Influence of the type of release oil on steel formwork corrosion and facing aesthetics

Laurent Libessart, Chafika Djelal, Pascale de Caro

INFLUENCE OF THE TYPE OF RELEASE OIL ON STEEL FORMWORK CORROSION AND FACING AESTHETICS

Laurent Libessart 1, Chafika Djelal 2, Pascale de Caro 3,4

(1) Laboratoire Génie Civil et géo-Environnement (LGCgE) – Lille Nord de France (EA 4515), Hautes Etudes d'Ingénieur, 13 Rue de Toul, F-59046 Lille Cedex, France
(2) Laboratoire Génie Civil et géo-Environnement (LGCgE) – Lille Nord de France (EA 4515), IUT de Béthune, 1230 Rue de l'Université, F-62400 Béthune, France
(3) Université de Toulouse, INP, LCA (Laboratoire de Chimie Agro-Industrielle), ENSIACET, 4 Allée Emile Monso, F-31030 Toulouse, France
(4) INRA, UMR 1010 CAI, F-31030 Toulouse, France

ABSTRACT

The quality of the concrete facings results from the implementation of release agents and the casing surface quality. It is interesting to characterize the behavior of release agents over the lifetime of the formwork. This study is based on the many ones test physicochemical and esthetics realized on two types of surface of formwork like on three types of applications. In complement, the ageing of the casing formwork was characterized by Electrochemical Spectroscopy of Impedance and thanks to the correlation with the aesthetic tests will allow to find from new mechanisms to the interfaces related to the studied oil's formulations.

1. INTRODUCTION

When removing formwork, two distinct elements become clearly apparent, namely the formwork itself which consists of a smooth and stiff material, and a concrete, a water-containing plastic material. From the time of concrete casting, there is an affinity between these two materials, and their interface gives rise to certain physicochemical mechanisms that are still poorly known. Once the concrete has hardened, the two elements can be separated: Such a step is commonly known as formwork removal. In the absence of an anti-adhesive separating layer (release oil), bonding would automatically occur, making its unmolding impossible without altering the facing surface [1]. Consequently, the aesthetics of these facings is directly correlated with the type of concrete/formwork interface.

In order to limit phenomena leading to the corrosion of metal form plates, metal formwork manufacturers (PERI, OUTINORD, SATECO, to name a few) have expressed interest in using new release oil mixes, which are capable of extending the formwork life cycle [2]. For this reason, release agents must be selected on the basis of the type of formwork and its compatibility with formwork skins. Such agents must be applied evenly across the entire formwork, on a clean surface and in thin layers of uniform thickness, before installing reinforcements [3].

It is noted that mineral oils remain very widespread despite their resulting environmental impact. Release agents are actually included in the category of lost lubricants, in particular through leaching into the water table from lubrication zones. Moreover, oil-based release agents cause a number of known nuisances for users, and related professional diseases have been catalogued by the French office of public health insurance (skin irritations by cutaneous exposure and inhalation of volatile organic compounds) [4]. To overcome these disadvantages, oils with vegetable-based formulations [5] and synthetic oils, both presumed to be less harmful to humans and the environment, have been developed.

To promote use of these oils in the concrete industry, the national union trade organization, which represents producers of concrete admixtures and mortars (SYNAD), has adopted a new charter on release oils in 2010 [6] having served to revise the year 2000 classification, so as to provide users with greater clarity, while pursuing the same objective of the enhanced use of vegetable oils.

Despite the entry of these new mix designs into the market, data are still insufficient to fully understand the specificities of their respective product families in terms of performance and use conditions. Therefore, the aim of the present study is to assess the influence of release oils on the quality of facings as well as on corrosion protection during outdoor formwork storage. The methodology adopted entails selecting four oil formulations: a vegetable oil (Oil 1), a synthetic oil (Oil 2), a mineral oil (Oil 3), and a vegetable oil associated with a synthetic oil (ester) (Oil 4).

2. MATERIAL AND METHODS

2.1 The moulds

Eight 30 x 30 x 30 cm^3 moulds were produced by a formwork manufacturer. The volume of the moulds is of 27 litres. The moulds were built with both new and used walls. Two moulds were required per test since the oils are to be applied on mould surfaces according to the following scheme (Fig.1) :

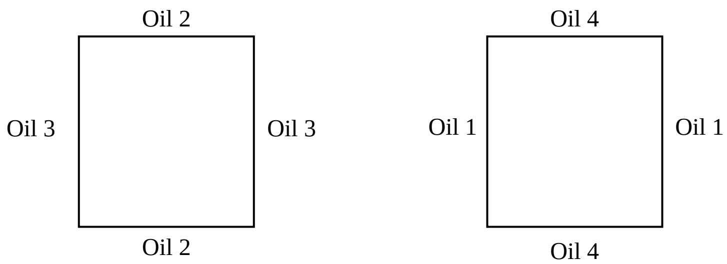


Fig. 1: Application pattern of test oils on the mould walls

The distribution of the moulds used in these tests was carried out as follows:

- Two new moulds (see Fig. 2) for application by spraying with conic and flat nozzles
- Two new moulds for application by spraying followed by scraping
- Two used moulds (see Fig. 3) for application by spraying with conic and flat nozzles
- Two used moulds for application by spraying followed by scraping.

The roughness of a surface is measured by moving a pick-up lift following a direction parallel at average surface to analyze. Measurements are carried out by a roughometer Surtronic 3+. The device precision is ± 0.1 µm.

The roughness values of mould surfaces were Ra = 1.30 µm for the new surface and 1.70 µm for the used surface. Ra is the most widely used international roughness parameter: it is the arithmetic average of profile deviations with respect to an average line.

