FULL SCALE PUMPING TESTS ON SCC: TEST DESCRIPTION AND RESULTS

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INTRODUCTION

Pumping of concrete is a daily applied process, providing the possibility of continuously filling a formwork. Reports have been created dealing with the composition and the workability of the concrete, with the maximal discharge and pressures, with the characteristics of pumps and pipes, … (1) On the other hand, only a very few fundamental scientific studies on this topic are available (2).
In case of self compacting concrete (SCC), the same rules, valid for traditional concrete (TC), are applied. On the other hand, the verification of these rules, or new rules, are not reported (yet). SCC is considered as a special case of TC, having an advantageous composition for the pumping process, which should simplify the pumping and reduce the problems.
This paper shows the results from a series of pumping tests. After a description of the equipment is provided, a set of surprising results is presented: SCC causes higher pressure losses, compared to TC. Further results will prove the existence of a less viscous layer near the wall, a temperature increase inside the concrete equivalent to the pressure loss and the importance of thixotropy.

PUMPING CIRCUIT

Concrete pump
The concrete pump used in this study is a standard available truck mounted twin cylinder piston pump (Schwing KVM 24-4 H, P 2023), with a maximal pressure of 95 bar and a maximal discharge of 150 m³/h (Fig. 1 left). It contains two cylinders, alternately pushing concrete inside the pipes and pulling concrete from the concrete reservoir. A very powerful system is able to switch the connection to the pipes from the one to the other cylinder, once the former is empty (and consequently, the latter is full). Each time the system switches cylinders, meaning each time the volume of a full cylinder is pumped inside the pipes is called a stroke. Each stroke contains, theoretically, 83.1 liter.

Piping circuit

The pipes are steel pipes with an inner diameter of 0.105 m, available in straight sections of 1 and 3 m. The connections between the pipes are equipped with rubber seals, in order to assure cement-paste tightness and steel clamps in order to maintain the connections. The circuit, in total 25m long, consists of a horizontal straight section of 12 m and a inclined part, providing the ability for the concrete to fall back inside the reservoir of the pump (Fig. 1 right).

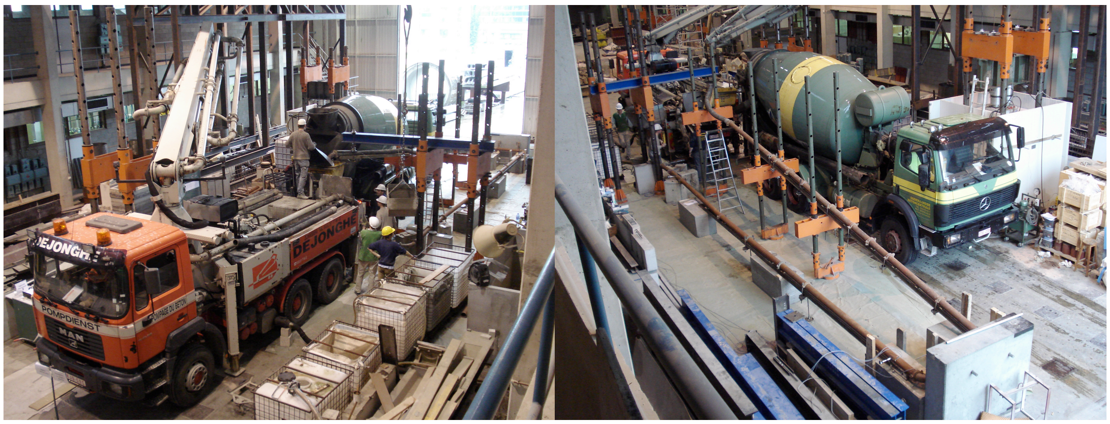

Figure 1: Left: concrete piston pump truck. Right: Piping circuit.

Measuring equipment

The pressure is measured by means of two pressure sensors, placed in the horizontal section of the circuit, at a distance of 10.11 m from each other. At the same location of each pressure sensor, three strain gauges are attached to the pipe, functioning as a back-up in case something happens with the pressure sensors. Near each pressure sensor, a temperature sensor is attached to the pipes, in order to evaluate the evolution in time. Each of these sensors is connected to a central measuring unit, registering all data 10 times per second (Fig. 2).

Figure 2: Pressure sensor, strain gauges and temperature sensor.

Measuring the discharge or the velocity is somewhat more complicated and an alternative procedure has been worked out. By recording the time needed for a certain amount of strokes, which contain theoretically 83.1 l each, one can calculate the volume of concrete flowing through the system per unit of time. This can be verified in the obtained time plot of the pressure measurements: each time the pump needs to switch between cylinders, the pressure drops to zero and builds up in less than one second. By calculating the time between two pressure drops, one obtains the discharge again (Fig. 3).

