ABSTRACT: The objective of this study is to identify the effect of a superplasticizer based on polycarboxylic ether on the tribological behavior of fresh concrete at the interfaces concrete/formwork and concrete/release agent/formwork. Friction tests on fresh concrete were carried out using a tribometer plan/plan. In order to study the behavior of the superplasticizer close to the formwork, three concretes with 30% of paste and different dosage of superplasticizer were formulated. The results show the role of the superplasticizer on the tribological behavior of fresh concrete. The increased of the dosage of superplasticizer reduces the friction stress. The results also show that the friction stress is more decreased in the presence of release agent.

1 INTRODUCTION

Since its origin, the concrete was always made from cement, water and aggregates. It from now on became an indispensable element in the world of construction, architecture and building. These last years, many interesting research have been performed on behavior of fresh concrete and the ease with which it can be introduced in the formwork to optimize the execution costs of projects.

During the casting process of fresh concrete in the formwork, several phenomena can occur at the interface concrete/formwork. Among these phenomena, the friction of the fresh concrete against the formwork wall which intervenes during and after casting, e.g. Proske, T. (2007). This friction at the interface concrete/formwork can be presented as a favorable factor to reduce lateral pressure exerted on the formwork or unfavorably to the quality of facing surface (e.g. Djelal et al (2004), Djelal et al (2008)).

In order to prevent the attachment of the concrete on of the metal surface, a release agent is used in the domain of construction to ensure the separation between the formwork and the hardened concrete. Depending on the nature of the release agent, two distinct phenomena can be present at the interface concrete/formwork. Mineral release agents act physically isolating the concrete to the wall, while for vegetable release agents, a chemical effect and physical effect that can be existing, e.g. Djelal et al (2008).

The tribological behavior of fresh concrete at the interface concrete/formwork depends mainly on the characteristics of the boundary layer near the wall, concrete composition and nature of the release agent. The objective of this paper is to study the influence of the dosage of superplasticizer and the nature of release agents in contact with one ordinary concrete and two concretes with superplasticizer. The characterization of these interfaces concrete/wall and concrete/oil/wall was realized using a tribometer plan/plan specially designed for studying such frictions due to the placement of concrete in formwork (e.g Vanhove et al (2004), Djelal et al (2004)).

The tests performed with the tribometer show how the nature of release agents and the composition of concrete influence the behavior at the interface concrete/formwork and concrete/oil/formwork. Results obtained also showed that the increase of the dosage of superplasticizer reduces the friction at the interface.
2 MATERIALS

2.1 Composition and properties of concretes

In order to study the effect of the dosage of superplasticizer at the interface concrete/formwork, three concretes were formulated with 30% of paste. The two ratios cement/filler (C/F) and aggregate/sand (a/s) were kept constant for the three compositions performed. The water/binder (W/B) depends of the dosage of superplasticizer for these concretes. The composition of the concretes is given in the table 1.

Table 1. Composition and properties of concretes

<table>
<thead>
<tr>
<th>Concretes</th>
<th>C30</th>
<th>C30A1</th>
<th>C30A2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paste volume (%)</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Cement CEM I 52.5 CP2 (kg/m³)</td>
<td>248</td>
<td>269</td>
<td>294</td>
</tr>
<tr>
<td>Limestone filler (kg/m³)</td>
<td>83</td>
<td>90</td>
<td>98</td>
</tr>
<tr>
<td>Sand 0/4 (kg/m³)</td>
<td>815</td>
<td>815</td>
<td>815</td>
</tr>
<tr>
<td>Coarse aggregate 4/8 (kg/m³)</td>
<td>279</td>
<td>279</td>
<td>279</td>
</tr>
<tr>
<td>Coarse aggregate 8/12.5 (kg/m³)</td>
<td>756</td>
<td>756</td>
<td>756</td>
</tr>
<tr>
<td>Water (kg/m³)</td>
<td>0</td>
<td>0.7</td>
<td>1.14</td>
</tr>
<tr>
<td>HRWRA, (%Sp/C)</td>
<td>189</td>
<td>179</td>
<td>169</td>
</tr>
<tr>
<td>Water/ (cement+ Limestone filler)</td>
<td>0.57</td>
<td>0.5</td>
<td>0.43</td>
</tr>
<tr>
<td>Coarse aggregate /Sand</td>
<td>1.27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slump (mm)</td>
<td>120</td>
<td>120</td>
<td>120</td>
</tr>
</tbody>
</table>

The cementitious materials used in all mixtures consisted of a CEM I 52.5 CP2 Type Portland cement with a Blaine fineness of 410 m²/kg and a density of 3100 kg/m³ and a ground granulated blast furnace slag. The coarse aggregate can reach 12.5 mm in diameter. The sand has a maximum size of 4 mm and consisted of a mass fraction of 0.66 % of particles with dimensions smaller than 0.08 mm.

