IN-SITU ON-LINE CONTROL OF SCC PRODUCTION REGULARITY

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Abstract

A new force sensor Viscoprobe™ in a mixer is tested and compared with Wattmeter - mixing power measurement - and concrete moisture probe Orbiter also in the same mixer of an industrial batching plant, over 11 SCC truck mixer productions. The Viscoprobe™ measures water proportioning variations batch per batch with ±1.2 L/m³ accuracy. The comparison of the 3 sensors signals leads to the improvement of each measurement accuracy through a better understanding of physical product evolution while mixing. With new processing of wattmeter and Orbiter measurements, accuracies are estimated ±2.5 L/m³. Should data be processed as in previous studies, accuracies are about ±4.5 L/m³. The measurement field of validity is different for each sensor and combined use is recommended (example Viscoprobe and wattmeter).

The combined use of several sensors and new processing methods improve the previously assumed accuracies and make measurement reliable. Once these tools, available from now on, are operating, online quality control and then close-loop control inside the mixer of production to the quality can be considered in the short term.

1. INTRODUCTION

On-line measurements into the mixer (batch per batch) are not an innovation [1,2,3] since two practices have been commonly used for more than 20 years. In the ready mix plant [4,5], the level of the mixing power is linked with the deviation of water proportioning (often the consequence of a bad monitoring of moisture content of aggregates). Water proportioning of the following batches is corrected consequently. In pre-cast factories (for example: blocks), water is introduced by stages until obtaining a pinpoint signal given by a moisture meter, most often a revolving resistive probe.

The use of such systems is rather positive. However, their development is slowed down by a lack of confidence in online measurements due to the current empirical use:

- These measurements are processed in relative response, from a batch to another. The result is conditioned to the skill of the operator. No protocol of calibration has been set up to
date, although either the wattmeter (sensitive to the wearing of the mixer, and to the
temperature of the engine…) or the revolving resistive probe (sensitive to variations of the
quality of water or cement…) has an unstable calibration throughout the time.
- Lack of a real measurement strategy and insufficient signal filtering of the wattmeter lead
to significant components of error. The sensors signal is related to the product evolution
inside the mixer which is noticeable during the mixing and homogenisation of concrete.
Before measurement, stabilization of the signals is awaited which however is rarely effective.

2. EXPERIMENTAL

The experimentation is carried out on Couvrot batching plant in the SBP Samer factory
over one usual day of production. Although installed on a factory site, the batching plant is
comparable to a production system of ready-mix concrete. The moisture of sand is measured
for each batch through a microwave moisture meter, small gravels moisture being considered
constant during all the day. The filling cycle is as follows: simultaneous introduction of
aggregates (natural moisture) and fines (cement and filler) then introduction of the liquid
components after about 15 seconds. A mixing time with all components is at least 55 seconds.
The concrete is discharged in a truck mixer before transportation into the factory.

For the experimentation, the 1.5m3(3600 kg) planetary mixer is equipped with 3 different
sensors: a wattmeter (A), a concrete moisture probe (B) and a Viscoprobe™

A - The wattmeter is based on the follow-up of mixer’s power consumption evolution
during mixing cycle.

B – The concrete moisture probe - Orbiter – is a more recently designed technology (2002)
than revolving resistive probe and uses a different measurement principle: the microwaves. It
measures the existing quantity of water in approx 1 liter around the probe.

C - Viscoprobe™ (2006), designated to evaluate the rheology of very fluid concrete - in
particular SCC - during mixing. The probe is a force sensor mounted on a steel probe with a
ball shape head moving inside concrete. In tested configuration, the probe sets on a mixing
star (epicyclical move) and the force oscillates between a min and a max taking into account
the variations of the speed in the concrete. For this test the probe provided sliding average and
amplitude of the force on around one planetary system revolution.

11 truck mixers have been filled with a total of 33 batches produced among 3 different
SCC mix designs and several batch sizes. In this paper only 1.5 m3 batches of one single mix
design are analysed: sand to gravel ratio of 1.05, 380 kg/m³ of cement and filler, one admix
(superplasticizer). The two other formulas, one with higher fine elements content and other
using air-entrainer agent, give consistent and complementary information not discussed here.

For some batches variations in water proportioning has been imposed. Slump-flow is
measured for each truck mixer at the batching plant at the end of each filling and, in 3 cases
after the introduction of the first batch. The 3 sensors are evaluated on a range of SCC with a
variable slump flow between 49 and 70 cm. The few concretes with a slump flow lower than
60 cm are those where water proportioning is voluntarily reduced.