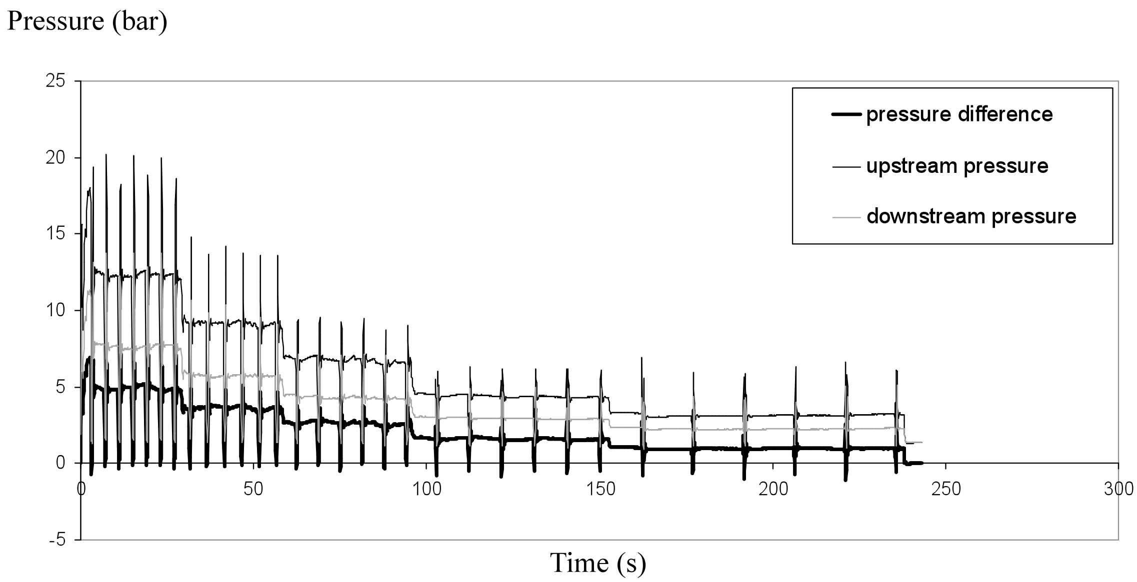

Figure 3: Time plot of pressure showing clearly the pressure drop at the end of each stroke.

In order to verify the real volume of a cylinder, the reservoir used for sampling is suspended to the rolling bridge and the weight is measured continuously by a load cell. Once the reservoir is closed, one full stroke is pumped inside the reservoir, and as density is known, the discharge can be calculated. Results show a very good agreement between the two measuring procedures for the discharge and between the calibration and the measuring procedures.

TESTING PROCEDURE

The amount of concrete needed to perform the tests is approximately 1.25 m^3, which is produced at a concrete manufacturing plant, 35 km away from the laboratory. The production and transporting time takes at least 45 minutes, and the first pumping test can start at a concrete age of approximately 1 hour.

A pumping cycle consists of pumping the concrete at the 5 lowest discharges available, maintaining each discharge for 5 full strokes as can be seen in figure 3. For each discharge, the average pressure loss is calculated and delivers one point in a pressure loss – discharge curve. This testing procedure is repeated each 30 minutes, for a total time between 60 minutes and 150 minutes, corresponding to a concrete age of 2 hours and 3.5 hours respectively. Previously to each pumping cycle, a sample of concrete is taken in order to determine the rheological properties with the Tattersall Mk-II rheometer (3) and

in order to perform the standard tests on fresh concrete (slump flow, V-funnel, …). In total, 14 SCC and 1 TC have been pumped.
The two SCC, which are shown as an example in this paper, contain 853 kg of sand, 698 kg of gravel with a maximal aggregate size of 16 mm, 360 kg of OPC, 240 kg of limestone filler and 165 liter of water. The amount of SP is variable. In this way, the first SCC had an initial slump flow of 720 mm, and the second 650 mm. The TC-mix contained 857 kg of sand, 914 kg of gravel with a maximal aggregate size of 14 mm, 318 kg of blast-furnace-slag cement, 10 kg of fly-ash, 171 liter of water and 4.15 kg of superplasticizer.

RESULTS AND DISCUSSION

Difference between self compacting and traditional concrete

As SCC behaves as a more fluid concrete, it is expected that lower pressure losses will be observed when compared to the pumping of TC. The experience of the pumping operator and tests results indicate the opposite: SCC requires larger pumping pressures compared to TC, especially at the higher discharges. In order to explain this phenomenon, a detailed examination of the rheological properties of both concretes must be performed.
The large fluidity of SCC, visualised by a slump flow test, is caused by the low yield stress (4). Pumping of concrete, however, is occurring at high shear stresses, which can be directly calculated from the pressure losses. As a result, the influence of the yield stress is very low. On the other hand, viscosity is the determining factor, together with the possible shear thickening (5), and as the viscosity of SCC is higher compared to TC, in order to maintain the stability, the cause of the higher pumping pressures is found.

