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# Influence of Viscosity Modifying Admixture on the Composition of SCC

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**Synopsis:** One of the key point to manufacture a reliable self-compacting concrete (SCC) is the volume of "powder" material (max size = 75 μm) which must be in the range of 170-200 L/m$^3$. This volume includes cement, mineral additions (fly ash, ground limestone, silica fume) and the finest particles of the sand, if any. If this volume is too much (>200 L/m$^3$) there would be some difficulties to transport and place the concrete because of its excessive viscosity. On the other hand, if the volume of the powder is too small (<170 L/m$^3$) there would be greater risk of segregation. Therefore, the role played by the mineral additions is important to obtain a reliable SCC without using an excessive amount of cement, just to compensate the absence of mineral additions. However, there are cases where these mineral additions are not available due to the their shortage. In such cases, a higher dosage of viscosity modifying admixture could be employed to compensate for the shortage of solid powder without using an excessive amount of cement.
The purpose of the work is to study whether or not this target can be achieved. A special VMA was adopted based on welan gum. Different SCCs were manufactured with cement content in the range of 350-400 kg/m$^3$ with and without 200 kg/m$^3$ of ground limestone filler. The dosage of the superplasticizer (based on acrylic polycarboxylate) was changed in the range of 5-8 L/m$^3$ of concrete in order to achieve a slump flow of at least 650 mm. The VMA was not needed when the volume of cement+ground limestone was about 190 L/m$^3$ and the slump flow was limited to 650 mm; to achieve more fluid SCCs (slump flow of at least 700 mm) a small dosage of VMA (2 L/m$^3$ of concrete) is needed. When the ground limestone is not used a reliable SCC can be obtained by increasing the dosage of VMA up to 7 L/m$^3$. In such a case, the VMA acts as "liquid" filler to compensate for the absence of solid filler.

**Keywords:** Segregation, Self-Compacting Concrete, Superplasticizer, Slump Flow Viscosity Modifying Agent.

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## INTRODUCTION

One of the key points [1] in the manufacture of self-compacting concrete (SCC) is the volume of the fine "powder" ($\mathbf{V_f}$), including cement and mineral addition in the form of fly ash, silica fume, blast furnace granulated ground slag (BFGGS), ground limestone and the finest particles of sand (< 75μm). This volume should be in the range of 170-200 L/m$^3$ of concrete (Fig. 1). If $\mathbf{V_f}$ is > 200 L/m$^3$, there could be difficulties in transporting this concrete because of its excessive viscosity. On the other hand, if $\mathbf{V_f}$ is too low (< 170 L/m$^3$) there could be some risk of segregation, specially when the volume of coarse aggregate $V_g$ is too high (> 340 L/m$^3$) [2]. In the absence of any mineral addition, $\mathbf{V_f}$ would coincide with the volume of portland cement ($\mathbf{V_c}$) and then the cement content should be in the range of 535-630 kg/m$^3$ if a specific gravity of 3.15 is assumed for portland cement. This excessive cement content would cause cracks promoted by thermal and drying shrinkage which would severely jeopardize the durability of the concrete structure.

Therefore, the availability of fine mineral filler to replace a significant volume of portland cement is absolutely needed to manufacture SCC. However, the SCC technology is widespread in the area of precast concrete (about 30%) but not yet in that of the ready mixed concrete (only 1%). This means that on the batching plant of a ready-mixed concrete there should be available a silo for the mineral addition of the filler only for some intermittent and sporadic production of SCC.



Moreover, in Europe with the advent of the new cement norms (EN 197-1) blended cements rather than pure portland cement are manufactured, so that there is a shortage of fly ash, BFGGS and ground limestone to be used as mineral additions on the concrete batching plant.

