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

Laurent Libessart, Chafika Djelal, Pascale de Caro

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1                   **INFLUENCE OF THE TYPE OF RELEASE OIL ON STEEL**  
2                   **FORMWORK CORROSION AND FACING AESTHETICS**  
3

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

5           (1) Laboratoire Génie Civil et géo-Environnement (LGCgE) – Lille Nord de France (EA 4515),  
6           Hautes Etudes d’Ingénieur, 13 Rue de Toul, F-59046 Lille Cedex, France

7           (2) Laboratoire Génie Civil et géo-Environnement (LGCgE) – Lille Nord de France (EA 4515), IUT  
8           de Béthune, 1230 Rue de l’Université, F-62400 Béthune, France

9           (3) Université de Toulouse, INP, LCA (Laboratoire de Chimie Agro-Industrielle), ENSIACET, 4  
10           Allée Emile Monso, F-31030 Toulouse, France

11           (4) INRA, UMR 1010 CAI, F-31030 Toulouse, France  
12

13   **ABSTRACT**

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

21   **1. INTRODUCTION**

22           When removing formwork, two distinct elements become clearly apparent, namely the  
23           formwork itself which consists of a smooth and stiff material, and a concrete, a water-  
24           containing plastic material. From the time of concrete casting, there is an affinity between  
25           these two materials, and their interface gives rise to certain physicochemical mechanisms that  
26           are still poorly known. Once the concrete has hardened, the two elements can be separated:  
27           Such a step is commonly known as formwork removal. In the absence of an anti-adhesive  
28           separating layer (release oil), bonding would automatically occur, making its unmolding

29 impossible without altering the facing surface [1]. Consequently, the aesthetics of these  
30 facings is directly correlated with the type of concrete/formwork interface.

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

38

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

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

52

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

60

## 61 2. MATERIAL AND METHODS

### 62 2.1 The moulds

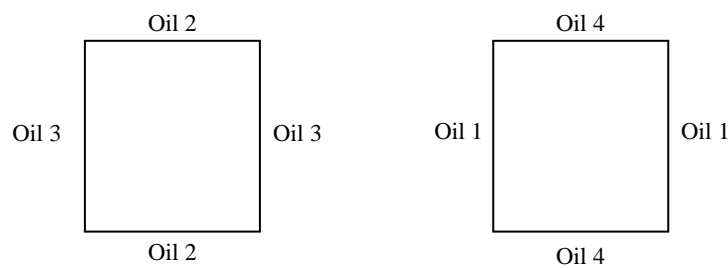
63 Eight 30 x 30 x 30 cm<sup>3</sup> moulds were produced by a formwork manufacturer. The volume of  
64 the moulds is of 27 litres. The moulds were built with both new and used walls. Two moulds  
65 were required per test since the oils are to be applied on mould surfaces according to the  
66 following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

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

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

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- 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.

78 The roughness of a surface is measured by moving a pick-up lift following a direction  
79 parallel at average surface to analyze. Measurements are carried out by a roughometer  
80 Surtronic 3+. The device precision is  $\pm 0.1 \mu\text{m}$ .

81 The roughness values of mould surfaces were  $R_a = 1.30 \mu\text{m}$  for the new surface and  $1.70$   
82  $\mu\text{m}$  for the used surface.  $R_a$  is the most widely used international roughness parameter: it is  
83 the arithmetic average of profile deviations with respect to an average line.

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86  
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89  
90 *Fig. 2: New formwork surface*



*Fig. 3: Used formwork surface*

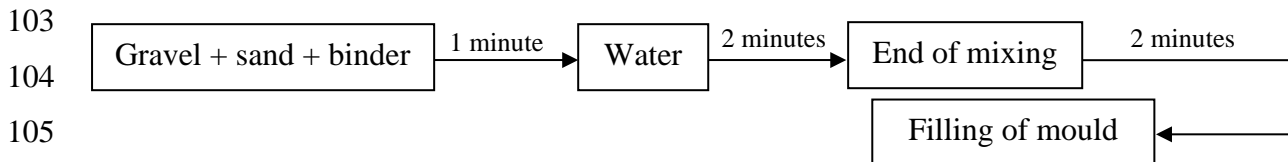
## 91 **2.2 The concrete**

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

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

98

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



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

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

### 115 **2.3 Release oils**

116 It is useful to recall that the classification system adopted by the SYNAD trade organisation  
117 [6] demonstrates that vegetable oil (Oil 1) display the best characteristics in terms of  
118 protecting the environment and human health (Table 2).

