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Influence of the SCC and the release agents on friction concrete/formwork ó Impact on the aesthetics concrete facing

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Abstract Architects nowadays demand impeccable aesthetic qualities of demoulded rough concretes. New mix designs are increasingly complex, and a concrete mix characterization often limits the workability attributes, in the aim of providing an assessment of concrete behavior at the time of its placement. The aesthetics of concrete facings however also depend on the actual mix design, location and release agents used. This study focuses on analyzing the influence of self-compacting concrete (SCC) and the choice of release agent on the evolution of frictional stresses at the concrete/formwork interface. A follow-up study has been conducted on the aesthetic quality of facings between an SCC and a concrete with additives, including mix designs with both mineral and vegetable oil. An analysis of shading color was also carried out over three periods, namely: 1 day, 2 days, and 7 days.

Keywords: SCC; Formulation; Friction; Aesthetics; Release agents; Interface

Introduction

Concrete has today become the preferred building material and moreover satisfies all demands of contemporary architecture. Concrete properties are determined by the specimen's composition [1], the corresponding characterization is often limited to a workability measurement. Well-controlled workability actually lowers the

risks of faulty workmanship while improving the ultimate quality of the structure. Sand and gravel constitute the skeleton of the mix, with the cement paste (composed of cement, water and sometimes an additive) serving to consolidate all contents. The aesthetics of facings depend on both the concrete mix design and the demoulding oil chosen [2]. For this reason, it is critical to study the interactions between the mix design and the oil, especially in the presence of an additive. Research conducted to date has focused on the interaction between superplasticizer concentration and type of release agent used as regards the evolution in frictional stresses at the concrete/formwork interface. The implementation conditions of the concrete in the formwork will be reproduced with the plane/plane tribometer specially designed for complex media [3]. It simulates the dynamic friction created with the interface formwork/oil/concrete. For this experimental campaign, study parameters were set on the basis of jobsite conditions. Six fresh concrete designs have been studied: one self-compacting concrete, four compositions using additives with two different paste volumes, and lastly a standard concrete without any additives. A vegetable based or mineral-based oil has been selected for this analysis. The aesthetics of the resulting facings have been investigated over three distinct periods: 1 day, 3 days and 7 days.

Equipment and Methods

The boundary layer

At the concrete/formwork interface, a thin layer known as a "boundary layer" is observed; it is composed of fine particles, water and, in some cases, superplasticizer. Depending on the selected input materials, these fines (defined as a grain size less than 80 μm) are basically contained in the cement and limestone filler. The physical characteristics and properties of this layer are indeed unique since its composition differs from the remainder of the mix. Desouza *et al.* [4] demonstrated that the ultimate quality of a facing is directly correlated with both the water/cement (W/C) ratio and fine particle content in the concrete. A rise in W/C ratio triggers an increase in the quantity of water found at the concrete/formwork interface.

During concrete pouring into the formwork, several factors may influence the composition of this layer, namely: the wall effect, the pouring method, and the concrete mix design. Beginning with the volume and until reaching the interface, a concrete can be divided schematically into three zones [4] :

- the concrete with its volume properties;
- a zone where the gravel disappears due to its size, leaving a void for a mix with the composition of a mortar (i.e. maximum grain diameter less than 5 mm);
- a boundary layer composed of cement, water, limestone fillers and, potentially, additives and demoulding oil.

Concretes

For the purpose of studying potential interactions between demoulding oils, additive and concrete during the concrete placement step, six mix designs have been analyzed, i.e.:

- self-compacting concrete (SCC) : 36% paste and 1.64% HRWRA*;
- concretes with additives:
 - C30A1: 30% paste, 0.7% HRWRA ;
 - C30A2 : 30% paste, 1,14 % HRWRA ;
 - C34A1 : 34 % paste, 0,68 % HRWRA ;
 - C34A2 : 34 % paste, 1 % HRWRA ;
- a standard concrete without additives (C30).