## SCOPE

The purpose of the present work is to assess whether the shortage or the absence of mineral additions can be compensated for the use of a viscosity modifying agent (VMA) in manufacturing stable SCC. In general, this admixture is considered to be an optional ingredient for the SCC manufacture to counterbalance an accidental excess of mixing water. This can happen when wet aggregate is used or when an excess water is surreptitiously used in the absence of control on the free water of the aggregate. Indeed, an other key point of the SCC technology is the *water-fine powder* ratio in volume ($\mathbf{V_w/V_f}$) which must be in the range of 0.85-1.20 (Fig. 1) [2]. If $\mathbf{V_w/V_f}$ is lower than 0.85 the concrete would become too viscous and cannot be easily transported by pump or chute; if $\mathbf{V_w/V_f}$ is too high (>1.20) again there would be a risk of segregation. However, this drawback can be managed through an adequate check of the water in the aggregates with respect to their absorption, without using VMA.

In the present work, VMA should be a compulsory admixture in the SCC manufacture and play an important role in counterbalancing the shortage or even the absence of any fine mineral addition except that already present in the blended cement. When SCC is sporadically produced in ready mix batching plant the intermittent use of a liquid-based VMA could be a cheaper and more effective solution to face the shortage of fine fillers. In other words, VMA could act as a "liquid filler" instead of the powder filler.

## MATERIALS AND TEST METHODS

Different SCCs were manufactured and assessed in terms of segregation and fluidity by using the following ingredients:

- CEM II B/L 32.5 R according to EN 197-1 was used as cement with a specific gravity of 3.09 in which 25% of the portland clinker is replaced by limestone in the grinding mill;
- natural sand (0-4 mm) and gravel (4-16 mm) both with a specific gravity of 2.7;
- ground limestone (max. size of 63 μm) with a specific gravity of 2.70 was used in some SCCs to attain a $\mathbf{V_w/V_f}$ of about 1;

- a polycarboxylic polymer with 20% active matter and a specific gravity of 1.1 was used to reach a slump flow level of at least 650 mm;
- in some SCCs a VMA, based on the welan gum [3] with a specific gravity of 1, was used to mitigate bleeding and segregation (Fig. 2);
- an adequate amount of mixing water was adopted to keep the water-cement ratio (w/c) in the range of 0.55-0.50.

Slump flow and L-box test were used to characterize the properties of the concrete mixtures in the fresh state: in particular the slump flow was used to determine the mobility of the concrete (it must be at least 550 mm), whereas the $\mathbf{H_2/H_1}$ ratio in Fig. 3 was adopted as parameter to assess the segregation ($\mathbf{H_2/H_1}$ must be at least 0.80 to ensure high passing ability SCC) [2].

Compressive strength was determined on cube specimens cured at 20°C with RH > 95% from 1 to 28 days.

## RESULTS AND DISCUSSION

Table 1 shows the content of the ingredients (in kg/m$^3$) and their volume (in L/m$^3$) in SCC mixtures A, B and C. Table 1 also presents the concrete properties in the fresh state in terms of slump flow and segregation assessed by visual rating and measurement of $\mathbf{H_2/H_1}$ from the L-box test.

Mixture A behaves as an acceptable SCC for the slump flow (650 mm) as well for the absence of segregation. The volume ($\mathbf{V_f}$) of fine materials (cement and ground limestone) is set to 187 L/m$^3$ which is in the middle of the reccomended range of 170-200 L/m$^3$. The *water-fine powder* volume ratio ($\mathbf{V_w/V_f}$) is at 1.02, which is in the middle of the allowed range of 0.85-1.20 for an acceptable SCC.

However, if the superplasticizer dosage is increased from 5.5 kg/m$^3$ of the mixture A to 6 kg/m$^3$ of the mixture B, in order to increase the slump flow of the mixture from 650 in the mixture A to 750 mm of the mixture B, $\mathbf{H_2/H_1}$ decreases from 0.82 (mixture A) to 0.75 (mixture B) indicating that there is some segregation; this was confirmed by visual observation.