Fig. 2: New formwork surface

Fig. 3: Used formwork surface

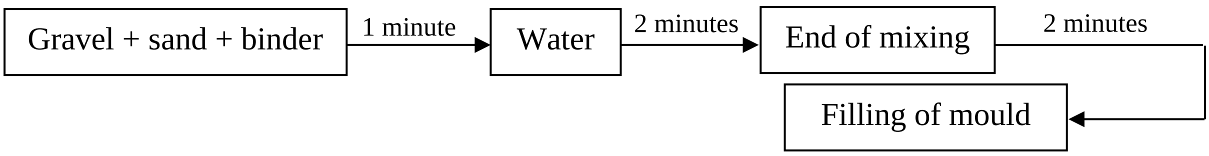
2.2 The concrete

To avoid the kinds of physicochemical reactions not easily interpreted between release oil ingredients and the admixture sometimes present in concrete, a conventional concrete without any admixtures was prepared for our study. Other studies [7, 8] are currently underway using various self-compacting concrete designs in order to examine interactions between chemical compounds in the oils and concrete. For our study, a 10-cm slump has been obtained using the Abrams cone. The composition of the test concrete is gathered in Table 1:

Table 1- Concrete composition

Components	Silex 5/15	Gravel 4/8	Sand 0/4	Cement CEM I 52,5	Fillers	Water	W/B
Quantities (kg/m^3)	761	281	826	258	86	167	0,49

This concrete was produced at a 200 liters capacity mixing plant. Mixing was carried out in accordance with the Standard NF P 18-404, entitled "Concretes: Mix design, suitability and inspection tests - Casting and storage of test specimens", which specifies the following operating procedure:



The tests were conducted in the laboratory at room temperature (about 20°C). The concrete was cast simultaneously in all moulds, with each mould being filled in two layers followed by vibration in 5 places for 10 seconds per layer.

It should be noted that our study has focused on aesthetic flaws encountered in the concrete facing after formwork removal [9]. The two modes of application described above were analysed from this perspective. In addition, colour variations, micro-bubbling, dusting on the concrete facing, dirtying, and dusting and attachment points on the formwork surface constitute the set of parameters selected to evaluate the appearance of facings and the quality of formwork walls.

2.3 Release oils

It is useful to recall that the classification system adopted by the SYNAD trade organisation [6] demonstrates that vegetable oil (Oil 1) display the best characteristics in terms of protecting the environment and human health (Table 2).

Table 2 - SYNAD classification system [6]

Type of oil	Environment	Health	Safety - Fire
Oil 1	4/5	3/5	4/5
Oil 2	3/5	3/5	4/5
Oil 3	1/5	1/5	4/5
Oil 4	3/5	3/5	4/5

Table 3 lists the characteristics of test oils.

Table 3 - Physicochemical characteristics of the test oils

	Oil 1	Oil 2	Oil 3	Oil 4
Nature	Liquid	Liquid	Liquid	Liquid
Composition	Vegetable oil	Synthetic oil	Mineral oil	Vegetable oil associated with a synthetic oil
Colour	Straw-coloured	Colourless	Umber	Colourless
Flash point (°C)	65	62	67	180
Density	0.85	0.82	0.86	0.88

Note that the flash point has been identified, both to assess the product's volatility and to determine the associated safety risks (release of flammable volatile organic compounds).

2.4 Procedure adopted for applying the oils

The procedure to apply the oils on the mould wall is particularly important because it can affect the quality of the surface's facing. It should be noted that, on project sites, it has been observed that an excessive amount of oil often leads to poor facing quality [9]. The release agent has to be applied on to clean surfaces evenly, without missing any spots while avoiding the accumulation of oil build-up. In other words, this procedure should be carried out to establish a continuous and uniform film. During prefabrication, release oil is applied using automated sprayers to provide for better control over the oil deposit, relative to both its quantity and surface area. On worksites, oil is most often sprayed onto formwork or else spread with a rubber scraper after spraying in order to remove any excess oil from the single layer. For this, it is recommended to use stainless steel nozzles to generate a fine mist [10].

For our study, the application step was carried out with a Laser Viton 7 sprayer. Two nozzles have been tested: a conic nozzle 15/10 and a flat nozzle 04/110. Scraping was performed with a rubber scraper after spraying.

2.5 Physicochemical characteristics of the test oils

2.5.1.Viscosity analysis

For this testing campaign, we implemented a cone-plane type HAAKE 401W rheometer, with a cone angle of 1° and consists of a plate and cone of radius R whose axis is perpendicular to the plane of the plate and its apex lies on the plate (Fig. 4). The device precision is ± 0.2 mPa.s and distances are in mm.

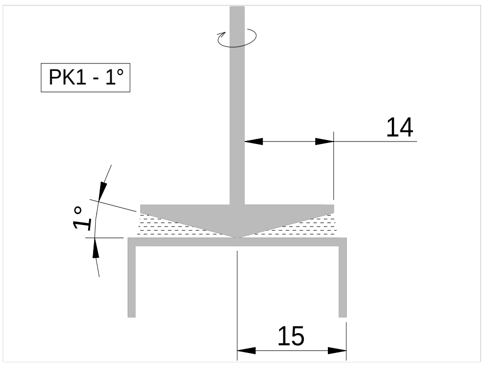


Fig. 4: Close-up of the plane cone

Note that rotational movement is transmitted to the upper part of the measurement geometry via a controlled torque motor. Viscosity values were measured at 0°C, 20°C and 40°C, and results are presented in figure 5.