* High range water reducing admixture (%Sp/Cement)

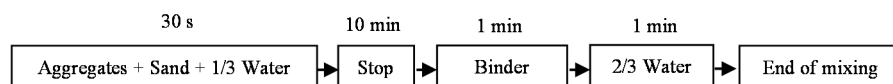
Table I. Mix concretes formulations

| Mixture | SCC | C30 | C30A1 | C30A2 | C34A1 | C34A2 |
|--|------|------|-------|-------|-------|-------|
| Paste volume (%) | 36 | 30 | 30 | 30 | 34 | 34 |
| Cement CEM I 52,5 CP2 (kg/m ³) | 367 | 248 | 269 | 294 | 306 | 333 |
| Limestone filler (kg/m ³) | 92 | 83 | 90 | 98 | 102 | 111 |
| Sand 0/4 (kg/m ³) | 751 | 815 | 815 | 815 | 768 | 768 |
| Coarse aggregate 4/8 (kg/m ³) | 243 | 279 | 279 | 279 | 263 | 263 |
| Coarse aggregate 8/12,5 (kg/m ³) | 658 | 756 | 756 | 756 | 712 | 712 |
| HRWRA *, (%Sp/Cement) | 1,64 | - | 0,7 | 1,14 | 0,68 | 1 |
| Water (l) | 206 | 189 | 179 | 169 | 204 | 191 |
| Water / (Cement+Limestone filler) | 0,49 | 0,57 | 0,5 | 0,43 | 0,5 | 0,43 |
| Slump (mm) | 650 | 130 | 130 | 130 | 150 | 150 |

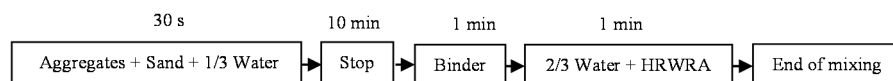
The concentration of superplasticizer was adjusted so as to retain the same workability (class S3) across all studied concretes. To achieve this, the water/binder (W/B) ratio was modified between the first superplasticizer adjustment (A1) and the second one (A2).

The concrete manufacturing process necessitates a well-defined mode of mixing. In terms of this particular study, the NF Standard entitled "Concretes - Analytical, feasibility and control testing - Specimen manufacturing and preservation" and the recommendations listed in the superplasticizer data sheet have been taken into account. The mixing procedure was carried out using dry materials according to these two protocols:

For standard concretes :



For concretes with superplasticizer and SCC :



The 10-minutes rest time corresponds to the time it takes for water to be absorbed by aggregates. This precaution serves to avoid any alteration of the rheological properties of concrete for a few minutes after the end of mixing. The mixer used to produce these concrete specimens was of the DIEM DZ120V type. This equipment is fitted with several blades in order to optimize the mixing step. Batches of 25-liter mixes were generated for each tribological test.

Release agents

The two release oils selected for this research belong to two different families, the first a mineral-based oil (M) the other vegetable based (V), (table II).

Table II. Release agents properties

| Nature of oil | Vegetable based oil (V) | Mineral oil (M) |
|-----------------------------|-------------------------|-----------------|
| Color | Yellow | Yellow |
| Flash point (°C) | > 100 | > 100 |
| Acid number (mg KOH/g) | 5.4 | 1 |
| Hydroxyde number (mg KOH/g) | 1 | 0.85 |
| Density | 0.93 | 0.86 |
| Viscosity (mPa.s) | 66.6 | 24.5 |
| Surface tension (mN/m) | 33.4 | 30.6 |

Oil M is a ready-to-use release agent with a delayed effect, in liquid form and of a pale yellow color. It is composed of a primary mineral base with an added acidifier and anti-corrosion agent (not introduced within the scope of this study). Given the composition of its base, oil M is not highly biodegradable and can thus cause severe groundwater pollution. Moreover, occupational diseases due to skin contact or inhalation of droplets of hydrocarbon-based oils have been recorded by health organizations.

Oil V is another ready-to-use release agent acting with a delayed effect. It is a light yellow color liquid, which contains both an acidifier and a solvent. It is prepared from vegetable materials, with the objectives to get a safer product for the environment and the users' health.

The plane/plane tribometer

The principle [5] behind this measurement device is as follows (figure 1) : an interchangeable plate slides between two concrete samples, with plate movement taking place by means of a motor coupled to an auger. Plate speed is controlled by the accompanying software SMCCWIN. The samples are pressurized by activating jacks, to a pressure of between 50 and 1700 kPa. The sample holders are cylinders fitted with a hatch for introducing the concrete. A tension sensor hooked up to the plate measures the tangential friction stresses. Shell heights ranging from 2 to 4 m have been evaluated; they correspond to pressures in the range of 50 to 100 kPa.

