grenoble et Ecole Nationale Supérieure des Mines de Saint-Etienne, France, 1991.