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Effect of Formwork Surface Texture Features on Surface Morphology, Roughness Parameters, and the Demolding Force of Cementitious Materials

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Abstract

Concrete is the commonly used building material. It has to be poured into the formwork to take the appropriate shape of a structural element. Therefore, the used formwork affects the surface parameters and final properties of cementitious materials. This paper aims to study the effect of formwork surface texture parameters and release agents on the surface of cementitious materials. Including a reference formwork (F17-Ref), mineral oil (F17-MO), vegetable oil (F17-VO), polyethylene terephthalate coated (PET), and polymeric coated (C20C27) formworks were prepared. For this purpose, pre-crack demolding tests on cement paste samples and pull-off demolding tests on concrete samples were conducted to analyze the adhesion between cement paste/concrete and formwork. The results highlight that the specimens with polymeric-coated plates had the lowest surface roughness values, but all of the coated formworks had almost similar surface energy. In addition, the experimental tests confirmed that samples subjected to PET and F17-VO formworks presented lower adhesive force. As a comparison vegetable oil showed better demolding behavior compared to mineral oil. On the other hand, the visual aspect reveals that the cementitious surfaces subjected to polymeric- coated formworks are shiny and smooth compared to the opaque surface of oil-coated formworks. Finally, based on the outcomes, the PET-coated formwork could be recommended as an alternative solution to release agentss.

Keywords: Adhesion • Concrete • Formwork • Demolding force • Surface microstructure • Release Agents

Introduction

Concrete is the most used material in the construction industry due to its lower cost and ability to cast in different sizes and shapes. The purpose of construction work in the future is to reduce hazardous working conditions, improve safety and efficiency, and limit harm to the environment. Here, the formwork assembly still remains a significant challenge due to the handling and transportation of heavy equipment, necessitating more time and human recourses to clean and oil them with a thinner layer of release agent [1]. In addition, the used mineral release agents in the construction sector have numerous environmental and individual impacts. For instance, such materials in close contact with people might cause skin cancer due to the toxicity of petroleum fractions, and respiratory system deficiency by the oil mist in the workplace [2-4]. A release agent, on the other hand, must be used to allow easy separation of the hardened concrete from the formwork and to reduce the adhesion forces at the concrete/formwork interface [5-7]. Moreover, the adhesion between the concrete and formwork interface is a combination of different factors such as mechanical interlocking related to surface morphology, capillary forces, physical forces, and chemical reactions [8-10]. Furthermore, there are certain parameters that define the adhesion between concrete and formworks such as surface roughness, type and materials of formwork, curing condition, friction, and the compaction method of concrete. These parameters have a direct impact on the surface roughness, surface porosity, hydration quality, and surface durability of cementitious materials. Thus, the surface and final physical and mechanical properties of cementitious structural elements are influenced by the demolding or adhesion force [10-12].

In this context, numerous research studies are performed to analyze the effect of surface texture of formwork, release agent, and other parameters on the demolding force between concrete and formwork. For instance, research work was conducted to investigate the adhesion between oil release agents and formwork. The authors considered three different types of formworks: new,used, and polished, with various surface roughness, in order to investigate the effect of formwork's roughness on adhesion force. Moreover, two types of release agents: mineral oil and vegetable ones were used. The roughness parameters and surface energy were measured. The outcomes indicate a direct correlation between the adhesion energy of various release agents and the final surface esthetics. In addition, the release agents with minimal adhesion energy value ensure good surface quality and the higher demolding force was the consequence of a rougher formwork surface. As a comparison, the vegetable oil had appropriate interfacial properties for demolding. While mineral oil did not demonstrate appropriate adhesion energy because of the lower contribution from their surface tension [1,10].

Moreover, an experimental study was conducted to explore the relation between formwork surface roughness and the demolding force. The objective was to investigate how the adhesion between concrete and formworks is affected by various morphological and thermodynamic surface properties of formwork. Here formworks with 3 different surface textures were considered: a) steel formwork with and without a demolding agent, b) polished stainless-steel formwork, and c) polymeric coated surfaces. Overall, the surface texture and surface energy were analyzed by interferometry and contact angle measurement, respectively. The outcomes from interferometry analysis showed that the surface area in contact with the cement is reduced for the polished surfaces and this value decreases with the increase of polishing. The adhesion force improved for the formworks with a less rough surface due to the reduced physical interlocking. Here, it was proven that the adhesion force decreased with the usage of release agent. In addition, the demolding

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force decreased with the reduction of surface texture. This reduction was more significant for the formworks having mineral oils and mirror-like formworks compared to others [13].

In the same manner, specific tests were carried-out to evaluate the replacement of vegetable- based release agents with conventional mineral oils. The variable parameters were hydration process, adhesion force, concrete facing, and surface porosity. The findings point-out that the vegetable-based release agent equals or even surpasses the mineral oil in terms of adhesion performance [14]. Similarly, an experimental study was carried out to explore the impact of release agents and concrete composition on the final surface quality with the help of imaging analysis and mechanical tests. The results demonstrate that the type of release agent (ethyl- alcohol and biodegradable-oil-based) did not have a significant effect on the concrete final appearance [15]. Moreover, numerous experimental research works were conducted to verify the effect of various release agents and formwork roughness on adhesion force, surface energy, and final facing of cementitious material [16-22].

Many studies have been conducted to investigate the effect of various parameters on surface texture and adhesion force between cementitious materials and formworks. Since the majority of conducted works considered affecting parameters and studied properties individually. For an optimum analysis of adhesion between cementitious materials and formworks, the simultaneous effects of the key factors are needed. Therefore, this study considered combinations of the key variables parameters, particularly, to compare the polymeric-coated surface with the oil-coated surface of formworks in terms of demolding force and the final aesthetic of the concrete surface. In addition, the effects of formworks' roughness parameters on cement surfaces were evaluated through Scanning Electron Microscopy (SEM) and interferometer microscopy (IM). Besides, the surface energy of used formworks was determined using contact angle measurements to establish a link between surface energy and demolding force.

Materials and Methods

Cement

In the present study, CEM II Portland cement conforming to NF EN 197-1/A1 [23] was used. The composition of CEM II is 65% clinker, 31% blast furnace slag, and 2% secondary component. Moreover, the detailed chemical composition of such cement is presented in Table 1.

Aggregates

Three fractions of aggregates were used for the preparation of concrete mixtures as per EN 933-1:2012 [24] standard requirements. Fine aggregates (sand) had the size of (0-4) mm, and coarse aggregates containing two types; a) fine coarse aggregates (4-8) mm and b) coarse aggregates (8-16) mm. The sieve analysis and distribution curves of aggregates are shown in Figure 1. The size distributions clearly present that the curves are uniform and no gaps were seen for the aggregates.

Formworks

Stainless steel plates having a rectangular shape with a dimension of 160 × 94 × 5 mm^3 and provided by Hussor Company were used. Whereas, the steel quality is in accordance with the NF EN 10088-2 standard [25] and its chemical composition is summarized in Table 2.

