Application of poly(vinyl acetate) and poly(1,4-butylene adipate) hydrophobic surface coatings on cementitious mortar specimens

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(Received May 22, 2020, Revised March 4, 2021, Accepted March 10, 2021)

Abstract. The main objective of this study is to characterize and evaluate the hydrophobic performance of polymer-based water-repellent coatings on cementitious mortar surfaces. Different concentrations of poly(vinyl acetate) (PVA) and poly(1,4-butylene adipate) (PBA) were prepared in the laboratory and their applicability and performance was tested experimentally by water absorption test and analysis of surface contact angles of cementitious mortar specimens. According to the results of this study, it can be stated that incorporation of nano polymer particles on the surface of cementitious mortar specimens can enhance contact angles and reduce water absorption by increasing hydrophobicity. However, a dosage limit exists for polymer materials in coating, and observed hydrophobic improvements decreases when polymer dosage reached beyond the limit. Additionally, it is observed that water absorption of polymer coated cementitious mortars is closely related with the results of surface contact angle.

Keywords: concrete; cementitious mortar; hydrophobic; water contact angle; water absorption

1. Introduction

Concrete, a naturally porous material, also tends to crack, making it highly susceptible to water absorption (Singh and Gupta 2020). Due to the concrete's hollow structure, liquid molecules can easily pass through the effects of ambient moisture, chemical liquids, sea water etc. Therefore, concrete, which is a hydrophilic material, significantly reduces the durability of structures and coatings, and consequently suffers from severe durability and strength losses due to the steel reinforcement corrosion inside (Angst et al. 2012, Muller et al. 2014, Huang et al. 2016, Gao et al. 2020). And in order to protect the concrete from such damages, it is thought that it will be very useful to apply various coating and water repellent treatment on the sample surfaces (Szafraniec et al. 2020). In these cases, high water impermeable concrete is needed, and it is thought that polymer modified concrete coatings will be effective in preventing water permeation and reinforcement corrosion especially in industrial floors and bridge decks (Mignon et al. 2017).

Advances in concrete technology to improve performance can be achieved mainly through material modification. The use of polymer materials as modifiers in concrete will provide significant performance improvements, because the polymers have higher compressive and tensile strength than normal concrete, they are also very successful in reducing the hollow structure in concrete (Abu-Jdayil et al. 2019). A variety of polymer products are available, from surface coatings to special paints and membranes, to help protect concrete structures from water and protect them from damage caused by water absorption. It is not easy to design and implement this type of protection with polymers that show different degrees of efficacy, both in different types and in practice, and sometimes require high budgets. When creating hydrophobic concrete through a coating process, it is sprayed, submerged or brushed onto a porous surface (Szafraniec et al. 2020). With hydrophobic concrete, both corrosion proofing and waterproofing properties will be achieved simultaneously. One of the main requirements of hydrophobic surface coatings of concrete is the ability of water resistance. Therefore, the coating itself must be water resistant but should also possess the additional performance properties expected. Thus, PVA and PVF are good candidates due to their hydrophobic properties and possible strong adhesion to cement surface. Hydrophobic ester groups are expected to decrease the hydration of cement. Moreover, the interaction of ester groups (in polymers) and metal oxides (in cement structure) will provide these polymers good adhesion properties. Non-covalent interactions between polymers and cement may provide additional contribution to an improved polymer-cement interaction.