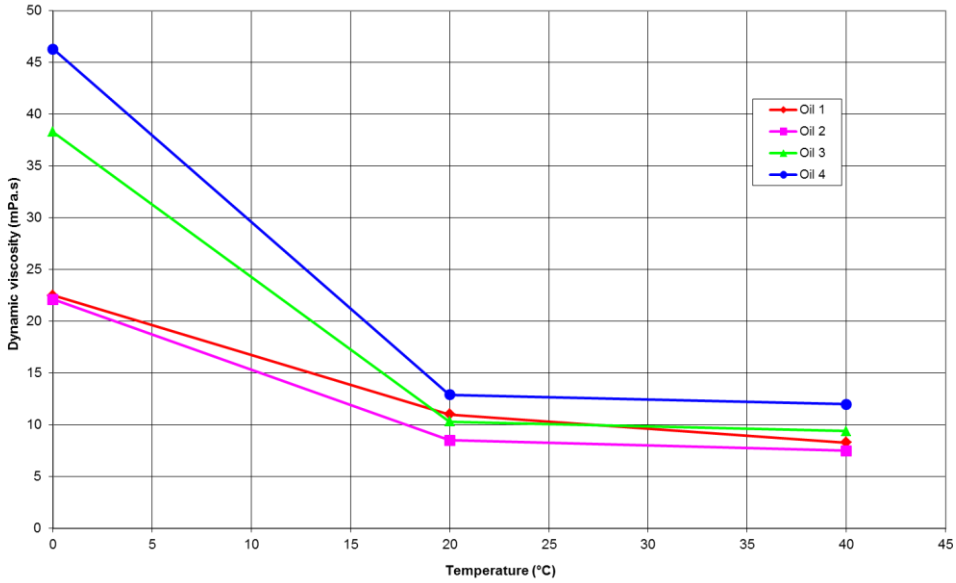


Fig. 5: Variation of dynamic viscosity according to temperature

Figure 5 shows that oils 1 and 2 display rather similar viscosity profiles, with moderate viscosity variations vs. temperature. In contrast, the viscosity of oil 4 increases substantially at 0°C. This behaviour may be ascribed to the ester introduced into the formulation, since it is likely to be a saturated ester (i.e. absence of a double bond on the hydrocarbon chain). Oil 3 exhibits an intermediate behaviour, in accordance with hydrocarbon-based synthetic oils, which are characterised by few intermolecular interactions. Since the vegetable oil remains quite fluid at low temperature, it probably contains a high oleic fraction (a hydrocarbon chain with 18 carbons and one unsaturation), thus yielding an attractive viscosity profile.

2.5.2. Evaluation of wetting power relative to the formwork

It was found that insufficient oil wettability may lead to oil flows on the formwork and thus alter the oil film. The capacity of a liquid to spread over a surface can be estimated by its wettability, which is derived by measuring the angle of contact between the liquid and its support (Fig. 6). In the case of release oil, wetting power influences the evenness of the film deposited. The affinity of this film to the support also depends however on viscosity and adhesion energy [11].

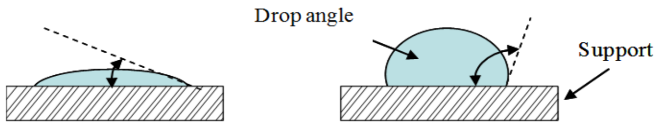


Fig. 6: Determination of the drop angle with respect to its spread

The device used for measuring the wettability is known goniometer which consists of a camera, a light source, a display screen, a plate and a motorised piston. A drop of liquid is deposited onto a sample (5 x 5 cm2) cut from a new formwork wall. The drop formed using a syringe is placed on a support driven in an upward motion. A photograph is taken at the very instant the drop makes contact with the support. Then, the angle of contact between the tangent of the drop and the support surface is automatically measured. Note that the drop must be spherical and adhere perfectly to the support.

Drop angle values are given in Table 4 at 20°C, with a dispersion of ± 0.5°.

Table 4 - Drop angle values

	Angle drops θ	
	New formwork surface	Used formwork surface
Oil 1	26.5	21.4
Oil 2	21.6	22.8
Oil 3	25.1	23.3
Oil 4	24.6	14.5

In the case of a new plate, the synthetic oil yielded the smallest drop angle, whereas the other three oils displayed very similar angle values. Oil offers greater wetting power when acting on new surfaces than on other material compositions. In contrast, for the used plate, the mixed vegetable-synthetic oil produced the smallest angle. Let us also note that a low level of wettability can cause oil to flow on the formwork. The reduction in the contact angle could be explained by a higher roughness for the used formwork surface. It is then easier for oil to get into the grooves of wear.

3. RESULTS

3.1 Correlation between film thickness and oil viscosity

The formwork sample is 5 x 3 cm², oil was deposited by spraying and eventually followed by spreading using a scraper. The oil film thickness was determined by weighing. This method was validated by implementing an analytical technique based on alpha radiation [11]. Results indicated a high level of agreement between these two measurement methods.

Knowing the oil mass density and the plate surface area, the sample thickness can simply be determined through weighing.

$$V = S \times e \;\leftrightarrow\; e = \frac{V}{S} \quad (1)$$

with $V = \frac{m}{\rho}$ (2)

which yields $$e = \frac{m}{\rho \times S} \quad (3)$$

S is the sample surface area (in m^2), ρ is the oil mass density (kg/m^3), V is the oil volume (in m^3), m is the oil film mass (kg), and e is the film thickness (m).

Table 5 presents the results of the thickness measurement at 20°C.

Table. 5 - Film thickness determination according to the weighing method

Type of oil	Film sprayed with a conic nozzle (µm)	Film sprayed with a flat nozzle (µm)	Film sprayed, then scraped (µm)
Oil 1	4.75	4.47	1.02
Oil 2	3.62	2.93	0.77
Oil 3	4.22	3.64	1.01
Oil 4	5.45	5.45	0.64

Measurement uncertainty amounted to +/- 0.15 µm, in assuming a weighing measurement error of 5%. After spraying, we obtained film thickness values lying between 3 and 5.5 µm.

The conic nozzle tended to produce a thicker film than the flat nozzle. Scraped films yielded thicknesses of between 0.6 and 1 µm. The film with oil 2 exhibited the least thickness, while oils 1 and 4 (containing vegetable esters) gave rise to the thickest applications.

3.2 Assessment of the aesthetics of rough facings

3.2.1. Facing grading system

It should be noted that the grading criteria adopted to evaluate facing quality are based on French Standard P18-503 [12] and listed in Table 6.

Table 6 - Grading criteria

Micro-bubbling, dusting, dirtying, attachment point	Degree of importance	Facing aspect
None	1	Excellent
Very Slight	2	Very good
Slight	3	Good
Moderate	4	Average
Important	5	Bad
Very important	6	Insignifiant

3.2.2. Facing appearance

The procedure below explains the sequence between casting, demoulding and the characterization of the surface.

The samples were stored in a laboratory at constant temperature and constant moisture.

The concrete facing is dried two hours after the demoulding. The traces of moisture related to the demoulding have then disappeared.

Table 7 reports the scores obtained when assessing facing appearance vs. type of mould and application system. The dispersion is 0.2 for tables 7 to 14.

