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Production and quality control of self-compacting concrete on local sites in Egypt

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الملخص :

على الرغم من أن الخرسانة ذاتية الدمك قد وصلت إلى مرحلة ما بعد الدراسات المعملية وأصبحت الآن منتجا متوافر للاستخدام ، إلا أن سلوكها وأدائها في الحالات الطازجة والمتصلدة على حد سواء – خاصة أثناء التنفيذ بالموقع - لا تزال بحاجة إلى فهم شامل. يقدم هذا البحث دراسة حول سلوك الخرسانة ذاتية الدمك في الحالات الطازجة والمتصلدة في قسمين رئيسيين. تصميم خلطة خرسانية ذات خصائص محددة بناء علي القدرة علي التدفق وقدرة الخرسانة في الحفاظ علي قوامها ومقاومة الضغط المستهدفة. ثم دراسة عملية ضخ الخرسانة ذاتية الدمك وتأثيرها علي الخصائص الطازجة والمتصلدة.

ABSTRACT:
Although self-compacting concrete (SCC) has matured beyond laboratory studies and has now become an industrial product, its characteristics behavior and performance, in the fresh and hardened states alike, still need to be thoroughly comprehended. At the present time, SCC is used in many construction projects in Egypt, bridges and high-rise building, due to its fresh and hardened excellence properties and the ease of placing it in a congested and irregular formwork without any vibrations. This paper presents a full-scale test on-site, it presents the results of a study on behavior of SCC in the fresh and hardened states. first, the focus was to design a mixture with specific properties based on the desired target flow-ability and compressive strength. Experimental work was performed on-site batching plant. Slump retention time was determined on-site. Secondly, concerned about pumping of self-compacting concrete and its effect on the concrete rheological properties and hardened properties too.

KEYWORDS: Pumping, concrete fresh properties, self-compacting concrete, quality control on-site, and real-scale test on-site.

1. Introduction

Self-Compacting Concrete (SCC) is one of the most recent used material in construction field in the world. Because of its followability (self-compactibility) into place and around obstructions under its own weight without flow blockage, and segregation and with no significant separation of constituent materials, therefore until the sitting, a lot of compaction energy can be reduced, it is considered more environmentally friendly than vibrated concrete [1]. Self-compacting concrete increases productivity due to its beneficial workability properties that makes it possible for the contractors to exclude the compaction work on-site. The resulting structure is less dependent on the workman skills on-site. The quality and durability of structures is more guaranteed and. Another issue that arises when trying to incorporate SCC into applications (concrete structures) is the lack of familiarity of many people in the concrete industry, including design engineers, ready-mix suppliers, construction workers, and execution or project engineers, with the product since this is such a recent technology. Effective technology transfers or on-site training becomes necessary. Using SCC in local construction industry in Egypt is limited so, the accurate quality control during the manufacturing and casting operations is so important. Taking into consideration delaying time between mixing and pouring of SCC. This delay causes change in fresh concrete properties. SCC is meant to improve cast-in-place performance and speed-up on-site working, considering material's performance (self-compact-ability).

Changes in concrete fresh properties caused by pumping is the main challenge in the casting process for a concrete practice. In the last few years, significant progress has been achieved in understanding the flow of the concrete in the pumping pipelines, including the behavior of the lubrication layer near the pipe surface [1]. SCC rheological properties and workability change due to pumping pressure or flow rate, pumping also probably influences the compressive strength of concrete [3-4].

2. Work plan

This study is divided into two phases. Phase I was planned to produce self-compacting concrete mixes with different available local materials by carrying out different trail mixes. Using ordinary Portland cement, crushed dolomite, sand, chemical admixtures, silica fume, and potable water with different contents (ingredients of materials were chosen carefully to produce the required composition) based on slump flow measurements, visual observation, slump loss with time and compressive strength results. By studying the effect of the different parameters (delaying time, slump loss and re-tempering) on the workability of concrete and choose the most suitable mix to be considered self-compacting concrete that can maintain its properties under site conditions. All mixes that have been done in this phase were designed according to the results mentioned in two [1,5]. All mixes were carried out on-site and by using the concrete batching plant of the project.