Throughout history, many different protective coating materials have been applied, including oils, waxes and paints, to prevent water absorption of concrete and to produce hydrophobic concrete (Ershad-Langroudi et al. 2014).
2019). As a result of many studies on this subject in the literature (Al-Kheetan et al. 2019a, Al-Kheetan et al. 2020, Al-Kheetan et al. 2021), great progress has been made in the production of water-repellent agents used for concrete today and in the development of hydrophobic processes on the concrete surface. And surface impregnation by many different water-repellent agents has proven to be an effective preventive method for concrete structures (Vries et al. 1998, Dai et al. 2010, Hou et al. 2014, Schröfl et al. 2015, Cai et al. others 2016, Zhang et al. 2017, Bai et al. 2017) investigated the effect of SiO2 nanoparticles in detail on the hydrophobicity of concrete surfaces coated with polymer paints and observed that the coatings had the highest surface contact angle and the most effective hydrophobic property when using 1% nano-SiO2 by weight. In addition, different studies have recently been focused on coating nano materials on metal surfaces (Bzgherzadeh et al. 2012, Ammar et al. 2016) and coating on concrete surfaces (Bai et al. 2017). As can be seen from the studies in the literature, Super hydrophobic coatings can be prepared by coating and holding some low surface energy materials on the surface of the concrete (Flores et al. 2013, Herb et al. 2015, Liu et al. 2016, Song et al. 2016, Weisheit et al. 2016). In one of the previous studies, materials such as Polytetrafluoroethylene (PTFE), polyester ether ketone (PEEK) and silanized diatomaceous earth (DE) were bonded with epoxy resin and hydrophobic concrete surfaces were obtained to obtain a super hydrophobic surface (Arabzadeh et al. 2017).

In order to obtain hydrophobic concrete with the most effective concrete surface coating, the basic requirements must be to prevent oxygen and water permeability to both concrete and reinforcing steel surface throughout the coating or film (Al-Kheetan et al. 2019b). Because, in response to strong localized interactions in hydrophilic regions, with the help of osmotic diffusion, corrosion damage can occur when water or air enters the coating by migration or migration through capillaries or microporous pores. Therefore, besides water absorption resistance in hydrophobic concretes, successful application of protective coating or film formation plays an important role (Siddika et al. 2019).

In this study, water permeability and surface hydrophobicity of raw cement were compared to samples surface modified by PVAc and PVB coatings having different concentrations, where the focus will be on increasing the water repellency of polymer modified cement mortar and its usability. Our aim is to produce a mortar surface having a significant water repellency. According to the above-mentioned literature, using hydrophobic polymeric materials as surface films would be a high-performance way to obtain hydrophobic mortar surfaces. For this purpose, various polymer compositions with auxiliary chemicals will be prepared in the laboratory and their applicability will be tested experimentally by surface coating on the cementitious mortar specimens and their efficiency for the protection of the specimens from water absorption is studied. Water absorption of mortar specimens coated with PVAc and PBA coatings were tested experimentally and surface contact angles of mortar specimens were evaluated with the help of a non-contact image processing technique. The adhesion of all these polymer materials on mortar, their effects on water absorption and hydrophobic performance will be investigated, the main purpose will be to find the type of polymer material, % volume fraction of polymer in emulsion and application method that minimizes the water permeability and hydrophilicity problem in concrete structures. And the decreased water permeability or, in other words, hydrophobic concrete can have numerous applications in construction and civil engineering due to its enhanced durability performance. Therefore, the hydrophobic surface that protects the cementitious mortar from water absorption can be obtained by covering the most suitable polymer on the mortar surface with impregnation applications in order to increase the durability and extend the service life of concrete structures. The target audience of the results of the study will be ready-mixed concrete companies, researchers working on concrete, all construction companies that are concrete practitioners, polymer chemistry researchers, polymer applicators.

2. Materials and mix design

The fine aggregate, sand, (0-4 mm) obtained from the same source and from the same crushing and screening plant were used in all the mortar mixtures of this study. The physical properties and grain size distribution of the sand used were given in Fig. 1. CEM I 42.5 type cement was used in the experimental study. The physical and chemical properties of the cement used were given in Table 1. And, the details of mortar mix proportions are presented in Table 2. Flow chart for the preparation and characterization of polymer coated cementitious mortar samples is given in Fig. 2.