Table 7: Influence of test parameters on facing appearance

Four-test averages

	New mould			Used mould		
	Conic nozzle	Spraying and scraping	Flat nozzle	Conic nozzle	Spraying and scraping	Flat nozzle
Oil 1	3.3	3	4.3	3.8	4.8	4.7
Oil 2	5	4.3	4.8	5.5	5.5	6
Oil 3	4.8	4	4.8	5.3	5.3	6
Oil 4	2.3	2	3.3	2.8	4.3	4

Examining this table, it appears that, on average, it is the mixed synthetic vegetable oil that provides the best results, followed by vegetable oil.

It is found that the mineral and synthetic oils reveal significant colour variations on the facing surfaces although they always seem to be less influenced by the type of delivery system used.

The photographs exhibited in Figs. 7 and 8 show the appearance of siding resulting from the application of oil using a conical nozzle.

Fig. 7: Facing obtained with vegetable oil

Fig. 8: Facing obtained with mineral oil

Moreover, the observation of surfaces on facings produced by applying oil with a flat nozzle indicates a lower quality, and this perception remains valid throughout the testing campaign.

3.2.3. Bubbling

Table 8 compares the results derived on bubbling vs. mould type and application system.

Table 8 - Influence of test parameters on bubbling

Four-test averages

	New mould			Used mould		
	Conic nozzle	Spraying and scraping	Flat nozzle	Conic nozzle	Spraying and scraping	Flat nozzle
Oil 1	4.3	3.3	5.3	3.3	3.5	5.3
Oil 2	3.5	3.5	5	4.3	3.3	4.3
Oil 3	3.8	3.8	4.8	4	4.3	5.3
Oil 4	2.8	2.3	3	2.3	2.5	3.7

For both mould types, bubbling is more pronounced with the flat nozzle. We note that spraying through a conic nozzle produces the same bubbling values as spraying combined with scraping. The oil mixture causes a small amount of bubbles, followed by the vegetable oil and synthetic oil in this order. Mineral oil is the worst performer. It should be noted that adding a synthetic ester to oil 4 serves to reduce bubbling.

3.2.4. Dusting

The dusting is observed over the facing or the formwork by the appearance of a film of cement dust. Table 9 shows the results obtained for dusting on the facing with regard to the type of mould and application system.

Table 9 - Influence of test parameters on facing dusting Four-test averages						
	New mould			Used mould		
	Conic nozzle	Spraying and scraping	Flat nozzle	Conic nozzle	Spraying and scraping	Flat nozzle
Oil 1	2	1.3	2	1.5	1.5	1.7
Oil 2	1	1	1	1	1	1
Oil 3	1	1	1	1	1	1
Oil 4	2	1.8	2.5	2.8	1.8	2.3

Relatively speaking, less dust formed on the facing removed from the used mould than from the new mould. Note also that the spray pattern associated with scraping application reduces dust accumulation. For the mineral and synthetic oils, no dust formed. Consequently, the presence of vegetable matter in oils 1 and 4 enhances the tendency to form dust.

3.3 Study of mould surface following formwork removal

3.3.1. Dusting of the mould

Table 10 shows the results recorded for mould dust formation according to both modes of application.

Table 10 - Influence of parameters on mould dust formation Four-test averages						
	New mould			Used mould		
	Conic nozzle	Spraying and scraping	Flat nozzle	Conic nozzle	Spraying and scraping	Flat nozzle
Oil 1	3.8	3.8	5	5.3	4	4.7
Oil 2	1.8	2	3.3	2.8	2.8	3.7
Oil 3	2	2	3.8	2.5	3	3.7
Oil 4	5	5.3	6	5.5	4.8	5.3

When drawing comparisons with Table 9, let us point out that more dust forms on the walls of used moulds (Figs. 9 and 10). Dust formation is more apparent with the flat nozzle. As before, the use of mineral and synthetic oils led to a smaller deposit on the mould surface.

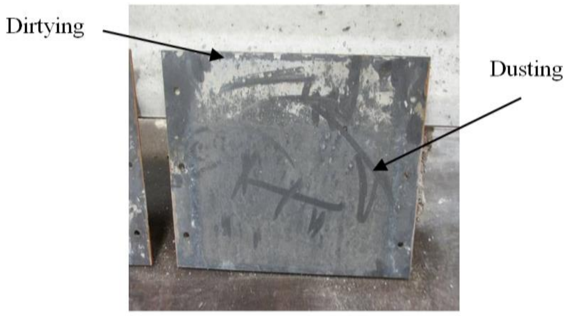


Fig. 9: Formwork obtained with vegetable oil

Fig. 10: Formwork obtained with mineral oil

3.3.2. Dirtying

The dirtying corresponds to dried cement milt.

Table 11 displays the dirtying scores broken down by mould type and application system.

Table 11 - Influence of parameters on mould fouling Four-test averages						
	New mould			Used mould		
	Conic nozzle	Spraying and scraping	Flat nozzle	Conic nozzle	Spraying and scraping	Flat nozzle
Oil 1	2.8	5.3	3	2.5	3.8	3
Oil 2	4	4.8	4.3	2.3	5.3	5
Oil 3	4.5	5.8	4.8	3.5	5.8	6
Oil 4	2.3	4	1.8	1.5	3.8	2.7

On average, used moulds appear to be cleaner. The application on a mould using a flat nozzle associated with a scraping causes fouling of the mould wall, while the application of a conical nozzle gives better results, although traces oil remain persistent. Vegetable oil produced less dirtying, followed by the mixed oil type. The presence of a synthetic agent in the mixed oil composition improves results when excluding the unfavourable case of scraping. In contrast, mineral and synthetic oils tend to heavily dirtying of the mould.

3.3.3. Attachment points

Attachment points are very localized zones of fixing of concrete on the surface of the formwork.

Table 12 reports the scores obtained on attachment points relative to mould type and application system.

Table 12 - Influence of parameters on attachment points Four-test averages						
	New mould			Used mould		
	Conic nozzle	Spraying and scraping	Flat nozzle	Conic nozzle	Spraying and scraping	Flat nozzle
Oil 1	2	1.5	1,5	1	1.3	2
Oil 2	1.5	2.5	3.8	1.3	1.8	3
Oil 3	2.8	2.5	3.5	1.8	2	3.7
Oil 4	1.5	1.8	1	1	1	1.3

Attachment points appear to be less prevalent on the used mould. The attachment phenomenon is attenuated when spraying with a conic nozzle. The Vegetable oil generates fewest attachment points, with mixed oil responsible for the second fewest. Note that surface defects are twice as high when the other two oils are used.