Phase II was planned to study the production and quality control parameters for on-site pumped self-compacting concrete. Studying the effect of site conditions on concrete fresh properties. The operation of Pouring concrete on-site depends on the speed. When fresh concrete delayed during long period taken to transport it to the job-site, (especially in our case in which, pouring concrete elements in a watercourse) concrete losses its fresh properties, meaning that workability or slump flow became hard to be pumped, then the need to redoes or re-tempering concrete is necessary to make it flowable as it was in its reference state when it come out from the batching plant mixer. Therefore, studying this process starting from mixing concrete to casting it in forms, taking into consideration transporting, pumping, casting delay, and re-tempering of fresh concrete.

3. Materials

The main variables were the cement content, the fine aggregate to coarse aggregate ratios and the dosage of the mineral additives (silica fume). Portland cement (CEM I N42.5) was used in all mixes. Crushed stone (dolomite) and natural siliceous sand were used as coarse and fine aggregates respectively. Three different Chemical admixtures were used ViscoCrete-3425 with polycarboxylates base, MasterEase-3978 with poly aryl ether (PAE) polymers base and MasterGlenium-RMC315 also was used with a modified Polycarboxylic ether base and all of them meet the requirements for superplasticizer.

Many variables of concrete composition and their ratios finding that a big number of variables supposed to result in a big number of mixes but it has not happened thanks to the mix compositions made by [1] and the recommended range of SCC mix compositions made by [5]. Table (1) represent the mix proportion ratios of Phase 1. For each mix of this phase the slump flow test was carried out.

All trail mixes were carried out in the concrete batching plant on-site, the mixer was a drum twin shaft mixer with 3 m3 capacity. The coarse aggregate and sand were loaded in the mixer at first, then cement and mineral admixture were loaded, after starting mixing cement and dry aggregates, 70 – 80 % of total water is loaded, and mix them all very well, finally the remaining water and chemical admixture were loaded. To make a homogenous mix, mixing time was not to be less than 60 seconds.

4. Mix design

Self-compacting concrete (SCC) requirements are mostly influenced by the fractions of the mix ingredients. In other words, to fulfil its main functional requirements (filling ability, passing ability and segregation resistance), major work in SCC should take into account designing appropriate volume fractions of the mix ingredients. Without paying attention to its mix proportioning, SCC will remain to be designed by a number of time and material-consuming trials before an optimum mix proportion is reached. Although it has passed from the research phase into real application, methods for proportioning SCC mixes have not kept pace with their production techniques.

Twenty-five trails mixes were carried out until we could get to the most suitable mix that can maintain its fresh properties as long as possible. Casting high strength concrete in a watercourse takes long time, so high performance self-compacting concrete should be used which can maintain its fresh properties during the long time of transporting process in addition to achieving the required compressive strength. Using available local materials, cement, sand, dolomite, silica fume and chemical admixtures mixes have been carried out. Empirical design method is based on empirical data available for mix parameter to determine the initial ingredients. The best estimates of the SCC mix proportions for required properties are performed through several trial mixes and alteration. Previous data for trails can be used as a guide to expect fresh and hardened properties of trail mix [1].

1. Effect of constituent materials on concrete fresh and hardened properties

Sand content in a SCC mixture is one of the most important factors that influence the workability of the concrete. Sand ratio change will lead to change of voids between aggregate particles and total surface area. Concrete mixes with 50% sand ratio showed good fluidity but less cohesiveness. Concrete mixes with 44% sand ratio showed more bleeding and tend to segregate.