The admixture (GLENIUM 27) used was a commercially available product. It is a high-range water-reducing admixture for concrete with low W/B and with a good workability. This admixture without Chlorine is a new generation of product based on polycarboxylic ether.

2.1.1 Concrete mixing

Each concrete has been produced in a batch of 30 l. The French standard NF P 18-404 is taken into consideration to prepare the concrete. The batch for the ordinary concrete is made from dry materials. The mixing procedure was performed using two protocols:

*For the ordinary concrete*

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```

*For the concretes with superplasticizer*

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[Aggregates + Sand + Binder] ➔ 70% of water ➔ Superplasticizer in 30% of water ➔ End of mixing
```

In the formulation of concrete, it is known that the use of superplasticizer can reduce water content, while keeping slump constant. For these concretes, a slump test is realized after each batch in order to control concrete flowability. If the workability of the concrete with admixture was not sufficient after the first addition of SP, some extra SP has been added and the concrete has been remixed for an extra 90 s. The results show that the ordinary concrete and concrete with superplasticizer are very plastic (Class S3) (table.1).
2.1.2 Rheological properties

The yield stress and the plastic viscosity of each concrete mixture were determined, using a rheometer type ICAR. The concrete mixture was placed in a 360 mm diameter container and filled to a height of 300 mm. The vane, which measured 127 mm in diameter and 127 mm in height, was positioned in the center of the concrete sample, between the vane and the sidewalls and a gap of 127 mm above and below the vane.

The protocol test begins with a pre-shear step, followed by a rest period so that the concrete can be completely restructured. The concrete is then sheared at a velocity of 3.14 rad/s during 20 s to obtain a complete breakdown of the material. Then, a ramped down from 3.14 rad/s to 0.314 rad/s, by steps of 0.0684 rad/s is applied. The flow curves obtained from the ICAR rheometer are shown in Figure 1.

![Flow curves obtained with ICAR rheometer.](image)

The values of the yield stress and plastic viscosity are deduced from these flow curves, as described by the Bingham model, by calculating the intercept of the linear fit for the yield stress and the slope as the plastic viscosity. The rheological properties are summarized in Table 2.

<table>
<thead>
<tr>
<th>Concrete mixtures</th>
<th>C30</th>
<th>C30A1</th>
<th>C30A2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield stress (Pa)</td>
<td>502.3</td>
<td>410.5</td>
<td>202.4</td>
</tr>
<tr>
<td>Plastic viscosity (Pa.s)</td>
<td>25.3</td>
<td>62.4</td>
<td>109.8</td>
</tr>
</tbody>
</table>

The results show that when the dosage of superplasticizer increases, the yield stress decreases, and the plastic viscosity increases.

The cement grains in contact with water have a tendency to agglomerate together to form a structural arrangement (flocs). This phenomenon promotes the trapping of certain amount of water inside the structural arrangement called flocs, e.g. Rixom (1986). When the superplasticizer is incorporated in the concrete mixtures, the cement particles can be dispersed by the steric and electrostatic repulsion, e.g. Bethmont (2008). This phenomenon reduces the intergranular friction freeing the amount of water trapped which improves the fluidity of concrete and yield stress decreases.

2.2 Characteristics of release agents

Currently, the most used releases agent are petrochemical-based products usually called mineral oils. But these products are not biodegradable and can be toxic for users. In this study, two
releases agent marketed were studied. The study was conducted with one formulation of mineral origin and one formulation of vegetable origin. The properties of the oils are given in Table 3.

The mineral composition comprises a mineral base composed of a hydrocarbon blend. The vegetable-based product is formulated with an ester prepared from vegetable oils. A small percentage of acidifier, mainly composed of oleic acid, is added to both formulations.

The acid index corresponds to the number of milligrams of potassium (KOH) required to neutralize a gram of oil. In the current case, the acid index enables the content to be quantified in COOH carboxylic functions. These functions correspond to free fatty acids that is, nonsaponified. More complex plant esters are prepared by esterification with a fatty acid of natural origin.

Table 3. Release agents properties

<table>
<thead>
<tr>
<th>Nature of the oil</th>
<th>Vegetable oil</th>
<th>Mineral oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference Hv</td>
<td>Hm</td>
<td></td>
</tr>
<tr>
<td>Color</td>
<td>yellow</td>
<td>yellow</td>
</tr>
<tr>
<td>Flash point (°C)</td>
<td>&gt; 100</td>
<td>&gt; 100</td>
</tr>
<tr>
<td>Acid number (mg KOH/g)</td>
<td>5.4</td>
<td>1</td>
</tr>
<tr>
<td>Hydroxyde number (mg KOH/g)</td>
<td>1</td>
<td>0.85</td>
</tr>
<tr>
<td>Density</td>
<td>0.93</td>
<td>0.86</td>
