1. ABSTRACT

Self-compacting concrete was developed for use in heavily reinforced structures and to reduce the consolidation accompanying noise at building sites. The main problem encountered for its utilization in usual building construction is its cost: 50% to 100% more than an ordinary concrete. A reduced cost is the main challenge of the present study which describes the design and the properties of a self-leveling concrete obtained at a cost only 12% higher than ordinary concrete.

Such concrete contains limited amounts of cementitious material (400 kg/m³) and superplasticizer (4.2 to 5.2 kg/m³), cheap viscosity agents (suspensions of starch or precipitated silica) and more water than available self-compacting concrete. Its strength is sufficient to allow demolding after 16 hours of hydration. The 28-day strength is higher than 30 MPa and after six months of hydration, the strength can reach 57 MPa. The bleeding and segregation of concrete are limited, while the drying shrinkage is higher than that of an ordinary concrete.

2. INTRODUCTION

Self-compacting concrete (SCC) is a concrete that can achieve full compaction without vibration, under self-weight only. For structural use in reinforced sections, high fluidity is a prime requirement. SCC must also be uniform and homogeneous, and therefore high cohesion or segregation resistance during flow is equally important [1]. SCC often incorporates several chemical admixtures, in particular a high-range water reducer admixture (HRWRA) and a viscosity agent (VA). The HRWRA is used to ensure fluidity and reduce the water-cementitious materials ratio. The VA is incorporated to enhance the yield value and viscosity of the fluid mixture, hence reducing bleeding, segregation, and settlement [2-5]. Another way to enhance deformability and stability is to increase the volume of the paste by incorporation of fly ash, ground granulated blast-furnace slag, or limestone filler [5]. Most developments and uses of SCC have been in Japan. It has been reported that SCC costs nearly double the price of a conventional concrete which has a strength of about 25 MPa and is used in ordinary building construction [6]. Such cost is unacceptable for general use in building construction, and therefore many efforts have been undertaken to decrease the overcost of SCC. For example, SIKA has developed a SCC only 35% more expensive than usual concrete [7].

In this study, the authors present the results obtained on self-leveling concrete (SLC), developed at a cost only 12% higher than that of usual concrete. SLC is not so viscous as SCC and contains more water. It is particularly suitable for casting slabs and screeds, where the level of flatness obtained is remarkable: the difference of level over 4 m long is smaller than 1 mm. Another major requirement was the early-age strength: the 16-hr strength had to be higher than 5 MPa to allow demolding.

3. EXPERIMENTAL PROGRAM

Materials

A Type CPA-CEM I 52.5 PM French portland cement was used. Its specific gravity was 3.1 and its Blaine fineness 360 m²/kg. The mixtures incorporated either Class F fly ash or powdered limestone, in order to enhance the workability. The Blaine fineness of limestone was 385 m²/kg and that of fly ash 270 m²/kg.

River sand (0/5 mm) and coarse aggregate (5/16 mm) were used. In the sand, 8% particles were larger than 5 mm.

A melamine-sulfonate was used as superplasticizer. It had a solid content of 30%. Two types of viscosity agents were used to enhance stability of SLC:
- an organic admixture: a liquid-based hydroxypropylated...
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starch with a solid content of 20%;
- a mineral admixture: a liquid-based precipitated silica with a solid content of 20%.

Mixture proportions

The quantity of fine particles (cement + mineral admixture) was maintained constant at 400 kg/m³, 260 kg/m³ Portland cement and 140 kg/m³ mineral admixture. This binder content is lower than that usually present in SCC, 500 kg/m³ [1]. The quantity of viscosity agent was fixed at 1.3 kg/m³ for the organic admixture and 3.9 kg/m³ for the mineral one. The quantity of mixing water was kept constant at 200 L/m³. The amount of superplasticizer was adjusted to get a static flow in the range of 550 to 600 mm within 10 seconds. This is the main requirement for SLC. The fluidity of concrete was assessed by the measurement of the static spread of a truncated cone having upper and lower diameters of 170 mm and 225 mm, respectively, and a height of 120 mm. When conventional slump test is used, the flow must be in the range of 600 to 650 mm to get SLC.