3.3.4. Overall assessment

Tables 13 and 14 present the overall assessment derived on the basis of the 6 above criteria for the four oil formulations on both types of surfaces under study. For table column entries on a specific application, the score corresponds to the aesthetic impacts on concrete facings and the mould. The last column indicates, for each oil tested, a composite score from the average of the six evaluations criteria described in detail above.

Table 13 - Average concrete facing quality score / New formwork surface						
	Concrete facing	Mould facing	Conic nozzle	Spraying and scraping	Flat nozzle	Total note
Oil 1	3.2	3.2	3.0	3.00	3.5	3.2
Oil 2	3.2	3.1	2.8	3.00	3.7	3.2
Oil 3	3.2	3.4	2.9	3.2	3.8	3.3
Oil 4	2.4	3.2	2.6	2.8	2.9	2.8

It can be concluded that Oil 4 offers the highest scores for each criterion evaluated, in significantly outperforming the three other types of oils tested.

Table 14 - Average concrete facing quality score / Used formwork surface

	Concrete facing	Mould facing	Conic nozzle	Spraying and scraping	Flat nozzle	Total note
Oil 1	3.3	3.1	2.9	3.1	3.6	3.2
Oil 2	3.5	3.1	2.8	3.3	3.8	3.3
Oil 3	3.7	3.5	3.0	3.5	4.3	3.6
Oil 4	2.9	3.0	2.6	3.0	3.2	3.0

For formwork removal with a used wall, we observe that Oils 1 and 4 tie for the best score; hence, introducing a used mould does not lead to a serious deterioration in the facing, while a conic nozzle remains the preferable mode of application.

The mixed oil definitely yields the best overall performance in terms of concrete facing and formwork quality. On the whole, oils containing a vegetable base are more highly rated, except for the dust formation criterion on the facing and mould, yet even this one-time lower score does not generate any fouling phenomena. In this case, applying the oil by scraping serves to minimize film thickness and thereby limits dust formation.

3.4. Mould surface corrosion study

Release oils were applied on plates (dimensions: 1 x 0.5 m^2) by conic spraying, followed on some specimens by spreading using a scraper. The plates were subsequently stored outdoors (Fig. 11).

Fig. 11: Formwork surface storage zone

A rating system was established in order to score the level of corrosion expansion [13] on the new formwork plates (Table 15).

Table 15 - Average concrete facing quality score

Corrosion	Magnitude of the studied phenomenon
None	1
Very slight	2
Slight	3
Moderate	4
Significant	5
Very significant	6

The steel plates were exposed to climatic conditions at the beginning of their outdoor storage period, which lasted for one month starting on March 27th 2006. The amount of precipitation falling on the city of Lille during the months of March and April 2006 is shown in Figure 12.

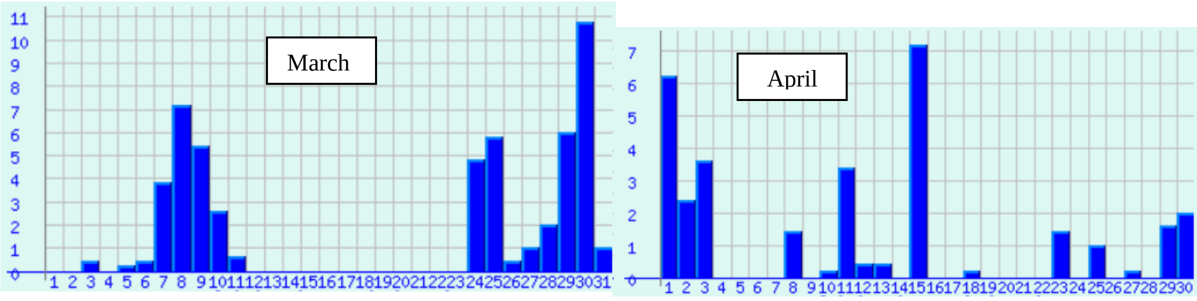


Fig. 12: Precipitation (mm) during March and April 2006 [14]

The following observations could be recorded (Table 16).

Table 16 - Average concrete facing quality score

	Exposure time											
	Day+5		**Day+10**		**Day+15**		**Day+20**		**Day+25**		**Day+30**	
	Spray	**Spray+ scrap**	**Spray**	**Spray+ scrap**	**Spray**	**Spray+ scrap**	**Spray**	**Spray+ scrap**	**Spray**	**Spray+ scrap**	**Spray**	**Spray+ scrap**
Oil 1	1	1	1	1	1	2	1	2	1	2	1	2
Oil 2	1	1	1	1	2	2	2	2	2	3	2	3
Oil 3	2	1	3	2	4	4	5	5	6	6	6	6
Oil 4	1	1	1	2	1	2	1	2	1	3	1	3

Micrographs recorded on March 31st 2006 ***Micrographs recorded on April 18th 2006***

Fig. 13: Micrographs both before and after storage of sprayed oil 3

Fig. 14: Micrographs both before and after storage of sprayed oil 2

Fig. 15: Micrographs both before and after storage of sprayed oil 4

Surface observations reveal that the oils containing a vegetable base better protect the metal surface from corrosion. The synthetic oil has also provided satisfactory results. Moreover, it is preferable to spray oil without scraping it in order to improve protection against corrosion. Mineral oil displays poor anti-corrosion properties. These observations will be cross-referenced with results from spectroscopic measurements of electrochemical impedance, as well as with findings from a study on interface mixes.

4. DISCUSSION

4.1. An evaluation of film protection properties using electrochemical impedance spectroscopy (EIS)

EIS measurements can be conducted not only at the corrosion potential, but also within the anodic or cathodic domain.

The selected steel grade was E24. The 10 x 10 cm^2 plates were supplied by the same formwork manufacturer. The steel was polished to remove calamine. Electrochemical measurements were performed using a conventional three-electrode set-up [11]. The electrolyte was composed of a 0.5 M solution of KOH + 0.1 M of NaOH. This solution featured a pH of 13.2, which replicated the pH of a concrete pore solution.