Moreover, including a reference plate, five different types of plates with varied surface properties were used as shown in Figure 1. The characteristics of used formworks are described as follows:

Reference formwork (F17-Ref): The reference formwork surface is made of 17% chromium ferritic stainless steel, therefore it is named F17-Ref.

F17-MO & F17-VO: The mineral or vegetable-based release agents with the defined characteristics were sprayed on the F17-Ref plates. The oil application was performed with the help of a soft hair paintbrush to cover the plate surface completely. The oil layer thickness was taken into account according to the recommendations of the producers.

PET: Here a coating of 190 µm polyethylene terephthalate commercial material was applied to the F17-Ref plates. Besides, under the PET, a very thin layer (t≈100 µm) of glue ensures the sticking of the PET to the F17-Ref plates.

C20C27: Polymeric coating layer developed by a partner of the project, Laboratoire de Photochimie et d'Ingenierie Macromoleculaires (LPIM) Laboratory was used. This coating consists of two layers:

Table 1. Chemical compositions of CEM II (%) [23]

PAF	INS	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_20	Na2O	S^-	Cl^-	CO_2	Free CaO	active Eq Na_2O
1.2	0.5	23.9	6.1	2.4	54.8	5.6	3	0.9	0.31	0.28	0.07	0.9	1.5	0.74
Potential composition of clinker:						C3A: 7				C3S: 63			C4AF:10	

Table 2. Formwork plate's characterization.

Elements	C	Si	Mn	Cr
%	0.05	0.35	0.4	16.5

a) b) c)

Figure 1. Formworks: a) F17-Ref, b) PET and c) C20C27.

1) C20 a commercial resin polymer solution was used in the bottom layer due to its adhesion properties to metal and

2) C27, the top acrylate resin layer was selected because of its moisture resistance. In addition, this layer acts as a demolding agent to ensure the aesthetics and durability of the concrete surface. Here, the photo-polymerization process is used to place layers on the formwork plates. The total thickness of such coating is 100 – 200 μm [26-28].

The nomenclatures of formwork plates, cement, and concrete samples are presented in Table 3.

Release agents: Two types of release agents were used: 1) mineral oil and 2) vegetable oil. The characteristics of used release agents provided by the producers are summarized in Table 4.

Experimental Methods

Pre-crack demolding test

The cement paste was prepared according to NF EN 196-3 standard considerations [29]. All the samples were prepared considering a w/c ratio of 0.4. The cylindrical PVC molds with a diameter of ø =2.54 cm were filled with 8 ml of cement paste as shown in Figure 2. Then, a mechanical test named the pre-crack demolding test is performed on the cement paste using a 3R BED-100 multi-purpose testing table with a displacement speed of 0.1 mm/s and max force of 500 N. In addition, for the observation of the fracture in the desired direction and to minimize the capillary force to the lowest value, the scotch tape was stuck to the plate under the edge of PVC molds (d=6 mm) Figure 2.

Pull-off demolding test

To explore bond properties between concrete and formwork, the pull-off demolding test was carried out on 10 cm cubical concrete specimens using SHIMADZU multi-purpose traction machine. The concrete ingredients were mixed as per NF P18-404 [30,31] code considerations. In order to maintain the consistency class of S4, a new generation of water reducer agent known as SikaCem superplasticizer confirmed by EN 934-2 [32-25] was used in the mixtures. Moreover, the w/c ratio was considered constant = 0.4 for all studied mix designs. The concrete mixtures were poured into the molds but before casting, two rectangular plates that represent formworks were placed inside the molds in opposite directions. Besides, two polystyrene layers were put in to prevent concrete from sticking to the edges of plates. Here, the contact area between steel plates and concrete was (94 × 90) mm^2. Samples were immediately moved to the curing room and cured inside molds for 24 hours at a temperature of 20 ± 2°C and humidity of RH >90%. Finally, the samples were demolded after 24 hours of curing. The mixture proportion of concrete is presented in Table 5.

The test setup was arranged where a constant lateral force (Flateral) of 2.0 kN was generated with the application of a U clamp to the back of the formwork plates to create the fracture mode II condition [36] and maintain a homogeneous pull-off demolding procedure Figure 3. Thereafter, the samples were fixed in a traction machine with the help of nuts and bolts at four corners. The plates were mounted to the traction arm and were subjected to a traction force at the rate of 0.5 mm/min up to fracture occurrence.

Table 3. Nomenclature of the used formwork, cement, and concrete samples.

Formwork Type	Name	Casted Samples	
		Cement paste	Concrete
Reference	F17-Ref	Cem-Ref	Con-Ref
Mineral oil coated	F17-MO	Cem-MO	Con-MO
Vegetable oil coated	F17-VO	Cem-VO	Con-VO
PET coated	PET	Cem-PET	Con-PET
C20C27 polymer coated	C20C27	Cem-C20C27	Con-C20C27

Table 4. Properties of release agents.

Release Agent	Commercial Name	Viscosity	Biodegradability	Usage
Mineral oil	SIKA® DECOFFRE MINERAL [27]	§ ≈ 23 mPa.s à + 20°C § ≈ 49 mPa.s à + 5°C	15-35 %	1 L/40 m^2
Vegetable oil	Vegetable oil, 357 LANKODEM VEG, [28]	29 ± 3 mm^2/S (20°C)	62 % at 28 days NF EN 9408-OCDE 301 F	1 L/60 m^2

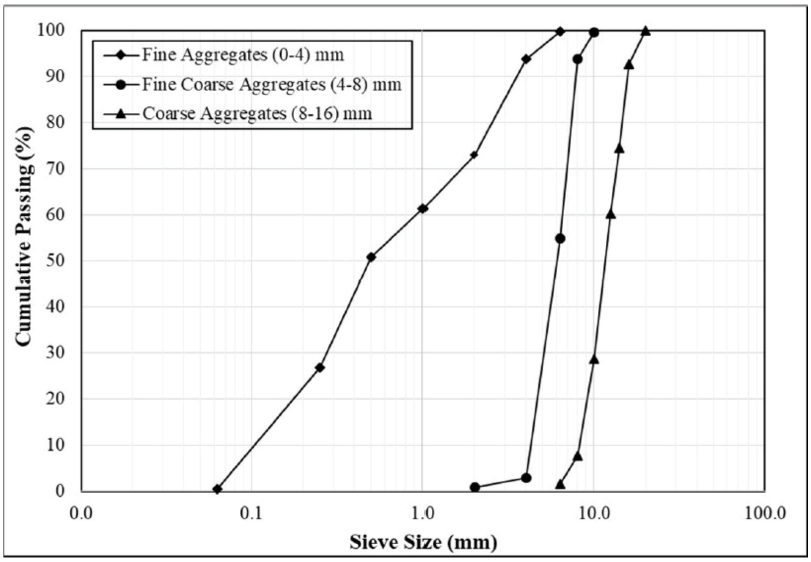

Figure 2. Size distribution curve for fine and coarse aggregates.