</tr>
<tr>
<td>Viscosity (mPa.s)</td>
<td>66.6</td>
<td>24.5</td>
</tr>
</tbody>
</table>

The method of applying the release agent on the wall formwork is very important because it determines the quality of the facing surface. On site, it is often sprayed on the formworks. The same method was applied on metal wall of the tribometer. Before the passage of concrete on the metal wall, the thickness of release agent film is approximately 3.5 to 4 µm.

2.3 Experimental method

To determine the shear stresses of concrete against the formwork, a plan/plan tribometer was used (figure.2) (e.g Vanhove et al (2004), Djelal et al (2004)). The principle of this device was inspired by the shear box used in soil mechanics. It can reproduce the conditions encountered in manufacturing industry of concrete walls or prefabricated elements. In particular, it allows to realize contacts at the interface concrete/release agent/formwork in sliding.

![Figure 2. Tribometer.](image)

Two cylinders with a diameter of 120 mm in which is placed the concrete are disposed on either side of a metal plate. A gasket system is assembled on the sample holder in order to avoid any loss of water. Setting in motion of the plate is carried out using a motor connected to an endless
screw. The maximal displacement of the metal plate is 800 mm. The plate is moved with a constant velocity while the traction force $F_{mes}$ is measured. The concrete is placed under pressure against the plate with a jack.

The friction stress is defined as follow:

$$f = \frac{Measured\ force - Parasitic\ force}{Area\ of\ the\ sample-holder} = \frac{F_{mes} - F_{par}}{S_c}$$  \hspace{1cm} (1)

$F_{par}$ is the resultant parasitic friction forces caused by the gasket system against the metal plate. The contact surface between the concrete and the metal plate is calculated from the diameter of the sample holder. In this case, it is $S_c = 113.1$ cm$^2$.

Experimental conditions are as follows:

- The metal plate was cut out of a wall formwork. Its roughness is $Ra = 0.9$ µm,
- The sliding velocity of the plate is 6 m/h corresponds to the average casting velocity of the concrete,
- The normal pressure: 30, 50, 70 and 90 kPa corresponds to the lateral pressure exerted by the concrete on the formwork of 1.2, 2, 2.8, and 3.6 meters high, respectively,
- Release agent: Mineral and vegetable release agents were used. The application of the oil film is realized with a sprayer equipped by a conic nozzle. After the passage of concrete, the initial film thickness is approximately 8 µm.

The characterization of the tribological behavior of the interface concrete/formwork or concrete/oil/formwork is based on the study of the evolution of the tangential stress with time.

3 RESULTS AND DISCUSSION

3.1 Effect of the dosage of superplasticizer on the friction stress

Figure 3 illustrates the evolution of the friction stress with the contact pressure for the three concrete mixtures without release agent. An increase in friction stress is observed when the contact pressure increases.

![Figure 3. Evolution of the friction stress with the contact pressure for the interface concrete/wall.](image)

The normal stress applied to the material is transmitted to the boundary layer by a chain of force. This phenomenon implies contacts grain-grain, which plays an important role in the stress
distribution at the interface and increased intergranular friction. When the contact pressure increases, the intensity of contact becomes more important between the grains forming the mixture, e.g. Silbert et al. (2002). The medium becomes more rigid at the interface, which requires a more important shear force to create a movement close to the wall. This configuration generates an increase of shear stresses at the interface concrete/formwork.

This figure highlights also the influence of dosage of superplasticizer in concrete at a constant paste volume. The results show that the friction stress decreases when the dosage of superplasticizer increases.

The addition of superplasticizer in concretes deflocculates the cement particles and increases the deformability of medium. At the interface, the boundary layer becomes less rigid. The mobility of cement and filler grains is easier and allows easier deformation of the medium under shear. This action can generate a decrease of shear stresses at the interface concrete/wall.

3.2 Effect of the release agents on the friction stress

The influence of the nature of release agents was studied. A comparison between the interfaces concrete/formwork and concrete/release agent/formwork will be discussed in this section. The figures 4, 5 and 6 show the friction stress as a function of contact pressure for three interfaces concrete/formwork, concrete/Hv/formwork and concrete/Hm/formwork.

![Figure 4. Evolution of the friction stress with the contact pressure for the ordinary concrete C30.](image)