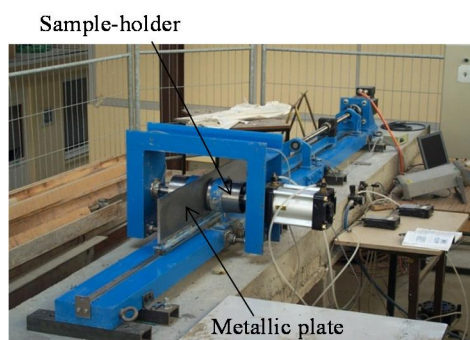


Figure 1. Plane/plane tribometer

Experimental conditions

For our experimental campaign, the test parameters replicate jobsite conditions in order to approximate the stresses being exerted on the oil film by the concrete. The casting speed and pressures at the formwork base constitute this study's key parameters. Tests were conducted on a plate cut out from a formwork wall with roughness values of $R_a = 0.7 \mu\text{m}$ and $R_t = 4 \mu\text{m}$.

Casting speed

The plate displacement speed corresponds to the casting speed of a concrete shell extending a certain height. A speed of 6 m/h was used for our testing campaign, which corresponds to the speed commonly practiced on worksites [6]. These speeds may also be expressed in mm/s:

Contact pressure

The contact pressure of the selected jack corresponds to the concrete pressures exerted at the formwork base for a given height. The vertical formwork elements are subjected, as a result of the fresh concrete, to a thrust perpendicular to the shuttering surface. The factors capable of influencing this pressure exerted on the formwork consist of: specific gravity of the concrete, workability measured using Abrams' cone, height of fresh concrete, minimum formwork dimension, and filling speed.

Results

Mix design characterization

In order to characterize SCC, the figure 2 shows the evolution in frictional stress vs. pressure for the studied mix designs.

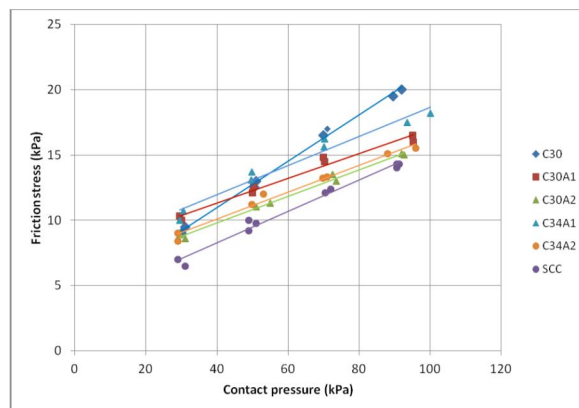


Figure 2. Friction stress as a function of contact pressure - Effet of superplasticizer

The SCC specimen displays the lowest frictional stresses. These results also demonstrate that frictional stress drops with an increase in superplasticizer concentration, regardless of the paste volume. The dispersing power on cement grains grows when a sufficient quantity of superplasticizer is present in the concrete. This phenomenon serves to improve fluidity while raising the concrete strain rate by reducing intergranular friction. At the interface, the boundary layer thus becomes less stiff. The cement grain and filler mobility is smoother and facilitates deformation of the sheared medium, which in turn lowers frictional stresses at the concrete/wall interface. The presence of superplasticizer enhances the level of interface control, independently of the paste volume in the composition. It had in fact already been proven [7] that a high paste volume was capable of increasing frictional stresses in a concrete wall.

Influence of release agents

The figure 3 presents the evolution in frictional stress vs. pressure for the various concrete mix designs, in comparing the two types of oils under study.