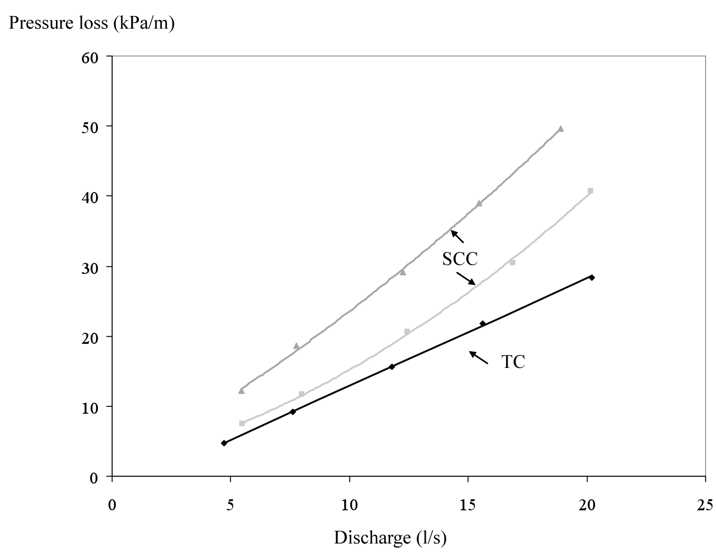

Figure 4: The pressure losses when pumping TC are lower compared to SCC, especially at the higher discharges.

In figure 4, the results of a pumping cycle of 2 SCC and 1 TC are shown, while figure 5 shows the extrapolation of the obtained rheological results into the proper shear stress interval. Remark that figure 5 is not exactly correct, due to other phenomena which are changing the shear rate, but it provides a good qualitative explanation.

Comparison with theoretical results

When calculating the pressure losses theoretically, based on hydraulics formulae (6), an overestimation of the pressure losses with a factor 6 to 10 (and even higher) is obtained. This proves that a less viscous layer near the wall must be formed in order to ease the flow of SCC. This less viscous layer can have three causes:

- The geometrical wall effect: Due to the pipe wall, the relative amount of fine materials increases near the boundary, causing the rheological properties to decrease. A linear decrease has currently been incorporated into the calculations, showing a significant drop in predicted pressure losses, but still the pressure losses are overestimated.
- Thixotropy: Due to the high shear rates near the wall, less particles are coagulated, causing an additional decrease in rheological properties near the wall (7)(8). This thixotropic effect has not been incorporated into the calculations.
- If the above mentioned effects are not sufficient when predicting the pressure losses, one can suspect that dynamic segregation can also play a role. This part is still under investigation.

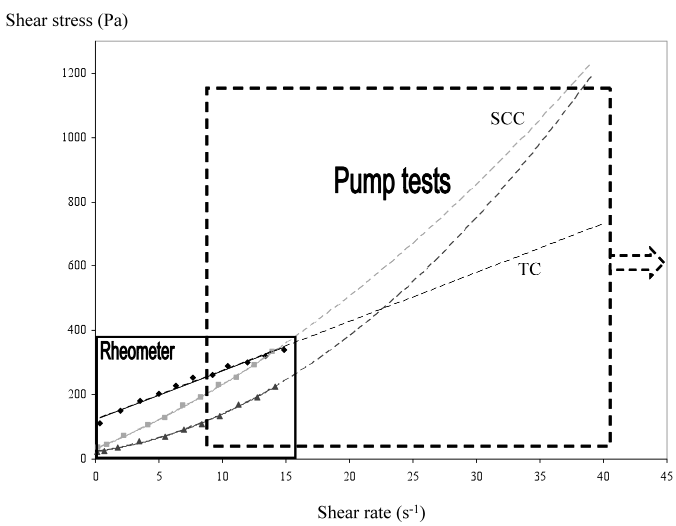

Figure 5: Extrapolation of the rheological data into the region of shear stresses, occurring during pumping tests shows the large influence of the viscosity.

Temperature increase

While pumping, the temperature of the concrete increases linearly with increasing pressure losses. This means that continuously pumping the same concrete in a loop circuit is a very disadvantageous situation, due to a possible large loss of workability. The temperature increase can be as high as 1°C/minute.

Influence of air content and thixotropy

Apparently, the pressure loss – discharge curve tends to decrease instead of increase in the first hour of pumping. This is contradictory to the loss of workability which has been

observed. This decrease in Δp-Q curves can be caused by two phenomena, most probably acting together: increase in air content and thixotropy. An increase in air content in the concrete causes a decrease in viscosity (4) and probably a decrease in shear thickening. Further investigations must point out how significant this increase in air content is.
Secondly, the coagulation state of the concrete is decreasing during the first cycles, until it reaches equilibrium at the third/fourth cycle. This decrease in coagulation causes a decrease in viscosity, and consequently, a decrease in pressure losses (7)(8). A more detailed analysis of the influence of thixotropy on the pressure losses is given in (9).

CONCLUSIONS

Large scale pumping tests on self compacting concrete have been performed by means of a truck mounted piston pump, and a loop circuit with a total length of 25 m.
Test results indicate that the pressure losses are dominated by the viscosity of the pumped concrete, together with the possible shear thickening, and that the yield stress has a very small influence. This result explains why pumping SCC causes larger pressure losses compared to the pumping of TC, especially at higher discharges.
Comparing the obtained experimental data with theoretical calculations shows that a less viscous concrete layer near the wall most probably exist. This layer can be caused by three phenomena: the geometrical wall effect, thixotropy and possibly dynamic segregation.
The increase in temperature is linearly related to the pressure losses.
Increase in air content and thixotropy cause the concrete to become more fluid during pumping, until a certain equilibrium is reached.

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