Table 1 Mix design proportions, Slump flow and compressive strength testing results

Mix code	Cement content (kg/m^3)	Silica fume content % of cement (by addition)	Water/ cementitious ratio	Chemical admixtures dosage % of cementitious content			Aggregate content ratios		Slump Flow (mm)	compressive strength @ 28 days (kg/cm^2)
				ViscoCrete-3425	MasterEase-3978	Master Glenium RMC315	Sand	Dolomite		
M1	450	8.90%	0.32	0.00%	0.00%	1.53%	50%	50%	630	670
M2	450	8.90%	0.26	0.00%	0.00%	2.65%	50%	50%	560	723
M3	450	8.90%	0.31	0.00%	0.00%	2.45%	50%	50%	620	671
M4	450	8.90%	0.3	0.00%	0.00%	1.84%	50%	50%	600	677
M5	450	8.90%	0.28	0.00%	2.24%	0.00%	50%	50%	590	698
M6	450	8.90%	0.31	2.04%	0.00%	0.00%	45%	55%	595	663
M7	475	9.50%	0.33	0.00%	2.12%	0.00%	47%	53%	660	626
M8	475	9.50%	0.33	0.00%	2.12%	0.00%	50%	50%	650	606
M9	475	9.50%	0.35	0.00%	0.00%	2.12%	44%	56%	700	604
M10	475	9.50%	0.31	0.00%	2.12%	0.00%	44%	56%	640	692
M11	475	9.50%	0.26	0.00%	0.00%	2.12%	44%	56%	400	872
M12	475	9.50%	0.27	0.00%	0.00%	2.12%	44%	56%	440	826
M13	475	9.50%	0.25	0.00%	0.00%	2.12%	44%	56%	420	855
M14	475	9.50%	0.27	0.00%	0.00%	2.69%	42%	58%	560	869
M15	475	9.50%	0.27	0.00%	0.00%	2.50%	39%	61%	550	770
M16	475	9.50%	0.28	1.92%	0.00%	0.00%	42%	58%	510	709
M17	475	9.50%	0.28	1.92%	0.00%	0.00%	39%	61%	470	638
M18	475	9.50%	0.3	1.92%	0.00%	0.00%	47%	53%	620	684
M19	475	9.50%	0.3	1.92%	0.00%	0.00%	39%	61%	500	790
M20	475	9.50%	0.3	0.00%	0.00%	1.63%	39%	61%	620	777
M21	475	9.50%	0.3	0.00%	0.00%	1.63%	47%	53%	610	743
M22	475	10.50%	0.33	0.00%	0.00%	1.43%	47%	53%	690	788
M23	475	10.50%	0.34	1.52%	0.00%	0.00%	47%	53%	700	691
M24	475	10.50%	0.35	0.00%	0.00%	1.60%	47%	53%	720	680
M25	475	10.50%	0.3	0.00%	0.00%	1.52%	47%	53%	670	823

Concrete mixes with 47% sand ratio showed good stability and less bleeding, the viscosity of the mix that keeps it stable for a sufficient time, more than two hours. The figures below 1, 2 and 3 show different trail mixes with different sand ratio and illustrate the relation between the water cement ratio and slump flow. Increasing water content increase the slump flow or the filling ability but it must be carefully controlled, more water means more sever segregation and less cohesiveness and less viscosity. In order to achieve optimum performance of SCC we should minimize the maximum aggregate size, because the maximum aggregate size affect the stability of the concrete. Increasing it lead to segregation and less passing ability. In this study a lot of congested reinforcing elements columns and diaphragms was poured and increasing the maximum aggregate size causes blockage. The maximum aggregate size used was 12.5 mm. Reduction of coarse aggregate content enhances the mix stability and make the concrete more cohesive, the most suitable ratio was sand/dolomite (47% / 53%). Using pozzolanic additives enhance the rheological properties of SCC mixes. Silica fume was used in this study with different ratios (content percentage by cement) 8.9%, 9.5% and 10.5%. It increases the hydration products and reduce the porosity of the concrete, fills and closes the pores or adjust the pore structures and adjust the grading of components to achieve an optimum compaction and it could adjust the mix cohesiveness. Silica fume enhance concrete workability, strength and durability.