Microscopic analysis

The hydration of cement paste samples was stopped after 24 hours of casting, using solvent exchange technics [32]. The microstructural analysis of the surface was performed using Philips XL30 ESEM® Environmental Scanning Electron Microscopy (E-SEM) equipment. This test using the environmental mode with a backscattered electron detector (BSE) was performed to well understand the cement paste surface subjected to various formworks and to explore the relationship between interferometry 3D image and the roughness parameters. Then, the morphological analyzes were carried-out under a low vacuum with 0.90 Torr water evaporation on cement paste surfaces without any pre-treatment like polish, metallization, or others.

In addition, Bruker Contour GT-K1 3D Optical Microscope with 2D/3D measurement capabilities of high resolutions, using non-contact surface metrology and imaging also known as white and green light interferometry was used to investigate surface roughness parameters (Sa and Sq). The interferometer operates with optic and interference objectives: one optic objective of 10XTTM with 8.5-9.5 mm work distance (WD) and two interference objectives, varying from millimetric to nanometric scale. Here, two surface parameters; arithmetical mean height (Sa) and root mean square height (Sq) were analyzed according to NF EN ISO 25178-2 [33] code considerations. Since the PET substrate and C20C27 are both transparent and light passes through the coated layer, therefore, a thin layer of gold (5-10 nm) was deposited by sputtering using a 108 Manual Sputter Coater to allow the surface imaging by the interferometer [34].

Table 5. Concrete mixture proportion for 1m^3.

Materials	Quantity, kg
CEM II 42.5 N	370
Water	148
Sand (0-4) mm	773
Gravel (4-8) mm	397
Gravel (8-16) mm	595
Superplasticizer	3% by cement weight

Wettability

In the present study, the contact angle measurement was performed at 20 ± 2°C and 44 ± 7% relative humidity according to NF EN 828: 2013 [35] standard. This measurement was carried out using Drop Shape Analyzer – DSA30 equipped with an ALLIED vision technology camera. A total of 400 angle measurements were carried out for each sample of plate with each reference liquid and then the average contact angle was calculated. The selected liquids for measuring the contact angle and their characteristics are presented in Table 6.

Results and Discussion

Surface energy and roughness parameters of used formworks

As previously presented that the surface energy of formworks was calculated by the contact angle measurement method. Three types of liquids (distilled water, glycerol, and ethylene glycol) were used to verify the hydrophobicity and hydrophilicity of used formworks. The obtained results for the contact angle are summarized in Table 7. It can be noted that the PET-

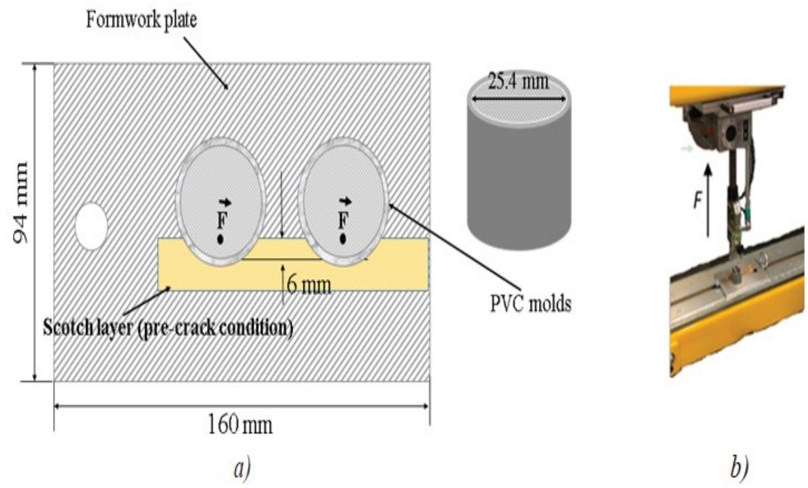

Figure 3. a) PVC molds placing on the formwork plates and b) cement paste pre-crack demolding test scheme [13].

Table 6. Characteristics of reference liquids for contact angle test [35].

Test Liquid	SurfaceTension (mN/m)	Dispers Proportion(mN/m)	Polar Proportion(mN/m)	Volumemass Density (kg/m^3)	CapillaryLength (m)
Distilled water	72.80	21.80	51.00	1000	0.0027
Glycerol	63.40	37.00	26.40	1260	0.0023
Ethylene glycol	47.70	30.90	16.80	1114	0.0021

Table 7. Formwork surface contact angle measurement using reference liquids.

Formwork Surface	Contact angel (°)			Surface Energy (mN/m)
	Water	Glycerol	Ethylene glycol	
F17-Ref	74.2 ± 2.8	65.4 ± 1.3	49.9 ± 2.2	31.74 ± 2.3
PET	113.8 ± 1.1	102.8 ± 0.7	57.7 ± 1.7	28.56 ± 0.8
C20C27	76.5 ± 2.4	75.2 ± 1.1	55.2 ± 1.9	27.60 ± 1.5

coated formworks present an angle greater than 90°, which represents the hydrophobic properties of the plates. On the other hand, the reference and C20C27 formworks were characterized as hydrophilic with an angle smaller than 90°. Moreover, the outcomes indicate that the lower angle for the reference plates was due to the highest roughness parameters.

Since the surface tension of mineral and vegetable oils has not been examined experimentally in this study. Therefore, data from the previous experimental works were used for further information and analysis. For instance, the mineral oil's contact angle was measured by putting a drop of mineral oil on the Polytetrafluoroethylene (PTFE) surface through the sessile drop test using an OCA10 tensiometer. While for the vegetable oil, the contact angle was measured using the pendant drop method. The results indicate that the surface tensions for mineral and vegetable oils are respectively, 28.09 ±1.7 (mN/m) and 24.5 ±1.5 (mN/m) [37-39].

In the context of surface roughness, the Sa and Sq surface roughness parameters were calculated through the stitching method measurement. The test was performed on 25 mm² area in the center of the cement samples (130 points imaging with 10% overlapping) using the Counter GT-K 3D interferometric microscope. For each variable parameter, 3 stitching image measurements were carried out as shown in Figure 4.

Moreover, the roughness parameters were calculated following PR NF EN ISO 25178-2 European standard [40] using Equations 8 & 9:

$$S_a = \frac{1}{A}\int_A |z(x,y)|\,dxdy \tag{8}$$

$$S_q = \sqrt{\frac{1}{A}\int_A \int z^2 |z(x,y)|\,dxdy} \tag{9}$$

The experimental results summarized in Table 8, indicate that the F17-Ref ad the highest surface roughness followed by C20C27 coated plates and PET ones, respectively. Here the gold (Au) sputter coating thickness (5-10) nm thick was ignored in the roughness parameters calculation. The stitched 3D and a point 2D measurement images are shown in a Figure 5. It can be seen that the reference formwork presents more irregularities compared to those coated ones.