119

120

121

122

123

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

124

125 Table 3 lists the characteristics of test oils.

Table 3 - Physicochemical characteristics of the test oils				
	Oil 1	Oil 2	Oil 3	Oil 4
<b>Nature</b>	Liquid	Liquid	Liquid	Liquid
<b>Composition</b>	Vegetable oil	Synthetic oil	Mineral oil	Vegetable oil associated with a synthetic oil
<b>Colour</b>	Straw-coloured	Colourless	Umber	Colourless
<b>Flash point (°C)</b>	65	62	67	180
<b>Density</b>	0.85	0.82	0.86	0.88

126

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

## 129 2.4 Procedure adopted for applying the oils

130 The procedure to apply the oils on the mould wall is particularly important because it can  
 131 affect the quality of the surface's facing. It should be noted that, on project sites, it has been  
 132 observed that an excessive amount of oil often leads to poor facing quality [9]. The release  
 133 agent has to be applied on to clean surfaces evenly, without missing any spots while avoiding  
 134 the accumulation of oil build-up. In other words, this procedure should be carried out to  
 135 establish a continuous and uniform film. During prefabrication, release oil is applied using

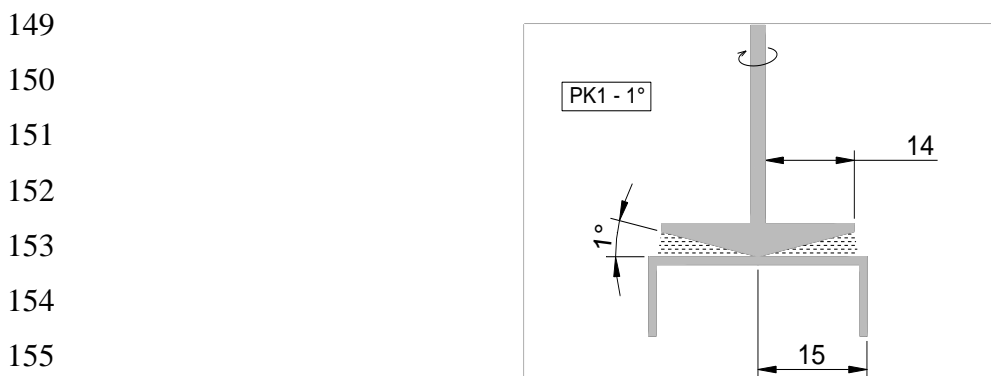
136 automated sprayers to provide for better control over the oil deposit, relative to both its  
137 quantity and surface area. On worksites, oil is most often sprayed onto formwork or else  
138 spread with a rubber scraper after spraying in order to remove any excess oil from the single  
139 layer. For this, it is recommended to use stainless steel nozzles to generate a fine mist [10].

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

## 143 2.5 Physicochemical characteristics of the test oils

### 144 2.5.1. Viscosity analysis

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



156 *Fig. 4: Close-up of the plane cone*

157

158 Note that rotational movement is transmitted to the upper part of the measurement  
159 geometry via a controlled torque motor. Viscosity values were measured at  $0^\circ\text{C}$ ,  $20^\circ\text{C}$  and  
160  $40^\circ\text{C}$ , and results are presented in figure 5.