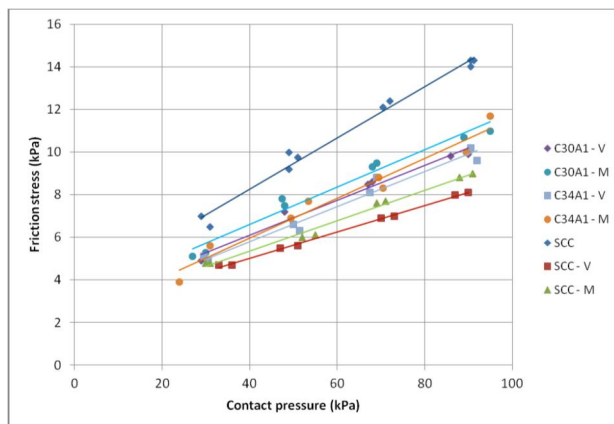


Figure 3. Friction stress as a function of contact pressure - Influence of release agents

The reductions in friction are more significant for the SCC when using the vegetable-based oil. In contrast, the deviation between the two types of oil remains small. Research conducted by Libessart [8] has indeed revealed a more significant impact of vegetable oil on the loss of friction in a concrete specimen with no additives, by comparison with the mineral oil-based mix design. Moreover, in the case of SCC and designs containing additives, the influence of the type of demoulding oil is less straightforward. Results have confirmed that superplasticizer introduced into a fresh concrete specimen induces nearly identical behavior for both oils at the interface. This finding may likely be explained by the lubricating properties of the boundary layer at the concrete/oil/formwork interface [7]. When in contact with concrete (a basic medium), the superplasticizer in carboxylate form tends to promote dispersion of the "soap-oil" micelle in the porous medium (see figure 4).

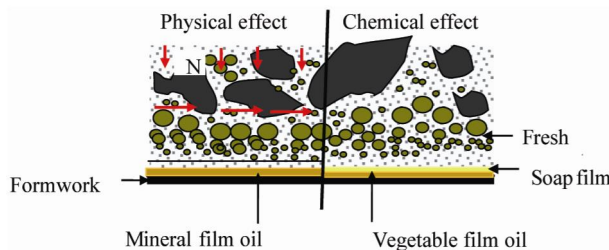


Figure 4. Representation of effects present at the concrete/ oil/formwork interface

In the case of vegetable oil, this dispersion generates an abundant quantity of soap content in the oil film, with this soap then stabilizing the interfacial emulsion and leading to strong lubrication performance.

In the mineral oil case, two phenomena arise:

- weakening of the oil film, which loses its thickness;
- formation of an emulsified buffer medium able to be stabilized by the superplasticizer.

Aesthetics of the facings

The concrete surface and formwork surface will both be analyzed in this section. The results presented are an average of three tests [2]. Concrete was poured into the formwork (30*30*30 cm). The table III lists the rating criteria used, while Table IV provides all relevant abbreviations.

Table III. Grading criteria

| Micro-Bubbling | Shading Color | Facing Aspect | Facing Aspect | Dusting, Dirtying, Attachment points | Degree of importance |
|----------------|---------------|---------------|---------------|--------------------------------------|----------------------|
| 0 / 0,2% | 0 / 10% | Perfect | 9 | None | +3 |
| 0,40% | 20% | Excellent | 8 / 6 | Slight | +2 |
| 0,60% | 30% | Good | 5 / 3 | A little | +1 |
| 0,80% | 40% | Average | 2 / 0 | Normal | 0 |
| 1,00% | 50% | Fair | -1 / -3 | Many | -1 |
| 1,20% | 60% | Poor | -2 / -6 | Important | -2 |
| > 1,20% | > 60% | Very Poor | -7 / -9 | Very important | -3 |

Table IV. Abbreviation used to evaluate the demolding performances

| Abbreviation | Concrete | Abbreviation | Mould |
|--------------|----------------|--------------|-------------------|
| Pa | Facing Aspect | Pom | Dusting |
| B | Micro-Bubbling | E | Dirtying |
| Pop | Dusting | PtAc | Attachment Points |
| S | Shading Color | | |

To quantify the occurrence of a particular shading color, the concrete surface was photographed with a digital camera. The shading color area was then measured by means of image analysis. The color was estimated as the ratio of the concrete aspect area over 30 cm × 30 cm to the total shading color area (i.e. shading color area / total concrete area × 100%).

Table V gives the results obtained for the SCC specimen, as this analysis was also carried out for mix designs C30A1 and C30A2. The three time periods were chosen so as to observe the evolution in facing after formwork removal. The dark spots did in fact disappear a few days after removing the formwork.