The S_a and S_q surface parameters demonstrate that the F17-Ref with Sa=4.56 ± 0.39 µ, Sq= 5.66 ± 0.46 µ) has the roughest surface parameters, followed by C20C27 with Sa= 0.93 ± 0.23 µ, Sq= 1.17 ± 0.37 µ and PET with Sa= 0.11 ± 0.02 µ, Sq= 0.14 ± 0.03 µ, respectively. Table 8 summarizes the results for the roughness of formwork plates through interferometry microscopy analysis.

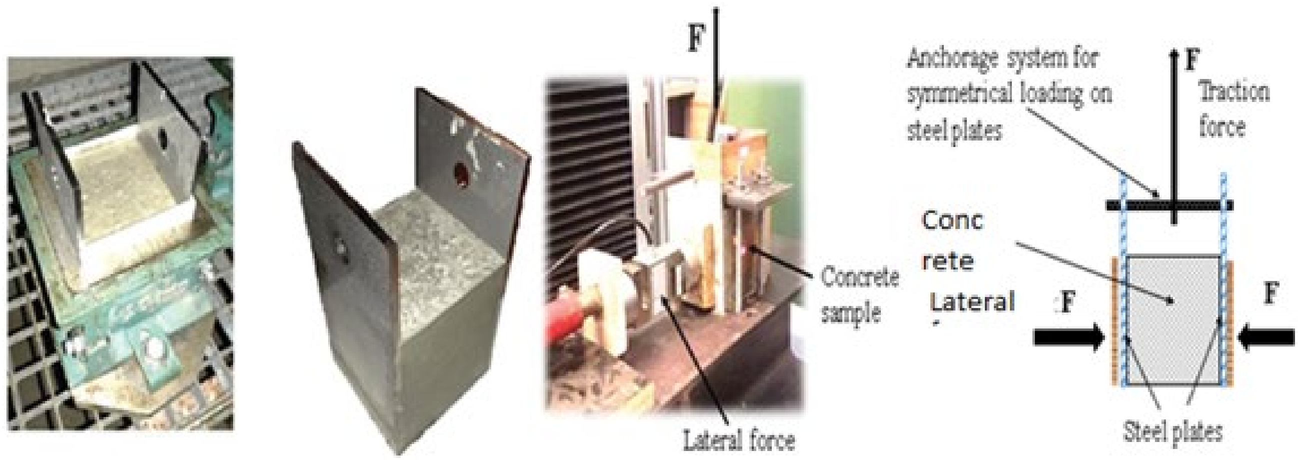

Figure 4. a) Concrete sample, and b) pull-off demolding test setup.

Table 8. Roughness parameters of formworks through interferometry microscopy.

Formwork Type	Sa (nm)	Sq (nm)	Remarks
F17-Ref	4563 ± 389	5663 ± 467	No treatment
PET	108 ± 21	141 ± 30	Metalized (gold)
C20C27	931 ± 235	1176 ± 370	Metalized (gold)

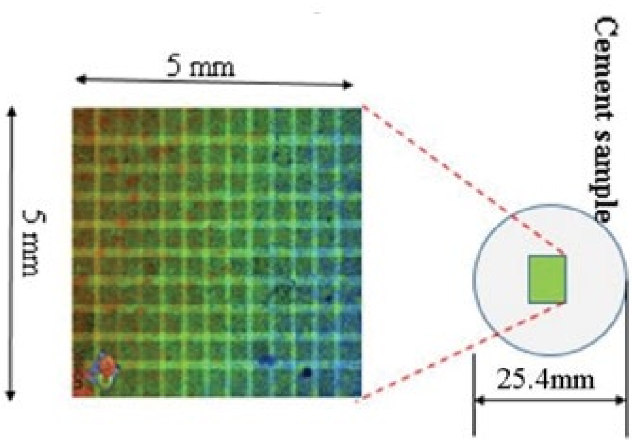

Figure 5. Stitching area for roughness measurement.

In order to correlate the effect of plates' morphology and surface parameters on the surface of cement samples, the roughness parameters at 24 hours of hydration were measured by an interferometry microscope after the pre-crack demolding tests. The experimental outcomes are presented in It can be seen that the cement paste subjected to the oil-coated formworks presents big cavities compared to those with polymeric-coated ones.

Table 9 results clearly indicate that the formwork roughness parameters affect the morphology of cement paste. Conspicuously, the higher roughness of cement surface was recorded for the cement samples with vegetable oil (Cem-VO). This is owing to the high attraction of the ester molecules in the vegetable oil for the formwork surface, which results in high viscosity. Moreover, the fatty acid glycerol esters in vegetable oil form a stable monolayer lubricant. This fatty acid gets into reaction with the cement's hydrous products and the formwork material which results in the formation of an organic salt layer (≈ 0.5-5 μm) [7,41]. The lower roughness values of the Cem-PET and Cem-C20C27 can be related to the combination of the impermeable nature and the lower surface roughness of polymeric materials [42]. It means that both properties give space for the hydrous products to grow tangentially to the formwork surface and facilitate the demolding process.

In addition, it can be clearly observed from Table 9 that both PET and C20C27 had a surface roughness of less than one micrometer, hence, the cement surfaces from these formworks had smoother surface roughness (Sa, Sq ≈ 1 μm) compared to the ones in contact with release agents. Furthermore, the interferometry imaging confirms the effect of the formwork morphology on the cement paste surfaces parameters (Figure 6). It can be seen that the cement paste subjected to the oil-coated formworks presents big cavities compared to those with polymeric-coated ones.

On the other hand, Figure 7 presents the SEM images, it reveals that the Cem-Ref samples had a porous surface compared to others, where the dark color areas signify the pores on the surface. The SEM analyzes indicate a percentage of hydrated products on the surface of Cem-Ref samples, while the unhydrated cement particles can be seen clearly by comparing to cement powder at the initial state. Moreover, the Cem-VO cement paste surfaces are similarly porous to reference ones, however, the Cem-VO cement paste surfaces had lower hydration compared to reference ones due to the existence of more unhydrated particles on the surface. The E-SEM results are in good agreement with the experimental outcomes of the surface roughness from interferometry analyzes. Besides, the cement paste surfaces subjected to the PET and C20C27 polymeric-coated formworks were smoother and less porous compared to others. It indicates that the hydration process on the surfaces is well advanced for such cement paste samples compared to Cem-Ref and Cem-VO. Therefore, it can be explained by the hydrophobicity behavior of polymeric-based substrate which results in the formation of a water layer between cement paste and formwork surface during the hydration process as shown in Figure 8 [43].

Finally, the E-SEM images shows that the hydrated surface of Cem-MO is similar to those against polymeric-coated formworks.