PBA (powder, MW 12000, Sigma-Aldrich) and PVAc (powder, MW ~100000, Sigma-Aldrich) were used as polymers to create hydrophobically coated mortar surfaces. Molecular structure of each repeating unit was shown in Fig. 3. All samples contain ester groups making the structure hydrophobic.

In the experimental study, the dimensions of the cement mortar specimens were determined to be as 5 cm×5 cm cube samples. And the details of the specimens can be

![Graph](image_url)

Fig. 1 Grain size distribution for the sand used in cement mortar mixtures
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Table 1 Physical and chemical properties of CEM I 42.5 cement

<table>
<thead>
<tr>
<th>Specifications</th>
<th>CEM I 42.5R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss on Ignition (%)</td>
<td>1.67</td>
</tr>
<tr>
<td>SO₃ (%)</td>
<td>2.724</td>
</tr>
<tr>
<td>Cl (%)</td>
<td>0.008</td>
</tr>
<tr>
<td>Insoluble Residue (%)</td>
<td>1.04</td>
</tr>
<tr>
<td>2-Day Compressive Strength (MPa)</td>
<td>27.3</td>
</tr>
<tr>
<td>7-Day Compressive Strength (MPa)</td>
<td>42.5</td>
</tr>
<tr>
<td>28-Day Compressive Strength (MPa)</td>
<td>57.3</td>
</tr>
<tr>
<td>Initial Setting Time (dk)</td>
<td>150</td>
</tr>
<tr>
<td>Final Setting Time (dk)</td>
<td>215</td>
</tr>
<tr>
<td>Volume Expansion (mm)</td>
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<tr>
<td>Density (gr/cm³)</td>
<td>3.12</td>
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<tr>
<td>Specific Surface (cm²/gr)</td>
<td>3950</td>
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Table 2 Mortar Mix Proportions

<table>
<thead>
<tr>
<th>Materials</th>
<th>Mortar Mix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement (kg/m³)</td>
<td>882</td>
</tr>
<tr>
<td>Sand (kg/m³)</td>
<td>2200</td>
</tr>
<tr>
<td>Water (kg/m³)</td>
<td>441</td>
</tr>
<tr>
<td>Admixture (kg/m³)</td>
<td>3</td>
</tr>
<tr>
<td>w/c</td>
<td>0.5</td>
</tr>
<tr>
<td>Air Content (%)</td>
<td>1</td>
</tr>
</tbody>
</table>

Fig. 3 Molecular structure of (a) Poly(vinyl acetate) and (b) Poly(1,4-butylene adipate)

Polymer solutions of different concentrations (4% and 8% by mass) were prepared using acetone (d: 0.79 g ml⁻¹) as solvent. The calculated amount of each polymer sample was accurately weighed and 50 ml aliquots of each polymer solution was prepared. Polymer beads were dissoluted into apparently transparent clear solutions under magnetic stirring at room temperature. Polymer coatings were applied onto mortar surfaces by dipping method. For each polymer solution, 2, 5, 10 and 20 dipping treatments were performed, and different coating thicknesses were adjusted. Two replicates of each sample from each group were prepared and investigated. Thus, 40 samples were prepared for each different polymer in total.

3.2 Water absorption

Water absorption resistance or sorptivity is an important key indicator for determining the durability and service life of hardened concrete, because it can significantly improve the long-term performance of concrete in aggressive environments by inhibiting water absorption. Water absorption resistance cannot be used to examine the quality of concrete (Neville 1995), but it is also known that most high-quality concrete shows less than 10% water absorption by mass. In order to understand the water absorption, the sorptivity index is used, which depends on the upward

found in Fig. 4, which were varied according to i) the type of polymer, ii) weight percentage of polymer content, and iii) number of dipping layers applied. And, two replicates of each sample were tested.