Table V. Aesthetics facing for the SCC over the periods: 1 day, 3 days and 7 days

| After 1 day | | | | | | | | |
|-------------|-----------|-----------------|---|-----|----|------------------|---|------|
| Material | Oil | Concrete facing | | | | Formwork surface | | |
| | | Pa | B | Pop | S | Pom | E | PtAc |
| Steel | Mineral | 1 | 1 | 3 | 0 | 3 | 1 | 2 |
| | Vegetable | 2 | 1 | 0 | -1 | 1 | 2 | |

| After 3 day | | | | | | | | |
|-------------|-----------|-----------------|---|-----|---|------------------|---|------|
| Material | Oil | Concrete facing | | | | Formwork surface | | |
| | | Pa | B | Pop | S | Pom | E | PtAc |
| Steel | Mineral | 2 | 1 | 3 | 2 | - | - | - |
| | Vegetable | 2 | 1 | 0 | 1 | - | - | - |

| After 7 day | | | | | | | | |
|-------------|-----------|-----------------|---|-----|---|------------------|---|------|
| Material | Oil | Concrete facing | | | | Formwork surface | | |
| | | Pa | B | Pop | S | Pom | E | PtAc |
| Steel | Mineral | 2 | 1 | 3 | 2 | - | - | - |
| | Vegetable | 3 | 1 | 0 | 2 | - | - | - |

Once the formwork has been removed, the concrete surface exhibits a shading color, which can be traced to two causes:

The first cause would be calcium hydroxide and calcium carbonate. Layers of both these compounds cover the concrete surface and prevent water from entering, resulting in a surface with a wet appearance. Moreover, these layers are flat, hence they do not reflect diffusely and appear to be even darker. The sequence responsible for creating a minute calcium hydroxide film consists of vibration and empty weight. The cement paste then fills the space between mold and fresh concrete, in producing a minute layer of calcium hydroxide, which in turn causes color shading. In addition, the empty weight of fresh concrete squeezes the cement paste; this color shading phenomenon is slow to lighten.

The second cause stems from the superplasticizer, which plays the role of surfactant. If a considerable amount of superplasticizer is used, it promotes mixing with a release agent and cement paste. Consequently, the vegetable oil adheres to the concrete surface, which would result in a dirty appearance. The shading color is

more pronounced in all mix designs. This color will lighten over time; it will gradually become uniform and aesthetics will be improved. For the SCC specimen however, the vegetable oil used is slow to remove the shading color. The formwork adheres easily to dust and attachment points. The black surface of the concrete is not flat. If the cause of shading color is minute layers of calcium hydroxide and calcium carbonate, then the surface would be flat; therefore, the cause of shading color is assumed to be the superplasticizer. The shading color of SCC concrete using mineral oil almost nearly disappears after 3 days, hence the vegetable oil is considered to be influenced by the surfactant.

The formwork used to pour the C30 concrete apparently yields the same result as with the C30A1 specimen. Yet the steel formwork sprayed with vegetable oil adheres to more dust than the formwork used to pour the C30A1 specimen. The formwork for C30A2 and SCC sprayed with vegetable oil does adhere to a large amount of dust. The cause for this adherence is both viscosity and superplasticizer. If viscosity is high, the demoulding agent decreases friction by means of vibration. If a large quantity of superplasticizer is introduced, this would promote mixing with a demoulding agent and cement paste. Consequently, the peeling force would decrease. The concrete surface using vegetable oil is in fact beautiful because the concrete features a gloss, which is not observed in the concrete when mineral oil is applied.

Conclusions

Tribological tests have confirmed that the concrete composition as well as the type of demoulding oils exert a strong impact on friction occurring at the concrete/formwork interface. The vegetable based demoulding oil leads to a reduced concrete friction on the formwork, compared to the results with the mineral oil, regardless of the paste volume. In the case of concretes with additives, the presence of superplasticizer makes the behavior of the two oils more similar. Superplasticizer has the effect of lowering the liquid/liquid or liquid/wall interfacial tension, which as a result promotes exchanges between the oil film and the pore solution. Regarding the aesthetic study, results have demonstrated a better quality of facing for SCC when vegetable oil is applied, despite the significant presence of dust on the facing.

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