The results show that increasing the friction stress as a function of the contact pressure is less pronounced for the interface concrete/release agent/formwork. The presence of the release agent on the metal plate reduces friction at the interface by the film between the concrete and wall. The agent release limits the penetration of fine particles in the roughness of the plate during the sliding of the fresh concrete. In this case, the mechanical adhesion is minimized by limiting the mechanical assembly concrete/roughness. Moreover, the use of release agents decreases the capillary forces by reducing the capacity of the plate to be wetted by water. This phenomenon can explain the reduction of friction at the interface concrete/release agents/formwork.

In addition, the results of figures 4, 5 and 6, show that vegetable release agent is more effective to reduce friction of concrete against formwork whatever the formulation tested. These results observed for the two release agents studied are similar to those found by Libessart (2006) in his study. The models proposed for the mineral and vegetable release agent can be taken to explain the phenomena observed at the interface.
Figure 5. Evolution of the friction stress with the contact pressure for concrete admixture C30A1.

Figure 6. Evolution of the friction stress with the contact pressure for concrete admixture C30A2.

In presence of the vegetable release agent, two effects can be present at the interface, chemical effect and physical effect. For the mineral release agent, for mineral release agent, only the physical effect can take place during friction, e.g Djelal et al (2008).

A chemical effect has been highlighted due to the saponification reaction between the ester and calcium hydroxide which occurs at the interface concrete/Hv/formwork. This chemical effect is the formation of soap by saponification. The soap formed can naturally organize with vegetable esters at the interface to form a double layer. This configuration is favorable to reduce friction.

The hydrophobic nature of mineral release agent prevents the concrete from adhering to the formwork. The physical effect "barrier" is controlled by the thickness of the film. It can appear in both release agents.

### 3.3 Effect of the dosage of superplasticizer on the behavior of the release agents

The figures 7 and 8 illustrate the evolution of friction stress as a function of contact pressure for two release agents. The results of figures show a combined effect of superplasticizer dosage and the ratio w/b on the behavior of release agent. Whatever the nature of the release agent, the friction stresses decrease when the dosage of superplasticizer increases.

Concretes studied have a constant volume of paste and a W/B which depends on the dosage of superplasticizer. When this W/B decreases, the amount of fines increases of 1.12 to 1.22% for
concretes C30A1 and C30A2 respectively. This phenomenon can increase the thickness of the boundary layer at the interface concrete/formwork.

![Figure 7. Evolution of the friction stress with the contact pressure for vegetable release agent.](image1)

![Figure 8. Evolution of the friction stress with the contact pressure for mineral release agent.](image2)

The fresh concrete unlike to his appearance does not present itself as a continuous medium. The various components of concrete will have specific roles during friction. In the case of concrete with a high W/B, the thickness of the boundary layer is not strong enough to prevent contact of the aggregates on the metal surface. This cause can break the release agent film.

In this configuration(figure 9-a), while moving the plate, the friction between the aggregate and the metal plate acts as a resistance force for the movements increasing friction stresses. This phenomenon can explain the high friction recorded for concretes with low amount of fine.

When the W/B in concrete is low, the thickness of the boundary layer becomes greater (figure 9-b). The contact aggregate/plate is minimized. This phenomenon facilitates the sliding of the concrete on the release agent film and reducing the friction stresses for concrete at low W/B.
3.4 Conclusion

The results reported in this paper illustrate the role of the dosage of superplasticizer and the nature of release agent on the tribological behavior during casting process of the fresh concrete in the formwork.

On one hand, the presence of the superplasticizer in concrete reduces the friction stresses at the interface concrete/wall. Results showed a significant reduction of friction for the C30A2 which has a higher dosage of superplasticizer.

On the other hand, the concrete friction on the formwork is more reduced for vegetable release agent due to the reaction of saponification of ester with calcium hydroxide and through its organized structure soap/release agent interface. This interface has the advantage of the chemical effect (saponification reaction) and the physical effects (film thickness) which greatly reduces the friction stresses. The resistance of release agent film during the concrete displacement is the key parameter to reduce the friction. This parameter mainly depends on the fluidity of concrete and the quantity of fines in the mixture.

References


Figure 9. Schematic representation of the influence of the W/B on the interface concrete/release agent/formwork: a) high ratio (W/B); b) low ratio (W/B).