3. Experimental methodology

3.1 Polymer coating

![Fig. 2 Flow chart for the preparation and characterization of polymer coated concrete samples](image-url)
moving of water into the concrete across joined pores (Gunesi et al. 2011). Additionally, the decrease in sorptivity or water absorption represents a tiny pore system that would prevent entrance of water and also aggressive components to concrete (Neville 1995). When the water is drawn into concrete, the measures of the rate of water to the capillary pores named as a sorptivity test. The water absorption performances of mortar samples were tested according to ASTM C 1585-04 (ASTM 2006) by measuring the total amount of water absorbed by the water contact to which a surface of the sample was exposed and the increase in sample mass resulting from it. The test was implemented on the cubic mortar specimens of a=50 mm, and the specimens first dried in an oven at 100 ±5°C to reach the constant mass. Within the experiment, the edge surfaces of the cement mortar cube samples with 14 days of strength prepared from the same mixture ratios were covered with silicone and brought into contact with water from one surface. As can be seen from Fig. 5, the cube samples in contact with water at a depth of approximately 2±1 cm, at regular time intervals (5, 10, 20 and 30 minutes, 1, 2, 3, 6 hours, 1, 2, 3, 5 and 7 days), removed from the water, and weighed after weighing the surface wetness. Test samples were immersed again in water immediately after weight measurement. As a result, the volume of water absorbed was measured by dividing the surface contact area of the samples (50×50 mm²) and the mass acquired by the mass of water. The relationship between these values and the square root of the time in which measurements are made will be given in graphs. According to the results of these experiments, the slope of the curves will be defined as the absorbency index (I) of concrete, as suggested by ASTM C 1585-04 and this parameter displays the absorption capacity of the samples compared to the water absorbed by the control sample.

**3.3 Surface contact angle**

When concrete comes into contact with water, most of the water is absorbed by the pores in the concrete due to capillary forces, and these capillary forces depend on the surface tension of the water, the angle (surface contact angle) of the water with the surface and the size of the pores in the concrete (Stefanidou et al. 2013). Surface angle is a basic parameter showing the wetting capacity of the surface (Marmur 2009), and when the surface angle is greater than 90°, it shows hydrophobicity, while when the surface angle is less than 90°, it shows hydrophilicity, which is a tendency to wet or absorb water as shown in Fig. 6. Super hydrophobicity refers to a contact angle that appears between 150° and 180° (Bormashenko 2018, Bormashenko et al. 2007).
Hydrophobic materials are materials with low surface energy and this is because there are no active groups in their surface chemistry to create a “hydrogen bond” with water. Normal concrete materials without coating are hydrophilic, with a relatively low surface angle when in contact with water.

Within the scope of this experimental study, an image analysis based optical set combined with a high resolution camera and an open-source software ImageJ was used for the measurement of the surface angle, based on the successful results of previous studies from the literature (Buahom 2018, Nezerka et al. 2018, Krzysztof 2020). At three different locations on the surface of mortar specimens, 5 µL constant volume of water drops were placed. Then, high-resolution photographs of the formed drops were taken by the method of dropping water on cement mortar samples with different types and proportions of polymer surface coatings. After these photos taken from each sample surface, the surface contact angle of each water drop was determined by image analysis technique with the help of ImageJ software. The image analysis based assessment of contact angles as shown in Fig. 9, is based on image binarization, identification of regions of interest, boundary smoothing, and contour differentiation.

4. Results and discussions

4.1 Water absorption

The main objective of this study is to decrease the water absorption of hydrophilic cementitious mortars. Therefore, in this part, the water absorption capacities and water absorption behaviors of cementitious mortar samples with
different concentrations and types of polymer-based hydrophobic surface coatings were investigated. Preparation of the experimental setup, immersion, and measurement of mass increase of mortar samples at determined time intervals were carried out with high precision according to the ASTM 1585 standard. The immersion technique has been shown to lead to the formation of thin and more stable layered structures on the surfaces (Aradi et al. 2008).