Adhesion force

Pre-crack demolding test: As previously indicated that the effect of formwork type on the adhesion/demolding force between cement paste and formwork was investigated by a pre-crack demolding test. The results tabulated in Table 10 reveal that Cem-Ref had the highest demolding force (121 ± 17.2N) among other types of formworks. It indicates that Cem-Ref had a 30% higher demolding force compared to Cem-C20C27 and 4 times higher than Cem-MO. Besides, the lowest adhesion force was obtained for the cement paste samples subjected to vegetable oil and PET-coated formworks. However, the demolding force for the Cem-VO and Cem-PET samples was too low to be recorded by the apparatus (<10 N).

Thus, it was observed from the results that the roughness of the formwork

Table 9. Roughness parameters of cement samples from interferometry microscopy.

Cement Samples	Sa (nm)	Sq (nm)
Cem-Ref	3670 ± 76	4850 ± 89
Cem-PET	1223 ± 65	2166 ± 70
Cem-C20C27	1130 ± 61	1770 ± 78
Cem-MO	3033 ± 68	4030 ± 84
Cem-VO	5754 ± 75	7551 ± 91

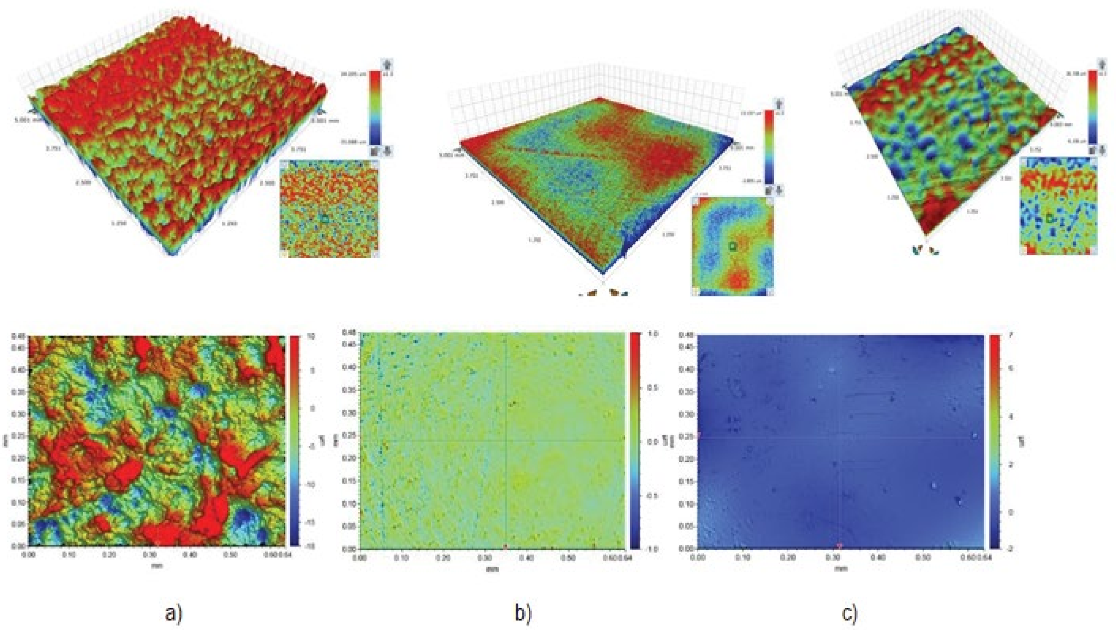

Figure 6. Formwork interferometry microscopy 3D and 2D images: a) F17-Ref, b) PET and c) C20C27.

surface has a direct relation to the adhesion between cement paste and formwork. Similar outputs were observed by the previous authors and they explained that fine cement particles, C-S-H and C-H, can be placed in the formwork's voids and cause the physical interlocking between two surfaces during the hydration process of cement [7,10,13,21,44].

On the other hand, it was underlined that there is no correlation between demolding force and surface energy of used formworks Figure 9. This means that the decreasing pattern in the surface energy could not be witnessed with the adhesion force. For example, the Cem-VO and Cem-PET present the lowest demolding force (<10 N), while the calculated surface energy of mentioned formworks is almost similar to other coated plates.

Besides, Figure 9 illustrates that the release agent affects significantly the demolding force. It could be explained that the vegetable oil enters into a chemical reaction associated with soap forming on the concrete surface, while, the mineral oil forms a physical barrier between formwork and cementitious surface due to its hydrophobic behavior [45,46]. It was found that the demolding force of F17-VO samples was lower than 10 N, which represents that the vegetable oils function better than mineral oils confirming the previous studies

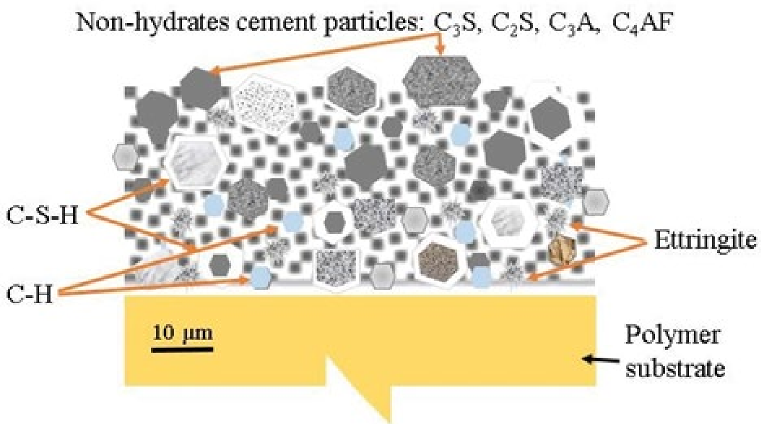

Figure 7. Accumulation of water layer at the polymeric substrate-cementitious materials.