Lowering w/c can increase the viscosity of the concrete, mixes M2, M11 and M13, but it also has low filling ability and too cohesive mix. For M1 its w/c is 0.32 and have a high slump flow value. Increasing silica fume and decreasing the coarse aggregate content will lead to increasing the sand content, which will improve mix stability, but it also can make the concrete so cohesive and have a high viscosity. But it will be hard to pump this sticky concrete. good mix must be stable and flowable which could be achieved by increasing the silica fume and adjust the superplasticizer content for the same water content, see mixes M10, M4 and M25. For mixes with silica fume content 10.5% it showed good stability and high slump flow values. M23 and M24 showed a high slump flow values but with a slight bleeding halo around the concrete after making slump flow test.

2. Effect of Re-tempering or Slump Retention for chosen mix M25

The main objective of re-tempering test is determining the period throw it the fresh mix have high slump flow or self-compact-ability properties, and determining the required dosage of chemical admixture that could be add to the mix meanwhile transporting concrete in a water course.

6.1 Slump retention (test I)

Concrete sample mixed or made at the concrete batching plant on site, .05 m^3 sample were put in a rotary pan with spiral blades, table 2 shows all recorded readings, the pan was rotating and uncovered for the first thirty minutes. Slump flow test was made after thirty minutes the concrete mix losses its fresh properties in a very short time and it is not accepted for pouring concrete in a water course especially in our case in which an old technique. Reasons led to slump loss are as follow: The pan was exposed and rotating for thirty minutes which made the wind passes through the concrete sample during rotation, area of pan slot to area of the pan (70%), the relative humidity 45%, all these reasons are enough to increase evaporation rate according to [1].

After the first thirty minutes' superplasticizer added (0.1 kg/m^3) which mean the dose of re-tempering 2 kg/m^3, figure 4 shows slump retention. The pan was covered by a plastic sheet and rotated for only one minute directly before making the measurements or tests which were repeated every thirty minutes, the plastic cover was totally wet and the rotation of the pan returned the water on the cover to the concrete mix.