On the other hand, if the increase in superplasticizer content from 5.5 to 6.0 kg/m$^3$ is accompanied by the addition of a small amount (2 kg/m$^3$) of the VMA, the slump flow increases from 650 mm (mixture A) to 750 mm (mixture C) without any segregation at all as confirmed by its $\mathbf{H_2/H_1}$ (0.83) which is higher than the minimum value (0.80) needed for unsegregable SCC. This is the typical role played by VMA expected in SCC technology: to counterbalance an excess of water or superplasticizer that could increase fluidity and favour the transformation of an un-segregable acceptable SCC (mixture A) to a segregable un-acceptable mixture (mixture B).

A new unespected role played by the VMA admixture will be illustrated in the present paper: how to remove from an acceptable SCC, like mixture of C of the present work, all the mineral filler without any segregation outcome. This, for instance, could be advantageously used to eliminate the filler silo in a concrete batching plant where SCC is produced intermittently. Table 2 shows the compositions and the properties in the fresh state of mixtures C, D and E. The elimination of about 200 kg/m$^3$ of ground limestone of the C mixture was replaced by an increase of 172 kg/m$^3$ of sand content in mixture D; moreover, to increase the slump loss from 700 mm (in mixture C) to 750 mm in mixture D, there was a slight increase in superplasticizer amount (from 6 to 8 kg/m$^3$); finally the dosage of VMA was significantly increased from 2 to 7 kg/m$^3$ in order to counteract the segregation caused by the reduction in the volume of fine material ($\mathbf{V_f/V_c}$ = 112 L/m$^3$ which is out of the recommended range of 170-200 L/m$^3$ for an unsegregable SCC). In spite of the strong increase in VMA dosage to eliminate the segregation of mixture D, this attempt was unsuccessful, as confirmed by the low $\mathbf{H_2/H_1}$ value of 0.70.

In order to be successful in facing this problem, the cement content of the mixture was tentatively increased from about 350 (in mixture C) up to 400 kg/m$^3$ in mixture E, corresponding to a $\mathbf{V_f}$ value of 129 L/m$^3$. Moreover, the amount of mixing water was increased from about 190 kg/m$^3$ in mixture C to 200 kg/m$^3$, so that the workability in terms of slump flow increased from 700 mm (mixture C) to 750 mm in mixture E. The most significant results for the E mixture consist in obtaining unsegregable SCC, even if $\mathbf{V_f}$ and $\mathbf{V_w/V_f}$ are out of the usual recommended ranges of 170-200 L/m$^3$ and 0.85-1.20 respectively. So, the elimination of mineral filler, such as the ground limestone, can be compensated for a significant increase of VMA from 2 to 7 kg/m$^3$ and a slight increase of blended cement (CEM II L-B 32.5 R) from 350 to 400 kg/m$^3$ equivalent to only 300 kg/m$^3$ of portland cement.

The results of compressive strength are shown in Fig. 4. In all the concrete, the strength development is the same (about 8 MPa at 1 day and 35 MPa at 28 days) due to the same w/c value (0.55), except for the E mixture that had higher strength because of the lower water-cement ratio (0.50).

## CONCLUSIONS

The results of the present work confirm that the VMA admixture can be advantageously used to attenuate the consequences of the unavoidable changes in the amount of water of the aggregate or to counteract the segregating effect caused by slight increase of superplasticizer dosage focused to an increase of the slump flow as in the C mixture with respect to mixture A (Table 1).

The incorporation of VMA led to complete elimination of the mineral filler: in such a case a slight increase in cement content must be accompanied by a significant increase in the dosage of VMA (for instance from 2 to 7 kg/m$^3$) in order to obtain an unsegregable SCC even in the absence of the mineral filler.

The cost increase due to the dosage increase of VMA is compensated by the cost reduction due to the elimination of mineral filler. This means that at least in the first and sporadic production of ready mixed SCC, the silo for the mineral filler is not needed and can be replaced by some drums of "liquid filler" in form of VMA.