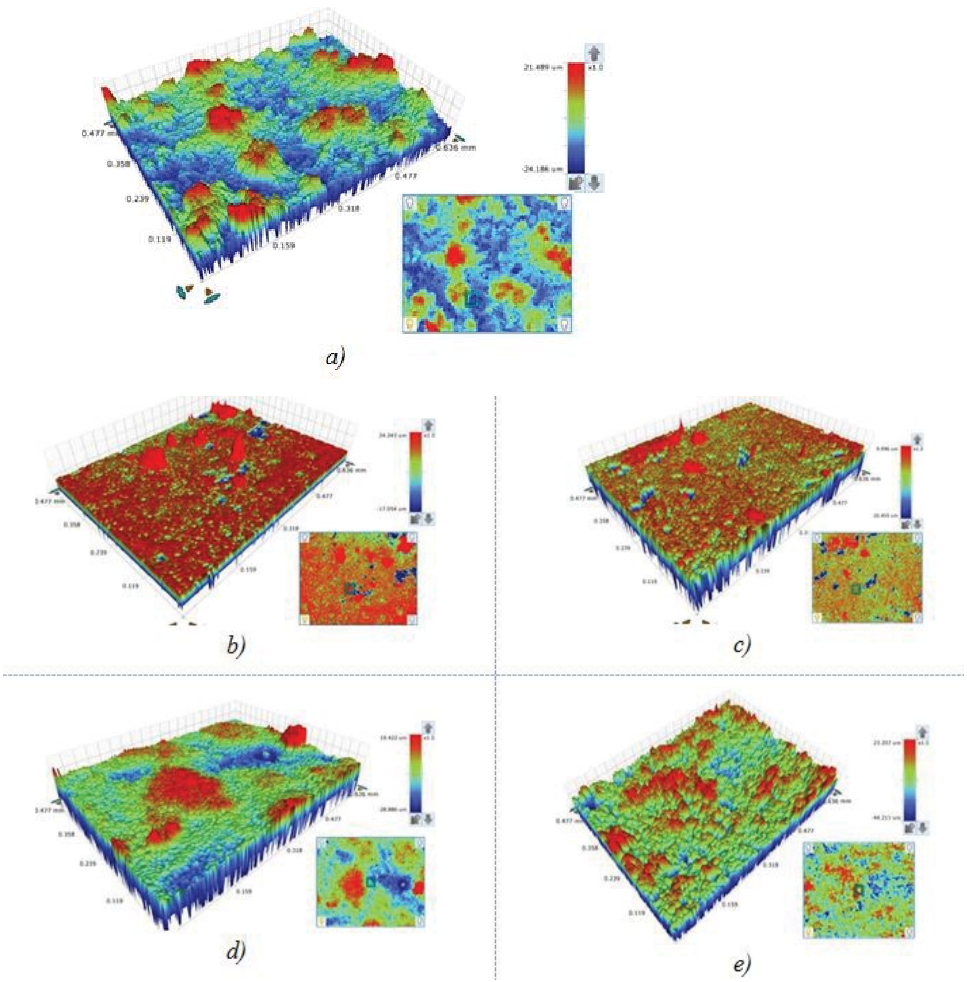

Figure 8. Interferometry microscopic imaging of the cement samples after 24 h of hydration: a) Cem-Ref, b) Cem-PET, c) Cem-C20C27, d) Cem-MO, and e) Cem-VO.

[1,10]. Moreover, it can be noticed that the PET-coated surface presents almost similar demolding force to the Cem- VO among other polymeric-coated formworks, and could be an alternative and eco-friendly solution for release agents.

Pull-off demolding test: In the same context, the pull-off demolding test was conducted to verify the demolding force on a macro scale between concrete and used formworks. The experimental results obtained through the pull-off demolding test are shown in Figure 10. The maximum adhesion between concrete and formwork is recorded for F17-Ref (14.26 ± 2.21 kN) which is 5 times more than that of coated surfaces. Moreover, the lowest adhesion performance was underlined for the Con-PET and Con-VO samples as 2.75 ± 0.33 kN and 2.68 ± 0.31 kN, respectively. Whereas, the Con-MO samples present an increase of 25% in demolding force compared to the Con-PET ones. Besides, Con-C20C27 formworks had almost 2 times higher demolding force (5.04 ± 1.36 kN) compared to the Con-PET one.

Table 10. Demolding force obtained from pre-crack demolding test.

Sample Type	Demolding Force (N)
Cem-Ref	121.8 ± 17.2
Cem-PET	<10
Cem-C20C27	90.5 ± 18.3
Cem-MO	39.16 ± 6.3
Cem-VO	<10

The experimentally results are in well agreement with the literature, whereas, the mineral and vegetable oil showed lower adhesion force compared to the reference one (without release agents) [2-4]. Since these release agents have significant environmental impacts, therefore, the PET can be considered a viable alternative to release agents in terms of releasing functionality. Finally, the tendency of findings of the pre-crack demolding test on cement paste samples are confirmed by the pull-off demolding test on concrete specimens.

The force-displacement curves for C20C27 samples are presented in Figures 11 and 12. It can be seen that the elastic behavior continues until the failure occurs and the formwork plate demolds suddenly without sign of plastic behavior. Furthermore, as shown in Figure 13, the curves illustrate a brittle fracture, and it should be noted that all used formworks, regardless of coating materials, displayed a similar fracture behavior.

Visual aspects

It is important to know that the cement paste samples subjected to the

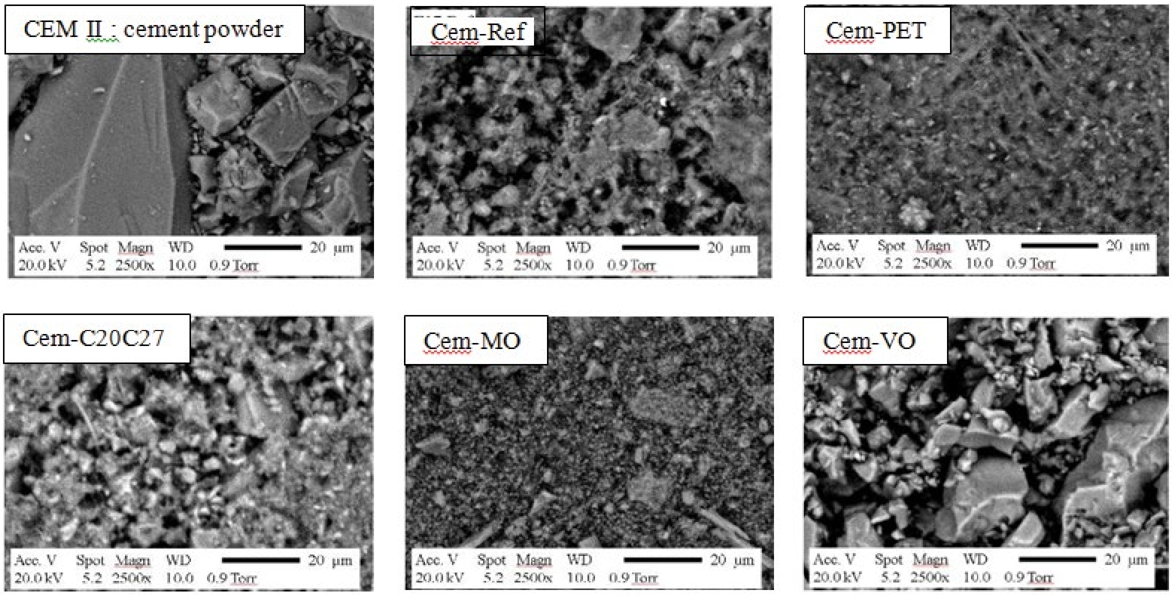

Figure 9. E-SEM analysis of powder of CEM II Portland cement and the cement paste samples after 24 h of hydration.