The effects of surface coating with the PVAc and PBA polymers used in different concentrations on the water absorption rates of cement mortars are shown in detail in Fig. 7, where each data point shows the average of two independent experiments. As can be seen from the Fig. 7, when compared to control samples, polymer surface coated cement mortar samples of all types and concentrations contribute to a greater reduction in water absorption rate. The results indicated that, the cumulative water intake of all samples increased gradually starting from the beginning. However, while water intake of control samples continued to increase to much higher levels, those of polymer coated samples remained stable at lower levels. It can be said that the control samples (without any coating) retain the hydrophilic properties of cement-based materials. However, concrete has a well-known highly porous surface. Considering the surface air gap of the mortar samples, it is not expected that the surface will be 100% covered by polymer solutions, but the chemical reactions between ester-structured polymers and surface components which was emphasized by similar studies show that polymer films bond to the concrete surface via covalent bonds (Van den Brand et al. 2004, Beentjes et al. 2006, De Wit et al. 2010). Besides, non-covalent bondings between superhydrophobic coatings and concrete ensures surface protection and better surface durability (Zhao et al. 2018).

When both PVAc and PBA surface coatings were examined, water absorption values were observed to be higher in samples coated with a polymer concentration of 4wt.% compared to that of coated with 8wt.%. This result was attributed to the increasing hydrophobic character of mortar surfaces coated with 8wt.% polymer solutions. Moreover, the water absorption difference between 4wt.% and 8wt.% polymer coatings is much more pronounced in samples coated with PVAc.

![Fig. 9 Water contact angle photographs of (a) 8PBA-10d and (b) 8PVAc-10d specimens and 8-bit black-white images of (c) 8PBA-10d and (b) 8PVAc-10d specimens prepared for image processing](image)

![Table 3 Rate of absorption and sportively in the coated and uncoated cement mortar specimens](table)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Duration</th>
<th>Average Water Absorption Rate (g/mm²/hr)</th>
<th>Average Percent Decrease in Absorption (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>10 m</td>
<td>1.20</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>1 hr</td>
<td>0.41</td>
<td>63.8</td>
</tr>
<tr>
<td></td>
<td>1 day</td>
<td>0.05</td>
<td>-</td>
</tr>
<tr>
<td>4PVAc</td>
<td>2d</td>
<td>0.42</td>
<td>63.8</td>
</tr>
<tr>
<td></td>
<td>5d</td>
<td>0.41</td>
<td>54.9</td>
</tr>
<tr>
<td></td>
<td>10d</td>
<td>0.24</td>
<td>40.5</td>
</tr>
<tr>
<td></td>
<td>20d</td>
<td>0.36</td>
<td>39.9</td>
</tr>
<tr>
<td>8PVAc</td>
<td>2d</td>
<td>0.29</td>
<td>78.9</td>
</tr>
<tr>
<td></td>
<td>5d</td>
<td>0.19</td>
<td>83.2</td>
</tr>
<tr>
<td></td>
<td>10d</td>
<td>0.26</td>
<td>80.4</td>
</tr>
<tr>
<td></td>
<td>20d</td>
<td>0.24</td>
<td>73.2</td>
</tr>
<tr>
<td>4PBA</td>
<td>2d</td>
<td>0.70</td>
<td>45.5</td>
</tr>
<tr>
<td></td>
<td>5d</td>
<td>0.82</td>
<td>42.7</td>
</tr>
<tr>
<td></td>
<td>10d</td>
<td>0.55</td>
<td>49.3</td>
</tr>
<tr>
<td></td>
<td>20d</td>
<td>0.60</td>
<td>51.8</td>
</tr>
<tr>
<td>8PBA</td>
<td>2d</td>
<td>0.82</td>
<td>60.6</td>
</tr>
<tr>
<td></td>
<td>5d</td>
<td>0.55</td>
<td>61.4</td>
</tr>
<tr>
<td></td>
<td>10d</td>
<td>0.70</td>
<td>48.6</td>
</tr>
<tr>
<td></td>
<td>20d</td>
<td>0.50</td>
<td>54.1</td>
</tr>
</tbody>
</table>