The working electrode was formed by the steel plate receiving the oil, to be applied with a rubber scraper so as to obtain a film with an approx. 1-µm thickness.

Once the oil was placed, the plate was fastened onto a Plexiglas cylindrical tube (S = 240 cm^2) for holding the electrolyte. The counter electrode was a large-sized platinum plate. Lastly, a saturated calomel electrode has served as the reference electrode (Fig. 16).

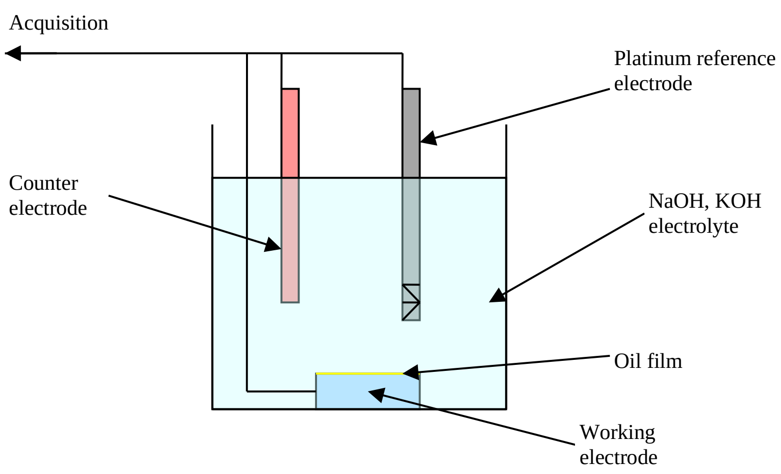


Fig. 16: Diagram of the experimental set-up

A measurement with bare steel yielded the reference curve. Each measurement was performed on a new steel plate and each oil formulation was tested twice to ensure measurement reproducibility. For purposes of comparison, measurements conducted with two of the test oils, a mineral oil (M1) and a vegetable oil (V1) with known impedances [11] were inserted into the graph. The dispersion is ± 500 (Ω.cm²).

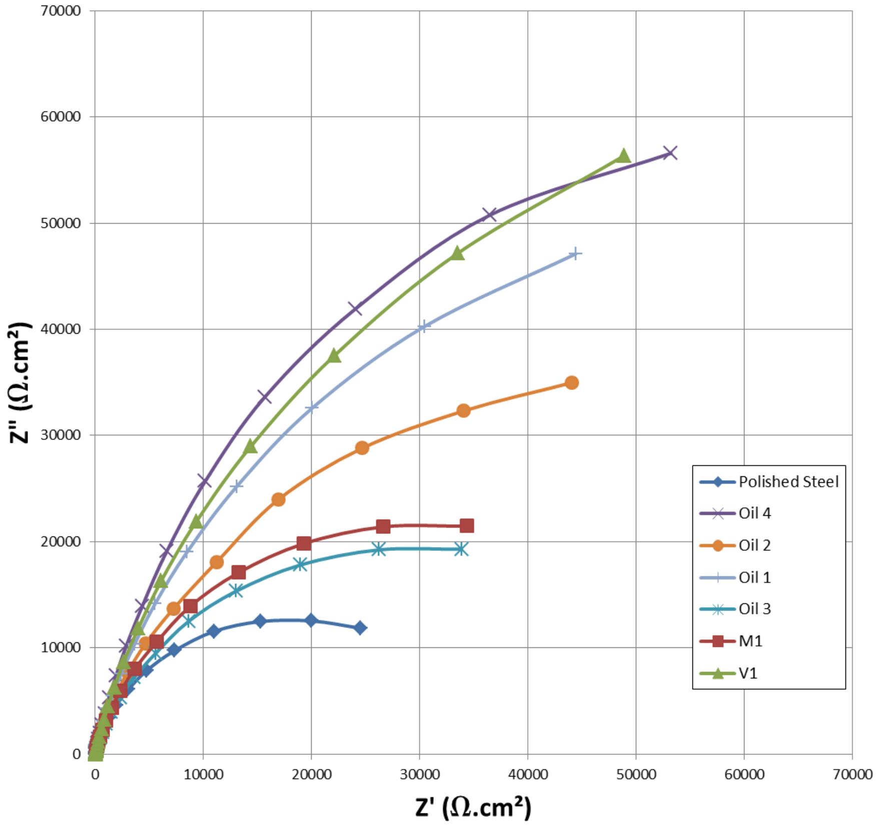


Fig. 17: EIS diagram obtained at the corrosion potential after 1 h of immersion in the electrolyte

Given the layout of these diagrams, the equivalent electrical circuit shown in Fig. 18 was introduced to obtain the characteristic parameters of the metal interface. The slope of the curve logZ = f(logf) is slightly less than 1, which justifies use of a constant phase element (CPE) instead of a capacitance in the equivalent electrical diagram.

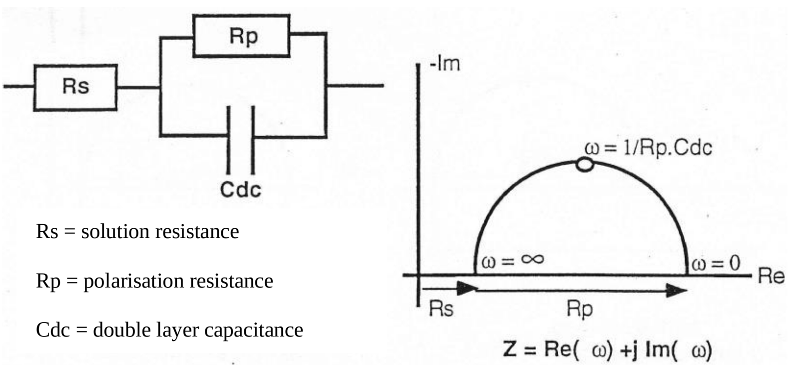


Fig. 18: Example of a choice of simple circuit related to the Nyquist diagram [15]

The CPE impedance is given by:

$$Z_{CPE} = \frac{1}{Q(j\omega)^{\alpha}} \qquad (4)$$

where Q is expressed in $\Omega^{-1}.m^{-2}.s^{\alpha}$.