The influence of the sand to gravel ratio (S/G) on the properties of SLC was investigated. Three S/G ratios were chosen: 1.00, 1.25, and 1.59. The mixture proportions of the twelve SLC investigated are presented in Table 1.

The water to total cementitious materials, calculated taking account of the water contained in admixtures, was 0.51 or 0.52. This value is higher than that present in SCC, which is in the range of 0.30 to 0.37 [1].

Whatever the composition of SLC might be, the unit weight was about the same, which indicated that neither starch nor precipitated silica entrained air.

Testing program

The rate of bleeding (RB) was measured on a surface of 550 cm² and a depth of 10 cm, 3 hours after casting. RB was defined as the ratio between the quantity of water that appeared at the surface of the sample and the total quantity of water contained in the concrete placed in the basin. The bleeding tests were carried out on three samples with a standard deviation lower than 2%.

Segregation of SLC means separation into mortar and coarse aggregate caused by settlement of coarse aggregate. In order to evaluate resistance to segregation, concrete was placed in a column (Fig. 1) 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 five millimeter mesh screen and weighed. There was no segregation and uniform distribution of coarse aggregates if the percent-

<table>
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<th>Mixture</th>
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<td>- Powdered limestone</td>
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<td>- Precipitated silica (kg/m³)</td>
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</table>

Table 1 – Mixture proportions of SLC

Fig. 1 – Form for measurement of segregation.
age of coarse aggregates retained on the screen, was close to the value derived from the following equation:
% of coarse aggregates = \[\frac{\text{amount of gravel (kg/m}^3) + \text{quantity of gravel in the sand (kg/m}^3)}{\text{unit weight of concrete (kg/m}^3)}\].

Each experiment was performed on three samples with a standard deviation lower than 5%.

The sand contained 8% aggregates coarser than 5 mm. A difference of 5% between the values obtained for lower and upper sections was considered to be representative of a homogeneous SLC. Otsuki et al. [8] and Van et al. [9], who have also developed methods for evaluating segregation resistance of self-compacting concrete, consider that a difference of 10% is satisfactory. The theoretical values obtained for the different concretes were as follows:
- S/G = 1.58 (Concretes 1, 4, 7, 10): 34.0%
- S/G = 1.25 (Concretes 2, 5, 8, 11): 37.6%
- S/G = 1.00 (Concretes 3, 6, 9, 12): 41.5%

In order to point out the efficiency of the viscosity agents, for each series of tests, a concrete without viscosity agent was also prepared. The amount of superplasticizer was adapted to get a flow of 550 mm. Whatever the concrete might be, segregation occurred in these concretes.

The compressive strengths at 16 hrs, 2, 7, 28, 90 and 180 days were measured on six cylinders (\(\varnothing = 110\) mm; \(h = 220\) mm), according to the French standard NFP 18-406. The standard deviation was lower than 3%. The modulus of elasticity was determined at 28 days on three samples, with a standard deviation lower than 5%. The unrestrained drying shrinkage was measured on six prismatic samples (70 \(\times\) 70 \(\times\) 280 mm) according to the French standard NFP 15-443. Three specimens were demolded at 24 hrs and kept in the testing room at 20°C ± 2°C and 50% ± 10% R.H. Autogenous shrinkage was also measured on three sealed specimens. The standard deviation observed was lower than 10%.

### 4. RESULTS AND DISCUSSION

#### Bleeding of SLC

As shown in Table 2, the bleeding of SLC was limited and particularly when using the starch-based viscosity agent. The S/G ratio had no influence on the rate of bleeding when the viscosity agent was starch. When precipitated silica was chosen as viscosity agent, the lower S/G, the higher the rate of bleeding.

The use of fly ash as mineral addition led to higher values of bleeding, specially when it was associated to precipitated silica. The beneficial influence of starch associated either to fly ash or limestone powder was clearly pointed out in this study.

#### Resistance to segregation

The results obtained are shown in Figs. 2 to 5.