3. RESULTS

Total water proportioning is calculated for each batch by adding proportioned water, water
content in additives and water from the aggregates. The gravels moisture does not seem to
fluctuate during the day of production. Both controls carried out through drying before and
after manufacture show close values for gravel s moistures. The sand moisture measured by probe remains also close to the checked value before and after manufacture. From typical fluctuations of moisture measurements, the uncertainty on water content in the batch is estimated at about 1.5 L/m³ (standard deviation).

Slump flow increases, in approx. linear way to the proportioning of water. The limit of SCC (60 cm) is reached for water proportioning of 177L/m³. Taking into account the good precision in concrete moisture evaluation we refer here to water proportioning, keeping in mind corresponding flow characteristics.

The wattmeter curves rise with the filling with the mixer and then decrease during mixing (Figure 1). The power final stabilization is postponed after a second rise of power for batches where water proportioning is quite lower. The highlighting of this second peak of power for batches of high viscosity concrete is characteristic of planetary type mixing systems. We will analyze further this phenomenon, thanks to the information given by Viscoprobe™.

The power is not really stabilized before discharge of the mixer, but its rate of evolution strongly decreases from the black dotted line on Figure 1, line that has a particular significance which will be discussed further [6].

![Figure 1. Time response during mixing of Viscoprobe™ (average), wattmeter and Orbiter probes](image)

Measurements of the Orbiter probe rise during aggregates and fines introduction, then rise again during the liquid components introduction (Figure 1). The signal of the probe reaches a maximum level (“peak”) about fifteen seconds after the end of the components introduction, then decreases over ten seconds to a minimum level, “trough”. The minimum level of the signal happens earlier when water proportioning increases.

About Viscoprobe™, the relationship between water proportioning and the average force is analyzed. The evolution of the average force with the operation is similar to the one of mixing
power. The average force increases during the filling phase of the mixer, followed by a peak. Then the signal decreases more or less rapidly according to water proportioning.

The cross analysis of the average force and the amplitude of the force can give more complete information over concrete rheology. However, for a relevant evaluation of the use of the Viscoprobe™ as a rheometer, available data are not sufficient. We can notice that relative evolution of the rheological parameters displayed by the probe agrees with the expected evolution due to a change of water proportioning. A time acquisition of the force during mixing and tests on selected mixtures would allow for a more comprehensive evaluation.

4. DISCUSSION

4.1 Typical points of the curves

The comparison of the average force displayed by Viscoprobe™ with the wattmeter curves (Figure 1) allows for a better understanding of the product evolution during mixing.

- Average force evolution within mixing time includes oscillation period of about 7 to 8 seconds. It matches with the period of mixer’s main revolution. The oscillations are the reflection of heterogeneity of the concrete. They appear to attenuate after the fluidity point. These oscillations are much less visible on the wattmeter curve because the power takes into account forces on all mixing blades (filter effect on the mechanical noise).

- A strong decrease of the force is seen on the batch with lowest water proportioning (163 L/m³), probably existing, but with an amplitude definitely reduced on batches with 168 and 169 L/m³. These decrease trend happens in the zone of wattmeter curve second peak and seems responsible for “dis functioning” of the Viscoprobe™ for non-SCC concrete (at least when Viscoprobe™ is set on mixing star). If we remind that the average force is linked to relative speed between the metal ball and material surrounding it, one can explain this decrease. As long as the material remains slightly cohesive (low distribution of water in the mixture which still remains in great proportion slightly wet) the material speed around the metal ball is reduced. As the cohesion of material increases (progressive distribution of water in the mixture) material is pulled and run with mixing star. The ball shape sensor hold on the mixing star is discharged. The material evolving to a granular fluid, its rotation with the mixing star fast decreases, and starts to load again onto the ball.

The trend changes in the Orbiter signal match to trend changes on the wattmeter

- Peak of Orbiter can be linked to the beginning of the second rise of power

- Trough of Orbiter corresponds to a drastic change in the decreasing power rate

This drastic change in the decreasing power rate corresponds to the transition phases, i.e. at the time when mixed material changes from a cohesive material into a granular fluid called herewith fluidity point [4,6]. For ready-mix production (when mixing is systematically finished in a truck mixer) the fluidity point is often considered by the producer as the right time to stop mixing (“end-point”).