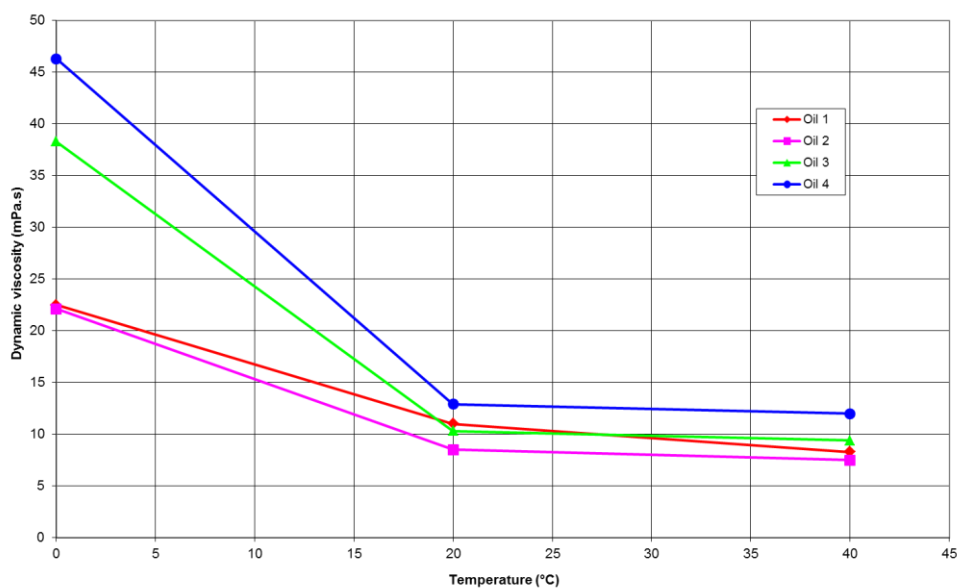


Fig. 5: Variation of dynamic viscosity according to temperature

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 163  
 164 Figure 5 shows that oils 1 and 2 display rather similar viscosity profiles, with moderate  
 165 viscosity variations vs. temperature. In contrast, the viscosity of oil 4 increases substantially at  
 166 0°C. This behaviour may be ascribed to the ester introduced into the formulation, since it is  
 167 likely to be a saturated ester (i.e. absence of a double bond on the hydrocarbon chain). Oil 3  
 168 exhibits an intermediate behaviour, in accordance with hydrocarbon-based synthetic oils,  
 169 which are characterised by few intermolecular interactions. Since the vegetable oil remains  
 170 quite fluid at low temperature, it probably contains a high oleic fraction (a hydrocarbon chain  
 171 with 18 carbons and one unsaturation), thus yielding an attractive viscosity profile.

### 2.5.2. Evaluation of wetting power relative to the formwork

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

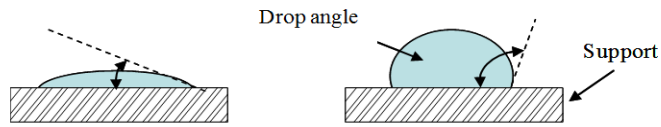


Fig. 6: Determination of the drop angle with respect to its spread

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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 cm<sup>2</sup>) 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  $\pm 0.5^\circ$ .

Table 4 - Drop angle values		
	Angle drops $\theta$	
	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

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197

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.

198 **3. RESULTS**

199 3.1 Correlation between film thickness and oil viscosity

200 The formwork sample is 5 x 3 cm<sup>2</sup>, oil was deposited by spraying and eventually followed  
 201 by spreading using a scraper. The oil film thickness was determined by weighing. This  
 202 method was validated by implementing an analytical technique based on alpha radiation [11].  
 203 Results indicated a high level of agreement between these two measurement methods.

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

206 
$$V = S \times e \leftrightarrow e = \frac{V}{S} \tag{1}$$

207 with 
$$V = \frac{m}{\rho} \tag{2}$$

208 which yields 
$$e = \frac{m}{\rho \times S} \tag{3}$$

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

211 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

212  
 213 Measurement uncertainty amounted to +/- 0.15 µm, in assuming a weighing measurement  
 214 error of 5%. After spraying, we obtained film thickness values lying between 3 and 5.5 µm.