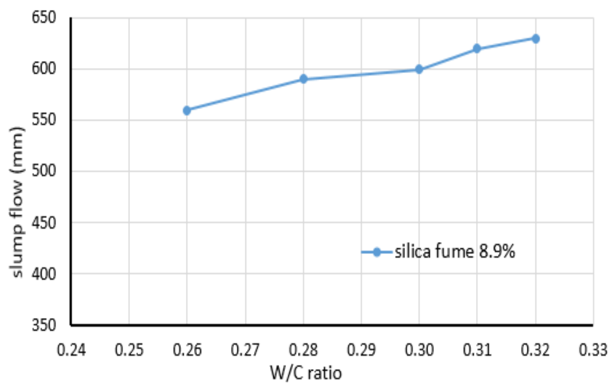

Figure 1 sand / dolomite (50:50) and cement content 450 kg/m^3

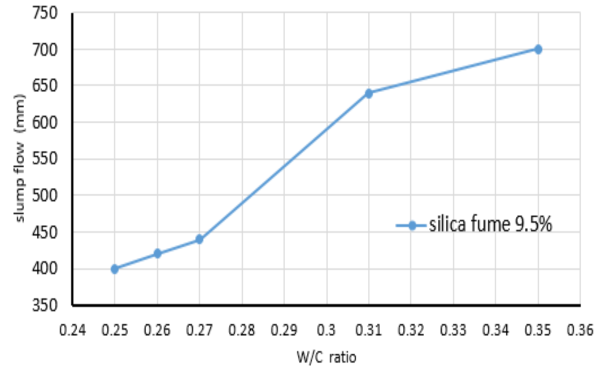

Figure 2 sand / dolomite (44:56) and cement content 475 kg/m^3

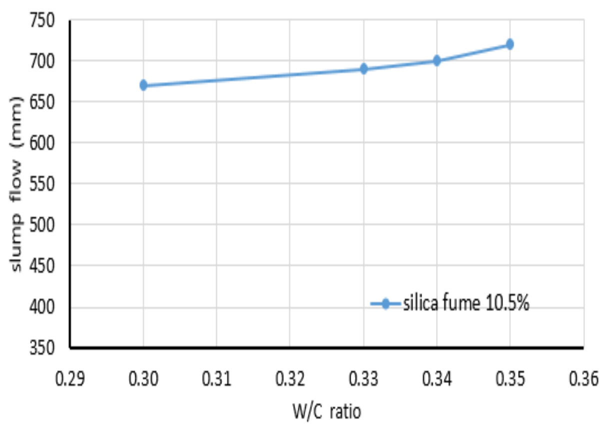

Figure 3 sand / dolomite (47:53) and cement content 475 kg/m^3

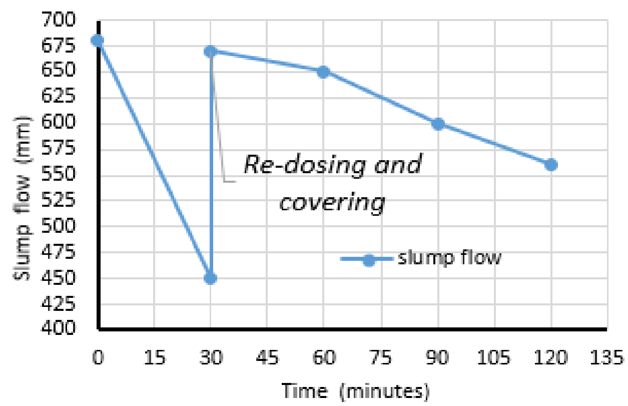

Figure 4 Slump retention for test I

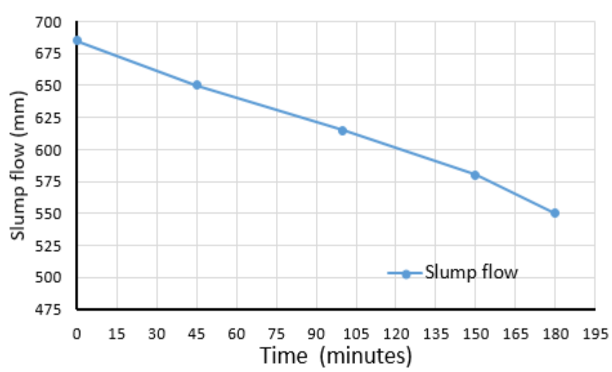

Figure 5 Slump retention for test II

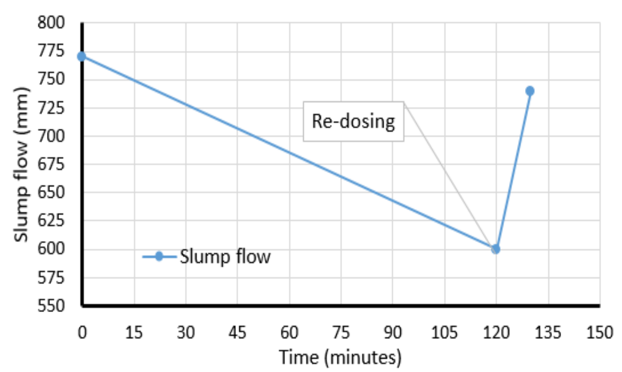

Figure 6 Slump retention for on-site test III

6.2 Slump retention (test II)

In this test sample was taken as same as test I with the same volume, but the pan was covered with a plastic sheet at the beginning of the test and it was rotated for only one minute (to return the condensed water on the plastic cover) directly before making the tests. The measurements made directly after mixing just like test I. This test continued for three hours, table 2 shows all test results.

6.3 Slump retention on-site (test III)

In order to reach job site due to pouring columns it took 1.5 hours to transport concrete to our job site, the same mix M25 was used but with higher dosage of chemical admixture, 8.5 liters of RMC315 were added at batching plant to increase concrete flow-ability to be poured in columns, table 2 shows test measurements, concrete truck capacity is 10 m^3 and was fully loaded. Concrete trip started from batching to the shore of the Nile, then concrete trucks were put on a pontoon and pulled to the job site, at the end of this trip slump flow decreased by 22% and concrete temperature raised by 2°, figure 6 shows slump retention. In order to return fresh concrete to its initial state re-dosing is a must, 1.5 l/m^3 were added to the fresh mix and rotating concrete trunk at its max speed for five minutes to make sure that the chemical admixture have been well mixed.