It is interesting to observe that the trough of the moisture probe signal is achieved at the fluidity points. From a practical point of view this indicates that:

- It is possible to measure with this probe water proportioning as discussed later at the trough of the signal, (“end-point”) without additional mixing time.

- The Orbiter probe can be used to determine the fluidity point (determination of a minimum) whereas that is sometimes difficult to estimate with the wattmeter.
For most of the batches, the mixing time is sometimes significantly lower than 55 seconds (mixing time in France for the certified plants). The suitable treatment would make it possible to reduce the mixing time without risk of quality lost for batches which have right water content. When water proportioning is low (163 L/m³) a longer mixing time is necessary (here 75 seconds). Similar incidents can appear in production following proportioning error. The lack of mixing generated can be avoided with a suitable treatment of online measurement.

4.2 Sensor precision assessment

![Graph showing probes signal evolution with concrete water proportioning](image)

The three sensors can measure water proportioning of a fluid concrete in the mixer, but the range of good precision is different for each sensor. It is to be noted that the moisture value is to be linked to the sensor global curve interpretation.

Orbiter probe has a large range of validity domain from vibrated concretes [6] to SCC. For SCC tested here, the processing of the trough of the signal allows to obtain a measuring precision better than ±2.5 L/m³ (standard deviation of 1.5 L/m³) (Figure 2). With the traditional processing of the maximum point the precision is about the same in previous studies [6], i.e. ±4.5 L/m³.

Power measured at the fluidity point gives a good values of water proportioning and thus of concrete rheology (which is still evolving). With this processing, the measuring precision is better than ±2.5 L/m³ similar to Orbiter. With the two sensors, the point with 163 L/m³ follows another trend and a different sensitivity must be considered for lower water proportioning.

Traditional processing of mixing power links water proportioning to power after fixed mixing time. The measuring precision is better than ±4.5 L/m³ (for a well calibrated wattmeter in the tested condition, standard deviation of 2.7 L/m³), similar to results presented by previous studies [7]. However, the wattmeter is not able to distinguish water proportioning difference from water over dosage in SCC. This is confirmed for batches with 199 and 203 L/m³. For these “extreme” SCC batches, Viscoprobe™ allows to determine water content with an excellent precision, about ±1.2 L/m³ (Figure 2). The curves of average forces are analyzed at fixed mixing time (mean values between 40 and 45 s). Viscoprobe™ can however give contradictory signals for concrete drier than SCC (by choice or proportioning error), its use should be systematically accompanied with the analysis of a wattmeter.
5. CONCLUSION AND FUTURE PROSPECTS

The Viscoprobe™ measures water proportioning variations batch per batch with ±1.2 L/m³ accuracy (90% confidence interval). Comparison of the 3 sensors signals enable to confirm previous researches with wattmeter and Orbiter, but also leads to the improvement of measurement processing which gives better accuracies. With new processing of wattmeter and Orbiter measurements, accuracies are estimated ±2.5 L/m³. Accuracies improve from ±4.5 L/m³ for a processing comparable to previous studies, down to ±2.5 L/m³ for processing of here studied measurements. Should data be processed as in previous studies, accuracies are about ±4.5 L/m³. The measurement field of validity is different for each sensor and combined use is recommended (example Viscoprobe and wattmeter).

The combined use of several sensors and new processing methods improve the previously assumed accuracies and make measurement reliable. Once these tools, available from now on, are operating, online quality control and then close-loop control inside the mixer of production to the quality can be considered in the short term.

Field of validity of each sensor is different. The Orbiter has a wide field of application including RMC vibrated concrete as well as SCC. The Wattmeter, which common field of application is vibrated concrete, enable as well measurement of water deviation in SCC. However, when water proportioning in SCC rises significantly, wattmeter comes out of its range of validity. These SCC concrete with high water content (for example following proportioning mistake) can be measured very accurately by Viscoprobe™.

In fact, Wattmeter and Viscoprobe™ give complementary measurements as the latest cannot help to estimate water deviation for lower fluid concrete than SCC. Thus, combined use of both sensors is recommended.

Results show that today, it is possible to follow-up very accurately online the evolution of concrete inside the mixer in an industrial process, to check water content and, potentially Rheology of SCC. The association of several sensors and new processing methods will enable to improve previously accepted accuracies and make measurements reliable. Online quality control in the mixer and close-loop control of production to quality of concrete while mixing can be considered in the short term, when concrete producers will really implement tools available from now on. Improvements, required for development of new concrete and in particular SCC, will help the rise of quality steadiness and reduce costs for all types of concrete.
REFERENCES