The film capacitance can then be calculated by applying the following equation:

$$C = Q\,(Re^{-1} + R^{-1})^{(\alpha-1)/\alpha} \qquad (5)$$

C being expressed in Farads.

It is worth noting that parameters of this physical model have been adjusted. The values of parameters R (± 500 $\Omega.cm^2$) and C (± 15 μFcm^{-2}) are gathered in Table 17.

Table 17 - Resistance and capacitance values for each oil formulation

	R ($\Omega.cm^2$)	C (μFcm^{-2})
Polished steel	29300	443
M1	48700	362
V1	134000	269
Oil 1	111600	244
Oil 2	82800	324
Oil 3	45700	317
Oil 4	135000	287

Figure 17 shows similarities in curve trends between the formulations for the two vegetable oils (V1 and Oil 1), as well as for the two mineral oils (M1 and Oil 3). Let us note that the vegetable-based formulations produce higher resistance values than mineral formulations. The synthetic formulation lies at an intermediate value. The following ranking is thus obtained in increasing order of impedance value:

Oil 3 < Oil 2 < Oil 1 < Oil 4

Conversely, capacitance values are lower for the vegetable formulations; such observations reflect the fact that vegetable-based oils demonstrate a protective power greater than what can be ascribed to the chemical characteristic of these oils (triglycerides). The presence of an ester in the mixed formulation (Oil 4) seems to enhance anti-corrosion properties. Finally, vegetable based formulations contribute to limit the corrosion of the formwork, which is likely to degrade the performances of demoulding. The lifetime of the formwork is thus longer and preserves the quality of the concrete facing. It is preferable to protect the formwork surface with a vegetable oil during the storage.

4.2. Study of interface mixes

In this part, the behaviour of the oil formulations placed in contact with a pore solution was studied. Pore solution was prepared from water and cement. A mix combining 100 g of cement with 500 g of water is left stirring for 3 minutes and then filtered to derive a basic aqueous phase loaded with calcium ions. 50 ml of pore solution were added to 10 ml of oil. The mix was then stirred for 15 seconds and left to rest for one hour.

Following this rest phase, interfacial media prepared are described as follows :

- Oil 1: Formation of 3 phases (oil/soap/water) with little soap
- Oil 2: Formation of 2 phases (oil/water)
- Oil 3: Formation of 2 phases (oil/water).
- Oil 4: Formation of 4 phases (oil/soap 1/soap 2/water)

In fact, the basic pH pore solution is likely to initiate a chemical process at the interface.

The different layers obtained in the model media are schematically represented in Figs. 19 - 21.

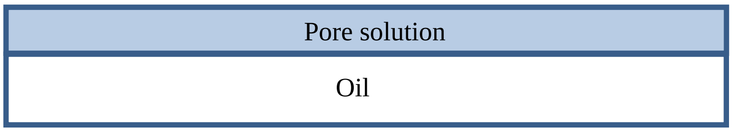


Fig. 19: Schematic configuration of the medium observed for oils 2 and 3

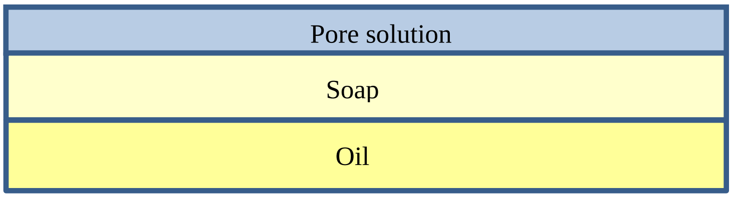


Fig. 20: Schematic configuration of the medium observed for oil 1

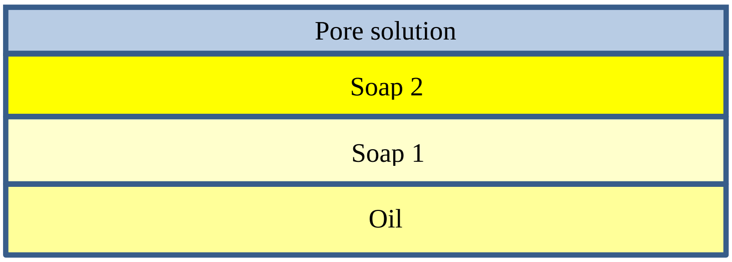


Fig. 21: Schematic configuration of the medium observed for oil 4

We observe that mineral-based formulations generates a small quantity of soap, as only acidifiers present in the composition as additives, are able to convert into soaps.

We check that lubricating properties are not governed by the soap film, but by the hydrophobicity and the thickness of oil film (Fig. 22)

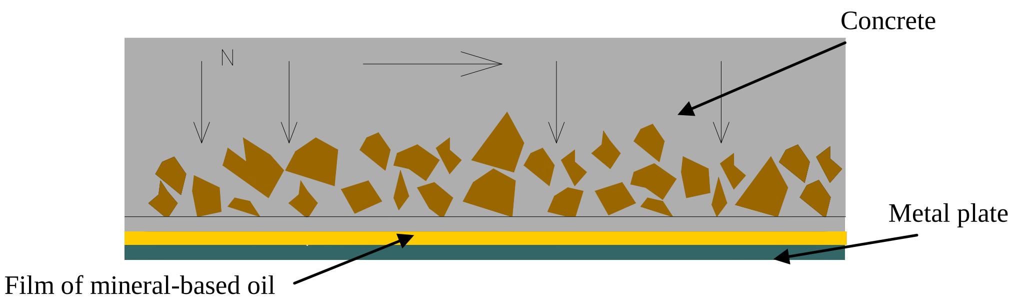


Fig. 22: Diagram depicting the sliding of concrete on the oil film

For vegetable based oils such as oils 1 and 4, carboxylates salt (soap) is mainly issued from the ester film. Due to their amphiphilic nature, oil and soap are chemisorbed at the interface, thus forming a double layer. This molecular organization confers specific lubricating properties [11, 16].

Moreover, oil 4 displays two soap layers; one is generated from the vegetable oil, and the other derived from a synthetic ester of the formulation. This double soap layer is probably stabilized by oleate calcium (salt of oleic acid used as an acidifier).

This interfacial structure may be at the origin of the performances observed about concrete protection and facing aesthetics (Fig. 23).