3. Pumping

In This phase of the study we are concerned about the consequences of pumping on the fresh properties of SCC by means of a full-scale pumping in a construction site in Egypt.

3.1 Testing procedure

Truck-mounted piston pump was used, capable of delivering a maximum pressure of 130 bar or maximum flow rate 120 m^3/h, it has a four arms with total 31.6 m length ended with a rubber hose 4 m length, pipe diameter 125 mm and rubber hose diameter 100 mm.

The working action of the pump is as follows, two cylinders with a volume 0.0873 m3 each alternately pull concrete from the hopper and push concrete inside the pipe line. The flow rate was recorded from the monitor of control panel of the pump. Pumping pressure was represented by a number of steps (the number of steps ranges from one to ten) each pumping step produces a different discharge rate which appears on the pump control panel monitor. Discharge rate ranges from 23 to 120 m^3/h, the discharge rate depends on the number of strokes per minute and cylinder volume. Slump flow, air content and concrete temperature were measured before and after pumping. Concrete molds were prepared to be sampled before and after pumping too to understand and optimize the pumping process, and its effect on the fresh and hardened properties of concrete.

Table 2 Results of slump retention tests

test number	Time / test	Concrete temperature (c°)	Air temperature (c°)	Slump flow (mm)	Air content
test I	Freshly mix	29	28	680	1.60%
	After 30 minutes	30	27.5	450	1.50%
	Re-dosing & Covering	30	27.5	670	1.80%
	After 60 minutes	29.6	25	650	1.76%
	After 90 minutes	28	24.7	600	1.70%
	After 120 minutes	26.9	23.5	560	1.60%
test II	Freshly mix	27	26	685	1.70%
	After 45 minutes	27	25	650	1.60%
	After 100 minutes	26.4	23	615	1.60%
	After 150 minutes	26	21	580	1.55%
	After 180 minutes	25.6	20	550	1.53%
test III	Freshly mix	27	26	770	1.73%
	After 1.5 hours	29	25	600	1.65%
	After re-dosing	28.8	25	740	1.71%

Table 3 Results of Compressive strength testing for re-tempering tests

test number	Sample	@ 28 days (kg/cm^2)	Difference of 28 days result
test I	Freshly mixed	820	–
	After 2 hours	877	6.95%
test II	Freshly mixed	821	–
	After 2.5 hours	829	0.97%
	After 3 hours	840	2.31%
test III	Freshly mixed	814	–
	After 2 hours	833	2.30%

Figure 7 pumping on-site

7.2 Pumping tests and observations

To make concrete flows in a pipeline under pressure –to start pumping- concrete must be applied to a pressure –shear stress- more than its shear stress –yield stress-, flowing of SCC under pressure resulting in changes in concrete rheology [6]. The trip from the concrete batching plant to the job site takes 1.5 hours. Concrete was re-dosed (return concrete to its initial slump flow by adding super- plasticizer by 1.5 l/m3 the same type used in mixing) at the job site, the bulk concrete in the trunk -10 m3 capacity- provoked formation of clusters or coagulations, less shear in the trunk. The pipeline setup was vertical (figure 7). SCC mixture M25 has been pumped at five discharges in ascending order. Pumping started with discharge rate of 25 m3/h -two steps- and then increased to the next step, each discharge was waited for until the pressure become stable at least 120 seconds, then making the measurements and taking samples.

The tests performed at five rates of discharge 2, 4, 6, 8 and 10 steps or strokes represent 25, 64, 80, 108 and 118 m^3/h respectively. At the lowest discharge rate 25 m3/h the slump flow was decreased by 2.9% from the initial slump, and temperature raised by 0.4 c°. the rate continued to increase to the next step 64 m3/h, slump was decreased, and temperature raised too. At discharge rate between 60 to 77 m3/h, there is no loss in slump and temperature increase was minimum, this rate depends on the composition of the mixture, water cement ratio and the past volume in the mix, pipeline diameter and length. So, it will be different for each mixture. Change in air content of concrete was recorded, a small increase with increasing the flow rate. Table 4 shows all recorded measurements during the experiment. At the highest rate applied on concrete in the test (118 m^3/h) the concrete getting out from the rubber hose shaped like a ball then flowed this takes from 3 to 5 seconds until concrete flow inside the steel mish see figure 8.