## REFERENCES


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**Table 1 – Composition and properties of fresh SCC mixtures A, B and C**

| COMPOSITION | A | | B | | C | |
|---|---|---|---|---|---|---|
| | By mass | By volume | By mass | By volume | By mass | By volume |
| Cement | 350 | 113 | 347 | 112 | 347 | 112 |
| Ground Limestone | 200 | 74 | 197 | 73 | 197 | 73 |
| $V_f$ | --- | 187 | --- | 185 | --- | 185 |
| Sand (0-4 mm) | 805 | 298 | 777 | 295 | 797 | 295 |
| Gravel (4-16 mm) | 810 | 300 | 805 | 298 | 805 | 298 |
| Water | 190 | 190 | 189 | 189 | 189 | 189 |
| Superplasticizer | 5.5 | 5.0 | 6.0 | 5.5 | 6.0 | 5.5 |
| VMA | --- | --- | --- | ---- | 2.0 | 2.0 |
| Air | --- | 20.0 | --- | 26.5 | --- | 25.5 |
| w/c | 0.55 | | 0.55 | | 0.55 | |
| $V_w/V_f$ | 1.02 | | 1.02 | | 1.02 | |
| PROPERTY | | | | | | |
| Slump Flow (mm) | 650 | | 750 | | 750 | |
| $H_2/H_1$ (L Box Test) | 0.82 | | 0.75 | | 0.83 | |
| Segregation (Visual Rating) | No | | Slight | | No | |

**Table 2 – Composition and properties of fresh SCC mixtures C, D and E**

| COMPOSITION | C | | D | | E | |
|---|---|---|---|---|---|---|
| | By mass | By volume | By mass | By volume | By mass | By volume |
| Cement | 347 | 112 | 347 | 112 | 400 | 129 |
| Ground Limestone | 197 | 73 | --- | --- | --- | --- |
| $V_f$ | --- | 185 | --- | 112 | --- | 129 |
| Sand (0-4 mm) | 797 | 295 | 969 | 359 | 910 | 337 |
| Gravel (4-16 mm) | 805 | 298 | 805 | 298 | 810 | 300 |
| Water | 189 | 189 | 191 | 191 | 200 | 200 |
| Superplasticizer | 6.0 | 5.5 | 8.0 | 7.3 | 7.7 | 7.0 |
| VMA | 2.0 | 2.0 | 7.0 | 7.0 | 7.0 | 7.0 |
| Air | --- | 25.5 | --- | 25.7 | --- | 20.0 |
| w/c | 0.55 | | 0.55 | | 0.50 | |
| $V_w/V_f$ | 1.02 | | 1.67 | | 1.55 | |
| PROPERTY | | | | | | |
| Slump Flow (mm) | 700 | | 750 | | 750 | |
| $H_2/H_1$ (L Box Test) | 0.81 | | 0.70 | | 0.82 | |
| Segregation (Visual Rating) | No | | Yes | | No | |

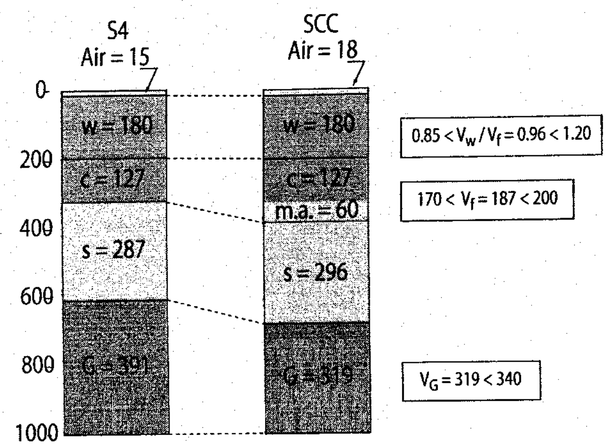


**Fig. 1 – Typical volume composition (L/m$^3$) of SCC Vs. S4. $V_f$ = powder volume = cement (c) + mineral addition (m.a.); w= water; s = sand volume; G = gravel**