215 The conic nozzle tended to produce a thicker film than the flat nozzle. Scraped films yielded  
 216 thicknesses of between 0.6 and 1  $\mu\text{m}$ . The film with oil 2 exhibited the least thickness, while  
 217 oils 1 and 4 (containing vegetable esters) gave rise to the thickest applications.

218 **3.2 Assessment of the aesthetics of rough facings**

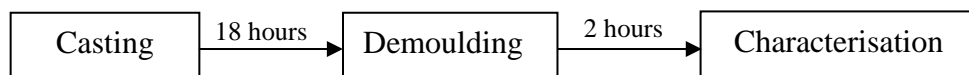
219 **3.2.1. Facing grading system**

220 It should be noted that the grading criteria adopted to evaluate facing quality are based on  
 221 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

222 **3.2.2. Facing appearance**

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



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

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

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

Table 7: Influence of test parameters on facing appearance						
<i>Four-test averages</i>						
	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

232

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

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

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



240

241 *Fig. 7: Facing obtained with vegetable oil*

*Fig. 8: Facing obtained with mineral oil*

242

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

246 **3.2.3. Bubbling**

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

Table 8 - Influence of test parameters on bubbling						
<i>Four-test averages</i>						
	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

248

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

254 **3.2.4. Dusting**

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

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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

264

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

### 269 3.3 Study of mould surface following formwork removal

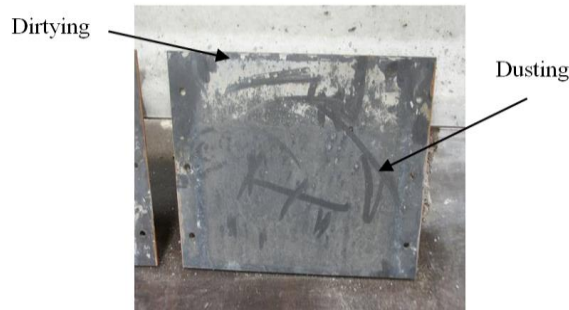
#### 270 3.3.1. Dusting of the mould

271 Table 10 shows the results recorded for mould dust formation according to both modes of  
 272 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

273

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



277

278

*Fig. 9: Formwork obtained with vegetable oil*

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*Fig. 10: Formwork obtained with mineral oil*

### 289 **3.3.2. Dirtying**

290 The dirtying corresponds to dried cement milt.

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

292

293

294

295

296



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

297

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

304

### 305 3.3.3. Attachment points

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

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

310

311

312

313

314

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

315

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

### 320 3.3.4. Overall assessment

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

326

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

327 It can be concluded that Oil 4 offers the highest scores for each criterion evaluated, in  
 328 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

329  
 330 For formwork removal with a used wall, we observe that Oils 1 and 4 tie for the best score;  
 331 hence, introducing a used mould does not lead to a serious deterioration in the facing, while a  
 332 conic nozzle remains the preferable mode of application.

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

338 **3.4. Mould surface corrosion study**

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



Fig. 11: Formwork surface storage zone

342

343

344 A rating system was established in order to score the level of corrosion expansion [13] on

345 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

346

347 The steel plates were exposed to climatic conditions at the beginning of their outdoor

348 storage period, which lasted for one month starting on March 27th 2006. The amount of

349 precipitation falling on the city of Lille during the months of March and April 2006 is shown

350 in Figure 12.