The rheological properties of liquid materials are a fundamentally described by the relation between shear stress and shear rate [7]. as a function of shear rate when the viscosity is decreasing with shear rate, in this case material called shear thinning, and increasing viscosity with shear rate, called shear thickening [8]. Increasing the velocity distribution in test equipment means increasing discharge rate with the high viscosity of SCC generates a phenomenon called shear thickening. Due to high viscosity it’s hard to create a lubrication layer in a pipeline wall and with high velocity the concrete its self is sheared. The suspension aggregates sheared. The out concrete from the rubber hose had the form of balls.

Figure 8 effect of high discharge rate on SCC

Table 4 Fresh properties of concrete before and after pumping

Flow rate/ test	Slump flow (mm)	Concrete temperature (c°)	Air content
Before pumping	690	31.9	1.70%
23–25 m^3/h	670	32.3	1.75%
63-65 m^3/h	680	32.4	1.79%
78-81 m^3/h	690	32.5	1.80%
107-110m^3/h	670	32.8	1.90%
113-118m^3/h	660	33	1.98%

Table 5 Hardened properties of concrete before and after pumping

Flow rate/ result	Compressive strength kg/cm^2	Difference %	Indirect tensile strength kg/cm^2	Difference %
Before pumping	820	----	60.5	----
23–25 m^3/h	831	+1.34	60.9	+0.66
63-65 m^3/h	840	+2.44	61	+0.83
78-81 m^3/h	838	+2.2	61.5	+1.65
107-110m^3/h	845	+3.05	61.3	+1.32
113-118m^3/h	850	+3.66	62	+2.48

4. Conclusions

Based on the experimental and the analysis of recorded results carried out in this research considering the previous parameters associated with this research program, the following general conclusions can be drawn:

- The maximum aggregate size to be minimized and the coarse aggregate content to be reduced to avoid segregation and blockage and increase stability, in this study the sand / dolomite ratio 47% / 53% was adjusted for M25.
- Pumping at low flow rates then increasing the rates until the optimum pumping flow rate reached. In this study the optimum flow rate was 60 to 77 m^3/hour and it was found that it did not affect the flow-ability of the mixture and can reduce the maintenance cost of the pumping machine due to shear lowering.
- Compressive strength cubes and indirect tensile strength cylinders sampled before and after pumping showed an increase due to pumping, it is thought that more dispersion of cement particles occur during pumping see table 5.
- The change in air content of the mixture due to pumping is not constant and no important changes in air content were observed.
- Shear thickening occur when pumping concrete with high flow rate subject to high shear rate, it is thought that high shear can form small agglomerates of cement particles to create a temporary cluster. It could be avoided by slowing down the flow rate.

References

[1] Khattab et al,2004, HP-SCC. Thesis of master degree.

[2] M. Choi, N. Roussel, Y. Kim, J. Kim, Lubrication layer properties during concrete pumping, Cem Concr Res (2013) 45: 69-78. https://doi.org/10.1016/j.cemconres.2012.11.001

[3] Feys D, Khayat KH, Khatib R (2016) How do concrete rheology, tribology, flow rate and pipe radius influence pumping pressure? Cem Conc Comp 66:38–46

[4] Feys D, De Schutter G, Verhoeven R (2013) Parameters influencing pressure during pumping of self-compacting concrete. Mat Struct 46:533–555

[5] EFNARC Guidelines. (2005). The European Guidelines for Self-Compacting Concrete; Specification, Production and Use. p. 63.

[6] G. Tattersall, P. Banfill, The rheology of fresh concrete, London: Pitman, 1983.

[7] C. Macosko, Rheology Principles, Measurements and Applications, New York, VCH, 1994.

[8] D. Feys, Interaction between Rheological Properties and Pumping of Self-Compacting Concrete, Ghent: Ghent University, 2009.