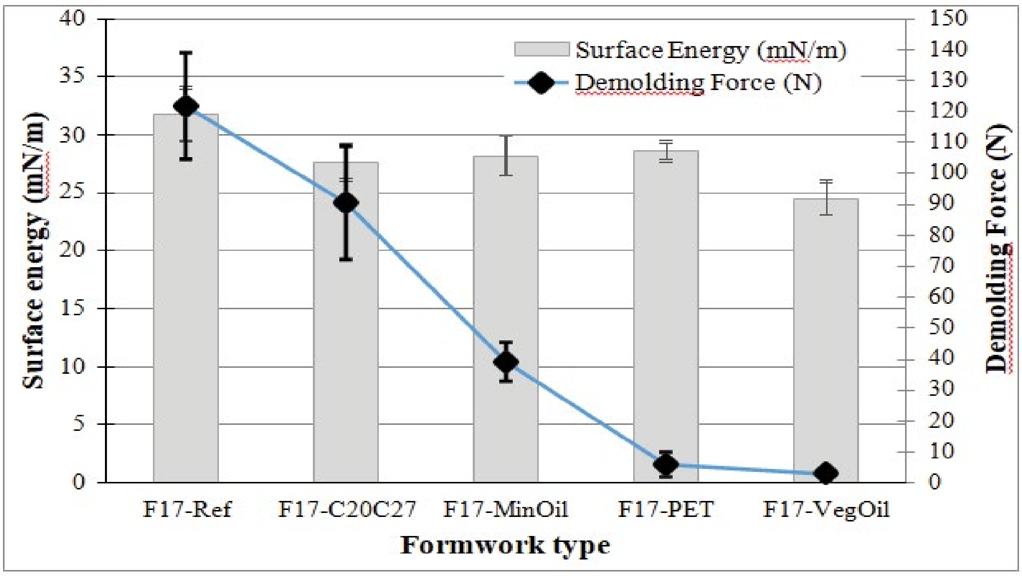

Figure 10. Observation of demolding force and surface energy of cement sample.

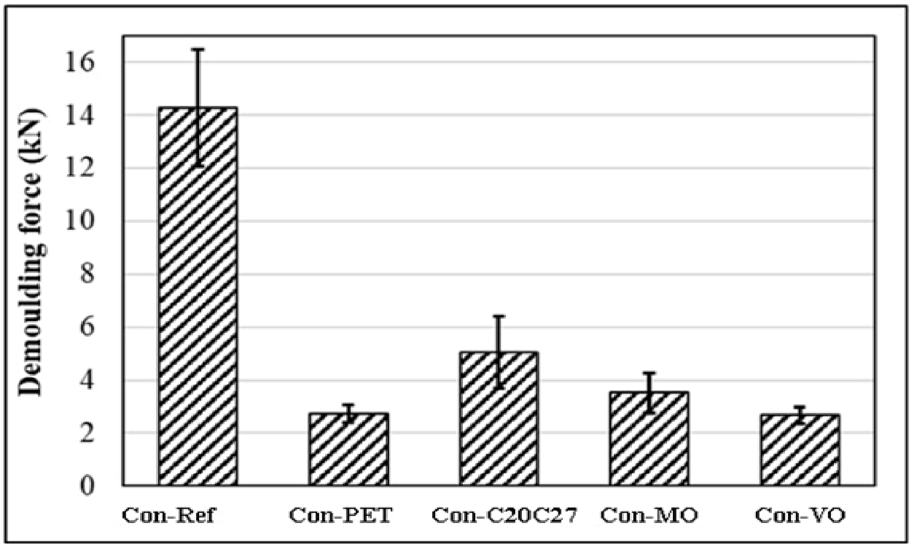

Figure 11. Concrete demolding force of different formworks.

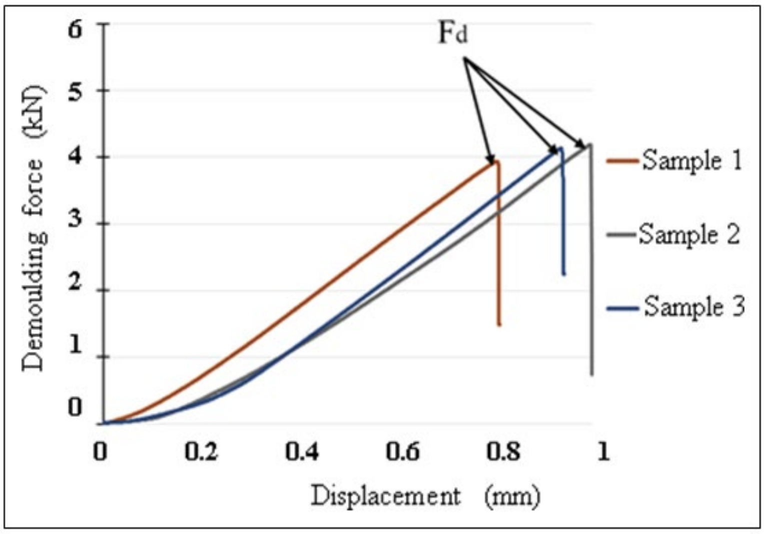

Figure 12. Fracture behavior of the pull-off demolding test (the drop in Fd is due to a sudden separation of plastes from concrete samples).

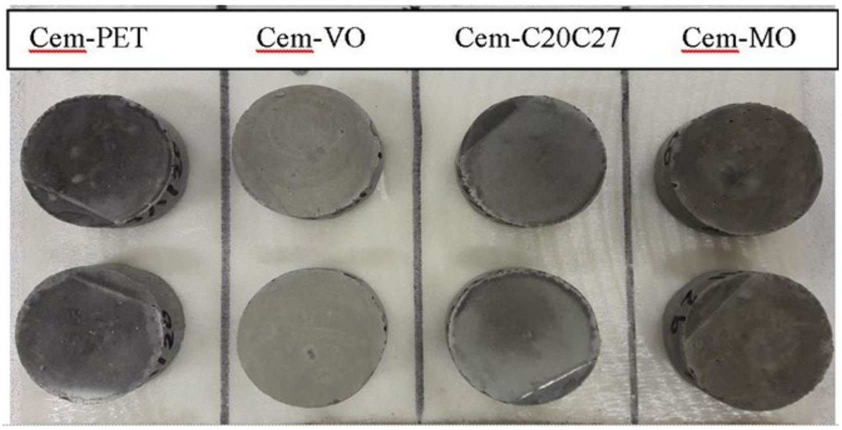

Figure 13. Cement paste surfaces in contact with used formworks after the pre-crack demolding test (24 hours of hydration).

polymeric-coated formworks (PET and C20C27) present a very smooth and shiny surface. Besides, it could be visually observed that these samples have fewer pores on their surfaces compared to those against F17-MO and F17-VO plates after 24 hours of hydration. On the other hand, the cement paste samples against formworks with release agents have an opaque surface as shown in Figure 14.

The surfaces of demolded concrete samples subjected to various types of formworks are regrouped in Figure 15. The concrete surfaces obtained from polymeric-coated formworks present a shiny and smooth appearance. While the surfaces from reference formwork and those with release agents have opaque properties. Therefore, it could be noted that the visual appearances of concrete samples after the pull-off demolding test were similar as were observed for the cement paste samples after the pre-crack demolding tests. This similarity could be explained by the concentration of cement paste on the surface of concrete samples. Moreover, after 3 months of curing, these features remained unchanged.