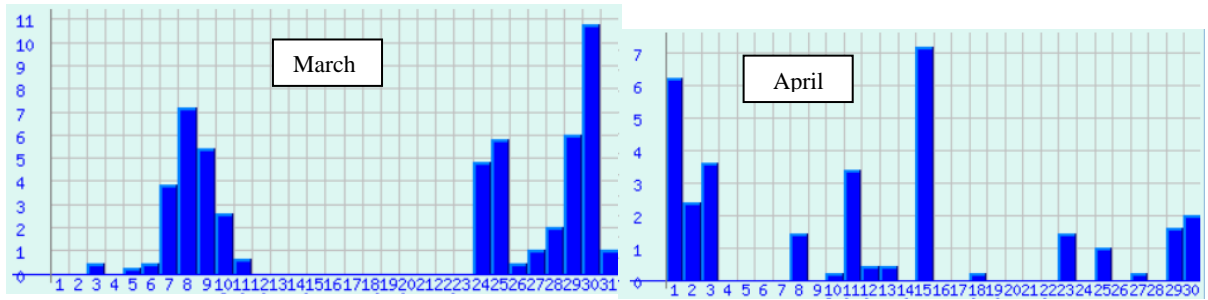


Fig. 12: Precipitation (mm) during March and April 2006 [14]

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 31<sup>st</sup> 2006



Micrographs recorded on April 18<sup>th</sup> 2006



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



362  
363  
364

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



365  
366  
367

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

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

374

375 **4. DISCUSSION**

376 **4.1. An evaluation of film protection properties using electrochemical impedance**  
377 **spectroscopy (EIS)**

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

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

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

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

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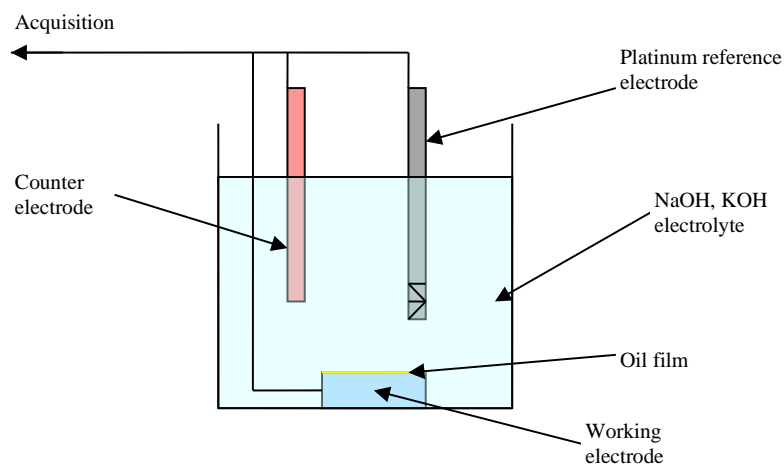
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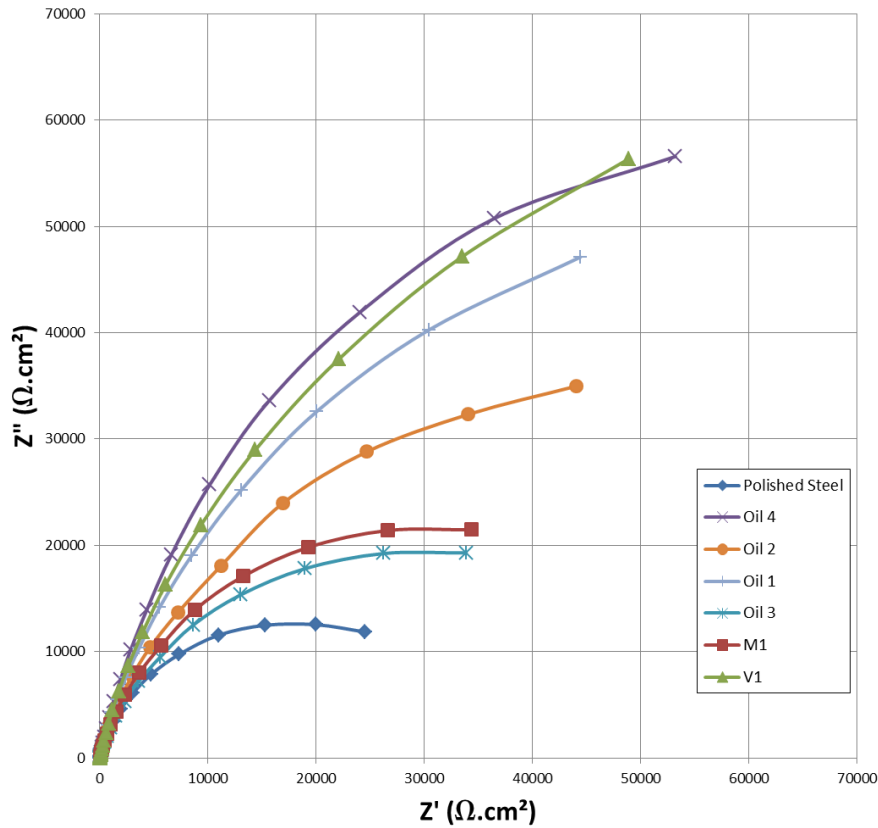
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*Fig. 16: Diagram of the experimental set-up*