When no viscosity agent is introduced in the concrete, segregation occurs whatever the mixture proportions may be: the difference between the lower and upper sections can reach 17%. From a technical point of view, when the amount of cementitious material in self-leveling concrete is limited to 400 kg/m³, a viscosity agent is needed to ensure good resistance to segregation.

As shown in Fig. 5, the use of precipitated silica leads to the best behavior whatever the S/G and type of additional cementitious material may be: the difference between the lower and upper sections is minimized. The association “precipitated silica + powdered limestone” generally leads to the lowest segregation.

Another important finding is that there is no direct relationship between bleeding and resistance to segregation: starch gives low bleeding while precipitated silica increases segregation resistance.

#### Compressive strength

The 16-hour compressive strength of the twelve concretes is shown in Fig. 6. All these concretes presented a strength higher than 5 MPa, which was one of the major requirements of the project.

The 28-day compressive strength and elastic modulus are presented in Figs. 7 and 8. These figures point out that:
1) S/G has generally no effect on the 28-d strength, except when powdered limestone and precipitated silica are simultaneously present in the mixture. In this case, the higher S/G, the higher the strength.
2) the use of fly ash leads to the highest strength, and specially when it is associated to precipitated silica.
3) the lower S/G, the higher the elastic modulus.

The strength after 180 days of hydration is shown in Fig. 9.

From Fig. 9, it appears that strengths higher than 55 MPa are always obtained when using fly ash and precipi-
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Precipitated silica; this result is also reached with starch when S/G ≥ 1.25. When using limestone powder, the 180-day compressive strength is close to 40 MPa, whatever the viscosity agent may be.

Due to the pozzolanic reaction, the strength of concretes containing fly ash is 40% higher than that of concretes cast with powdered limestone. The pozzolanic activity of fly ash is clearly established in Fig. 10, which illustrates the increase in strength observed between 28 and 180 days. With fly ash the strength increase is always higher than 133%, while it is only higher than 110% with powdered limestone.
Shrinkage

Both autogenous and drying shrinkages were measured. The values obtained after 180 days of hydration are shown in Figs. 11 and 12. From Fig. 11, it appears that the use of powdered limestone limits the autogenous shrinkage, whatever the type of viscosity agent and the S/G ratio may be. This can be explained by a higher chemical shrinkage associated with the pozzolanic reaction between cement and fly ash, as reported by Justnes et al. [10]. The S/G ratio does not play an important role on autogenous shrinkage of SLC.

The drying shrinkage is in the range of 570 to 710
These values are below those observed for some super-workable concretes cast with lower water to cementitious material ratios (0.30 to 0.40): 1000 to 1200 µm/m \[11, 12\]. According to the results shown in Fig. 11, the tendency that the greater the S/G, the higher the drying shrinkage can be observed. The presence of starch limits the drying shrinkage. The higher values are observed when fly ash and precipitated silica are used together, and especially when S/G = 1.58. This represents the case where the total amount of fine particles present in the concrete is the highest and corresponds to concrete no. 6.
The respective compositions and relative costs of an ordinary concrete and one of the self-leveling concretes (mixture no. 9) are reported in Table 3.

From Table 3, it appears that one cubic meter of self-leveling concrete is 12% more expensive than ordinary concrete. This is mainly due to the low cost of the viscosity agent, and the limited quantities of superplasticizer and additional fine material.

## 5. CONCLUSION

Based upon this laboratory research, the following conclusions can be drawn:

1) self-leveling concrete (SLC) can be developed at reduced cost by using a cheap viscosity agent (modified starch), limiting the superplasticizer content in the range of 4.2 to 5.2 kg/m³ and the cementitious material at 400 kg/m³;

2) such SLC presents an average 28-day compressive strength higher than 30 MPa, whatever the sand to gravel ratio may be. Strength up to 57 MPa after 6 months of hydration can be observed;

3) the use of starch as viscosity agent considerably limits the bleeding of concrete while that of precipitated silica has a beneficial effect on the resistance to segregation;

4) the use of fly ash as supplementary cementitious material leads to increased bleeding and autogenous shrinkage but also enhances the compressive strength;

5) the coarse aggregate fraction in the concrete has only a slight effect on the strength but increases the bleeding of SLC.

## REFERENCES