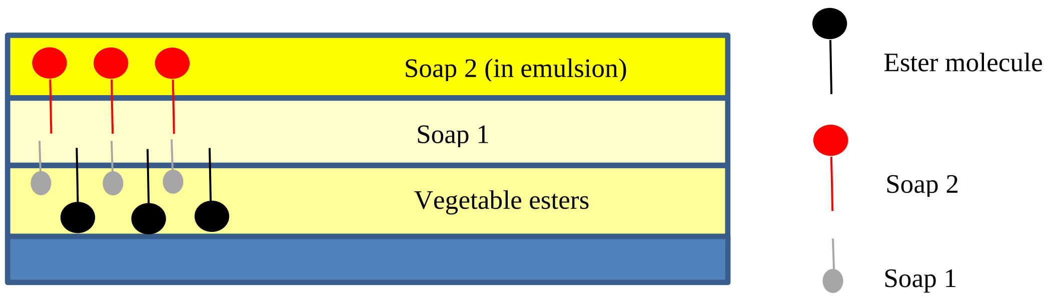


Fig. 23: Organization of the soap/oil interface

4. CONCLUSION

In this paper, the influence of release oils on the quality of facings as well as on corrosion protection during outdoor formwork storage has been assessed. This multi-criteria study was intended to correlate the choice of a release oil and its application conditions with both formwork removal performance and facing quality. Based on our conducted experiments, the main finding has emerged:

Viscosity measurements between 0° and 40°C revealed that oil viscosity profiles diverge substantially below 20°C, which can complicate spraying for the most viscous oils. We verified that film thickness was dependent on the viscosity of the oil being sprayed: the more fluid the oil, the thicker the film. Consequently, thickness varies with temperature.

The observed variations in wetting power with respect to the formwork do not appear to be significant for facing quality, at least under the standardised test conditions. Introduction of a used mould does not adversely affect facing aesthetics, though it does cause dust to form on the mould. Scraping the film may offer an attractive solution, in particular for vegetable-based oils, even if the scraping operation tends to foul the mould further.

According to the various test results, it seems that the vegetable oil and mixed oil produce the best aesthetic outcome (in terms of bubbling, colour and appearance), when accompanied by a conic nozzle application. These good findings may be explained by the concrete/formwork interface construction.

The reconstitution of pore mixes has enabled differentiating the way in which oils act. The media obtained have exposed the formation of a soap layer in the case of vegetable-based oil. Moreover, the interface resulting from the mixed oil exhibits a unique configuration due to the formation of two types of soap. This profile appears to promote the desired properties, with the exception of dust formation on the facings and moulds.

The film thickness for vegetable-based oils stands out as a critical parameter in controlling the dusting phenomenon. Depositing a thin vegetable-based oil film also provides a way to reduce the amounts implemented in order to meet a reasonable cost target per square meter of formwork oil that remains roughly the same as conventional oil.

Furthermore, the interface structure tends to favour protecting formwork surfaces against corrosion, with these properties being evaluated by means of electrochemical impedance spectrometry measurements in the presence of pore mixes.

The obtained results reveal a better resistance with vegetable oil-based films (i.e. Oils 1 and 4). This protective power is enhanced in the presence of the synthetic ester (Oil 4), which shows the efficiency of the double soap layer for concrete hydrophobation. By improving formwork wall protection against inclement weather, it is indeed possible to extend formwork life cycle. It is clear that the performances of formulations associating a vegetable ester with a synthetic ester suggest their application when guaranteeing both the technical performance and eco-compatibility sought when introducing such products.

REFERENCES

[1] Gawrilow I., “Palm oil usage in lubrification” 3rd Global Oils and Fats Business Forum, “Interfacing with the Global Oils and Fats Business” USA October 8, 2003

[2] Raynaud C., « Coffrage métallique; développement d'une stratégie éco-durable », France BTP, juin 2010

[3] OUTINORD, « Parements de qualité des parois en béton », Collection technique syndicat français de l’échafaudage, du coffrage et de l’étaiement, avril 2005.

[4] Aide-mémoire juridique TJ19, « Les maladies professionnelles – Tableau n°36 », INRS, 2012.

[5] Projet SUMOVERA, « Application of Vegetable-Oil based Concrete Mould Release Agents », State of the Art Document, 1999.

[6] Syndicat national des adjuvants pour bétons et mortiers (SYNAD), « Classification Synad des agents de démoulage », 2010.

[7] Bouharoun S., Vanhove Y., Djelal C., De Caro P., Dubois I., “Interactions between Superplasticizer and Release Agents at the Concrete/Formwork Interface”, Materials Sciences and Applications, Vol 3, pp 384-389, 2012.

[8] Feys D.,Verhoeven R. and De Schutter G., « Influence of demoulding oil on the rheological properties of fresh self-compacting concrete and its consequences during casting », Concrete Plant International, pp48-57, 2009.

[9] Lemaire G., Escadeillas G., Ringot E., ”Evaluating concrete surfaces using an image analysis process”, Construction and Building Materials, Vol. 19, pp604-611, 2005.

[10] Baty G., Reynolds R., « Release agents – How they work », Concrete International, p 52-54, 1997.

[11] Djelal C., De Caro P., Libessart L., Dubois I. and Pebere N., “Comprehension of demoulding mechanims at the formwork.oil/concrete interface”, Materials and Structure, Vol. 41, pp571-581, 2008.

[12] AFNOR P18-503, « Surface et parements de béton – Eléments d’identification », nov. 1989.

[13] Ochoa de Echevarrieta N., « Propriété inhibitrices d'un mélange d'amines grasses et de sels d'acide phosphonocarboxyliques vis-à-vis de la corrosion d'un acier de carbone-Influence des conditions hydrodynamiques sur le mécanisme d'inhibition », Thèse de doctorat de l'Université Paul Sabatier de Toulouse, 2004.

[14] http://www.meteociel.fr/climatologie

[15] Keddam M., « Principes et application des techniques électrochimiques en corrosion » - CNRS – pp1-14 - 1991.

[16] Bouharoun S., De Caro P., Dubois I., Djelal C., Vanhove Y., "Effect of a superplasticizer on the properties of the concrete/oil/formwork interface", Construction and Building Materials, Vol. 47, pp1137-1144, 2013.