403 A measurement with bare steel yielded the reference curve. Each measurement was  
 404 performed on a new steel plate and each oil formulation was tested twice to ensure  
 405 measurement reproducibility. For purposes of comparison, measurements conducted with two  
 406 of the test oils, a mineral oil (M1) and a vegetable oil (V1) with known impedances [11] were  
 407 inserted into the graph. The dispersion is  $\pm 500$  ( $\Omega \cdot \text{cm}^2$ ).



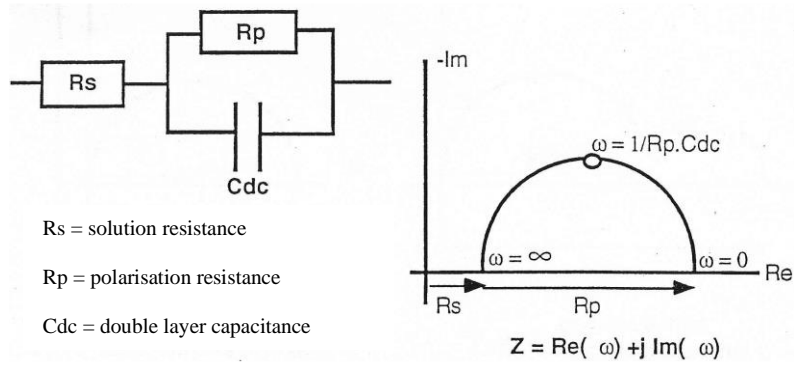
408  
 409 *Fig. 17: EIS diagram obtained at the corrosion potential after 1 h of immersion in the*  
 410 *electrolyte*  
 411

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

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

428 The CPE impedance is given by:

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

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

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

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

433 C being expressed in Farads.

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

436

Table 17 - Resistance and capacitance values for each oil formulation		
	R ( $\Omega \cdot \text{cm}^2$ )	C ( $\mu\text{Fcm}^{-2}$ )
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

437

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

443 Oil 3 < Oil 2 < Oil 1 < Oil 4

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

## 452 **4.2. Study of interface mixes**

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

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

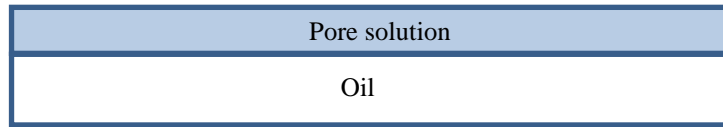
- 459 ➤ Oil 1: Formation of 3 phases (oil/soap/water) with little soap
- 460 ➤ Oil 2: Formation of 2 phases (oil/water)
- 461 ➤ Oil 3: Formation of 2 phases (oil/water).
- 462 ➤ Oil 4: Formation of 4 phases (oil/soap 1/soap 2/water)

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

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

465 21.