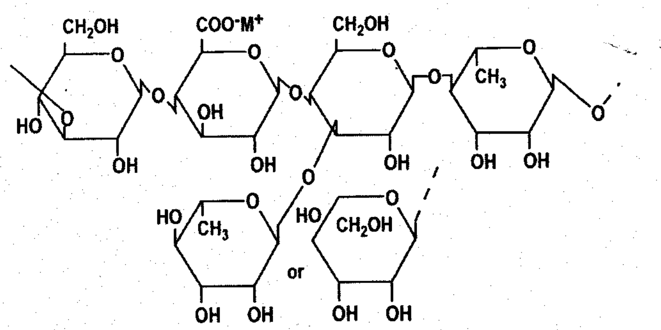


**Fig. 2 – Chemical composition of the polymer welan-gum**

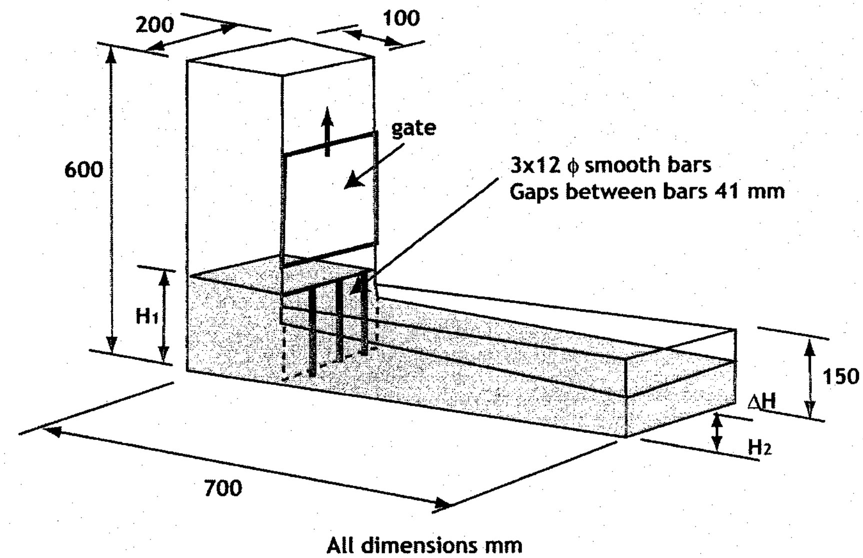


**Fig. 3 – General Assembly of L-box**

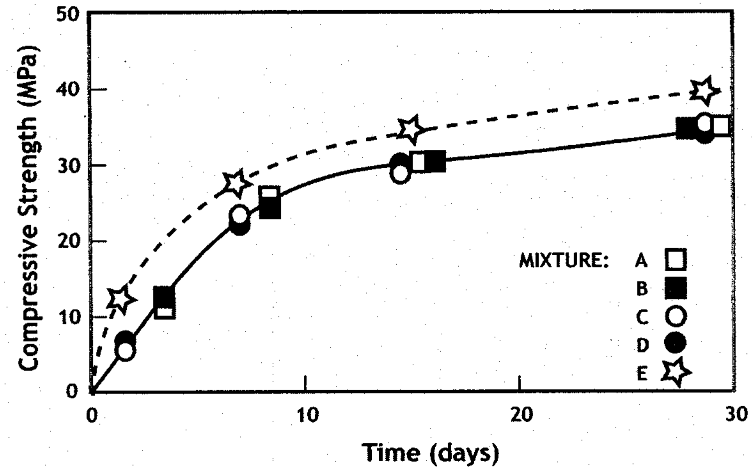


**Fig. 4 –Cube compressive strength from 1 to 28 days for the different mixtures**