The state of plates with various coating materials after demolding tests are illustrated in Erreur! Source du renvoi introuvable. The images indicate signs of cement paste/concrete splinters on the surface of reference formworks and C20C27. Moreover, some microscopic scale scratches are observed on PET-coated formwork after the pull-off demolding test. However, no cement paste particles were found on PET-coated formwork and those with release agents after demolding. Regarding detachment of polymeric-coated formworks, some defections and detachment were observed for the plates for C20C27.

The visual analyzes for the plates and cement paste/concrete samples are summarized in Table 11. It could be explained that all coated formworks present adhesive failure behaviors during the demolding process except samples with reference formwork. However, the final appearance is different for the samples against the polymeric-coated compared to those of release agents.

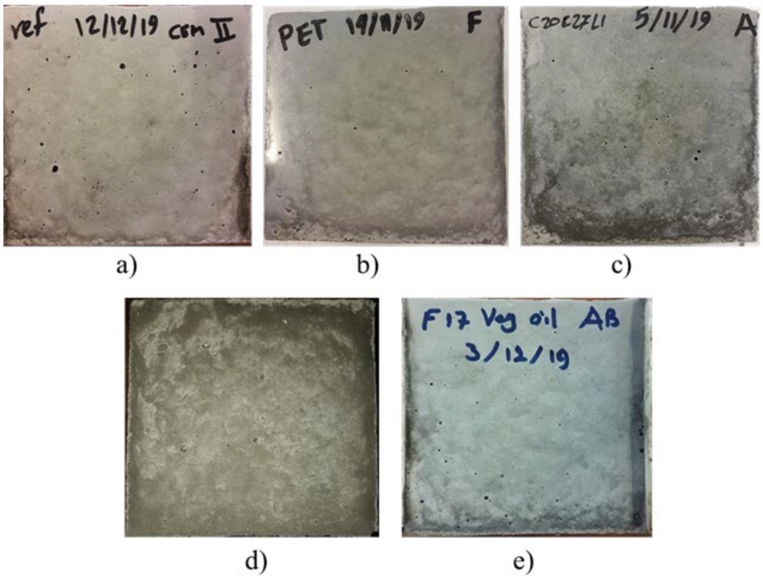

Figure 14. Concrete surfaces after the demolding test (24 h); a) Con-Ref, b) Con-PET, c) Con-C20C27, d) Con-MO, and e) Con-VO.

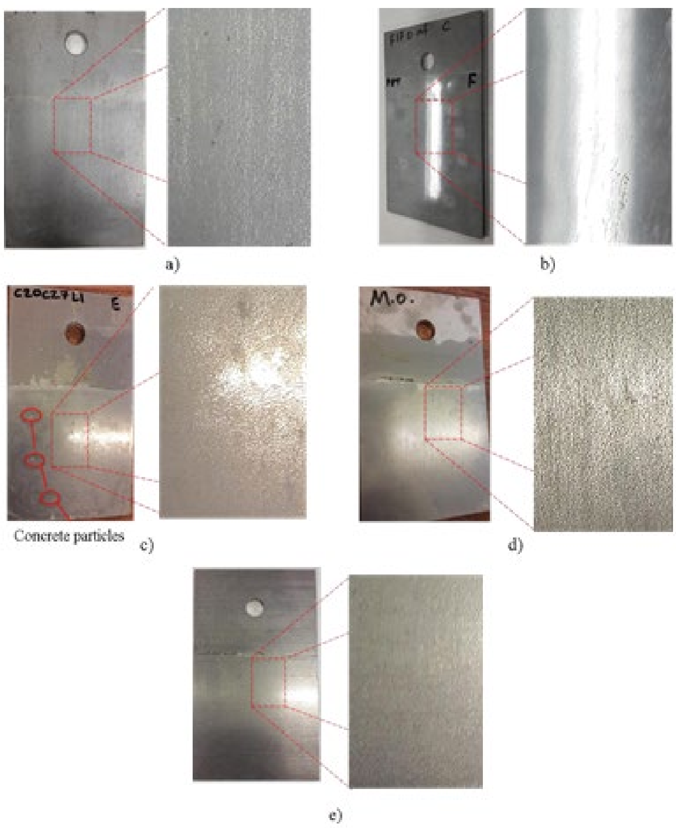

Figure 15. Formwork surface after demolding a) F17-Ref, b) PET, c) C20C27, d) F17-MO, and e) F17-VO.

Table 11. Failure types of concrete and cement samples regarding the formworks.

Concrete and Cement Samples	Surface Before Test	Surface After Test	Skin	Failure Type
Cem-Ref & Con-Ref	Reference	- Rust - Concrete particles	Opaque	Cohesive
Cem-PET & Con-PET	0.19 mm of PET layer	- No corrosion or rust - Scratchesappearance	Shiny	Adhesive
Cem-C20C27 & Con-C20C27	Laboratoire de Photochimie et d'Ingenierie Macromoleculaires (LPIM) Product			
Cem-MO & Con-MO	Release agent coated	- No corrosion or rust - No concrete particle	Opaque	
Cem-VO & Con-VO				

Conclusion

This experimental work was carried out to examine the effect of formwork's surface roughness parameters on adhesion force between the formwork and concrete/cement paste. For this, various types of coating were used to explore their effect on microstructural properties of cementitious materials after 24 hours of hydration. Therefore, the major concluding points drawn from the above experiments are as follows:

- The surface energy data show that coated plates, regardless of coating material type, have nearly similar surface energy. However, the highest surface energy was observed for the reference plate (F17-Ref) without any coating materials.
- Mechanical interlocking occurs at the microscopic scale in the absence of a releasing substrate due to irregularities on the formwork surface and the concrete. Furthermore, Van der Waals forces and hydrogen bonding improve concrete-metal formwork adhesion.
- The lowest surface roughness parameters were detected for cement paste samples subjected to polymeric-coated plates (Cem-PET and Cem-C20C27) compared to those with release agents. Here the highest value was recorded for Cem-VO.
- The microstructure analysis using E-SEM shows that the Cem-VO present a porous surface with a lower degree of surface hydration. Therefore, its highest value of surface roughness subjected to the coated formworks can be linked to the existence of unhydrated cement particles and pores among the samples.
- Moreover, releasing agents exhibit variable separation tendencies depending on their chemical characterizations. These materials link to the formwork surface by Van der Waals forces and show a hydrodynamics characteristics. In comparison to mineral oil, vegetable oil demonstrated improved functionality in terms of demolding due to its higher viscosity qualities and creation of a thin monomolecular ester layer.
- Both pull-off and pre-crack demolding tests illustrate that the PET and F17-VO had better performance with a lower adhesion force.
- Cementitious surfaces subjected to polymeric-coated formwork produce shiny and smooth surfaces, whereas mineral and vegetable release agents produce opaque and rougher surfaces.
- Overall the PET can be considered as an alternative for the replacing of used release agents due to its lower adhesion force and durability in terms of usage repeatability.

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