466



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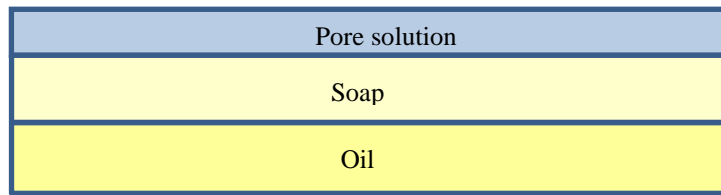
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*Fig. 19: Schematic configuration of the medium observed for oils 2 and 3*

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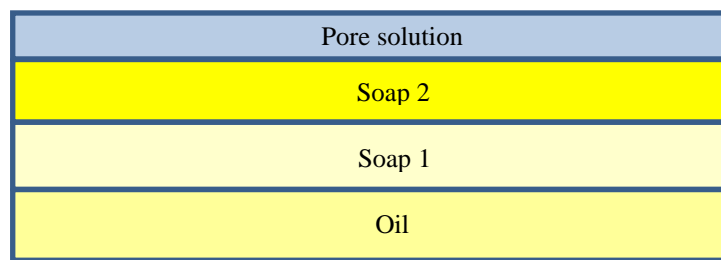
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*Fig. 20: Schematic configuration of the medium observed for oil 1*

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

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485

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.

486

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

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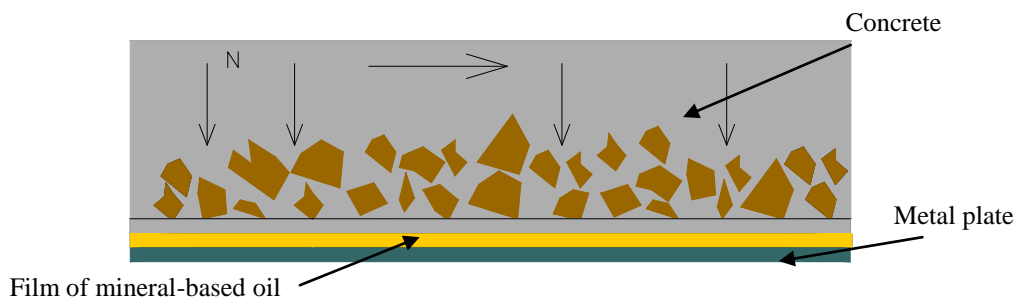
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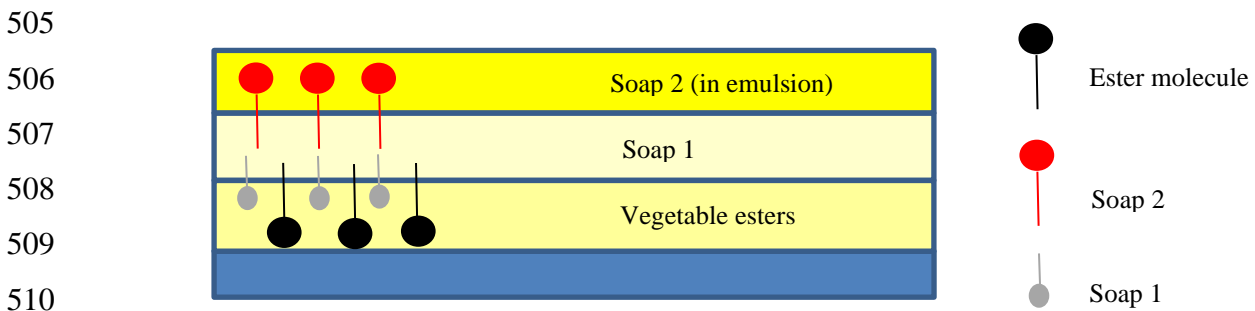


*Fig. 22: Diagram depicting the sliding of concrete on the oil film*

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

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

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



511 *Fig. 23: Organization of the soap/oil interface*

512

#### 513 4. CONCLUSION

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

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

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

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

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

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

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

544 The obtained results reveal a better resistance with vegetable oil-based films (i.e. Oils 1 and  
545 4). This protective power is enhanced in the presence of the synthetic ester (Oil 4), which  
546 shows the efficiency of the double soap layer for concrete hydrophobation. By improving  
547 formwork wall protection against inclement weather, it is indeed possible to extend formwork

548 life cycle. It is clear that the performances of formulations associating a vegetable ester with a  
549 synthetic ester suggest their application when guaranteeing both the technical performance  
550 and eco-compatibility sought when introducing such products.

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