The water permeation characteristics of mortar surfaces coated with 4-8wt.% PVAc and PBA given in Fig. 6(a-d) also showed the improving effects of PVAc coatings at both 4wt.% and 8wt% concentrations compared to PBA coatings. Percent reduction in water absorption compared to the control sample were in the range of 39.9-63.8% and 73.2-83.2% in PVAc-4% and PVAc-8% respectively (Table 3).
In case of PVAc, increasing the concentration of the polymer solution resulted in a more hydrophobic surface emerging with a lower water intake profile. This waterproofing effect of 8% PVAc samples is almost equivalent to the waterproofing effect (85%) of the nano composite waterproof coating (Scarfato et al. 2012). This may be due to the increased concentration of the polymer, which allows a more comprehensive interaction between the polymer and cement mortar and to cover the surface air gaps of the samples well. The water permeation levels were in a narrow range in the mortar samples coated with PVAc-8wt.% for all four dipping numbers while lowest water absorption levels were observed for 2 and 5 dipping numbers in PVAc-4wt.%. Water permeation levels of samples coated with PVAc-4wt.% increased with increasing dipping number. This unexpected result was attributed to the stable and non-disintegrating structure of the PVAc matrix which can reach to a limited swelling degree in aqueous solution (Strubing et al. 2008).

When the weight percentage of PVAc is low, density of the un-crosslinked polymer chains will be low and their distribution will be sparse in the solution. In such a case repeating dipping treatments may result in a much more porous surface coating and hydrostatic forces force H2O molecules to diffuse into the porous structure of the thicker polymer coating. PVAc-8 wt.% solution would be much denser in terms of the polymer chains inside, and polymer coating would be much more clustered (non-porous) resulting in a more hydrophobic structure.

Among the 8% PVAc coated samples, mortar samples with a surface coated with 5 times dipping, as mentioned before, were successful samples that provided the lowest water absorption. In contrast, 4% PBA coated samples reduced the absorption between 42-52% and caused the lowest reduction. One reason for this may be explained by the low concentration of polymer, but another reason may be that the performance of PBA polymer coatings is lower than that of PVAc coatings.

Another acceptable reason might be the probable extraordinary crystal structure of PBA. PBA solidifies and forms ring-banded spherulites surrounded by phase domains with an average size of ~150-200 μm upon cooling down and holding at ambient temperature (~28-30°C), (Nurkhamidah and Woo 2011). When the diameters of H2O molecules of 0.28 nm (Werneckle and Werneckle 2014) were considered, it would be expectable to attribute the lower performance of PBA to the diffusion of H2O molecules into the spherulites. In a relevant literature, the water diffusion constant of the isotactic polypropylene spherulites were found to be 15.9 μm²/s; while the corresponding value of trans crystalline polymer was 10 μm²/s (Ton-That and Jungnickel 1999).

The results in this study showed that there was a great reduction in the water absorption of the samples with the coatings applied on the mortar sample surface with the solutions of PVAc and PBA polymer materials. In addition, the effectiveness of each coated polymer type and the polymer content percentage gave different water absorption values as can be seen in the Fig. 7 and Table 3.

As expected, uncoated cement mortar samples (control samples) absorbed water very quickly, especially in the first 6 hours, and after 7 days, the total absorption was approximately 12 grams, which corresponds to 4% by weight. Experimental results showed significant improving effects of PVAc and PBA coatings on reducing water absorption and increasing the durability of cement mortar samples.

### 4.2 Reduction in water absorption

As can be seen from the Fig. 8, where the water absorption rates are given in different time periods (10 minutes, 1 hour and 1 day), the water absorption rates of all samples in the first 10 minutes are quite high compared to the water absorption rate they reach within 1 hour. However, especially after the 1st hour, water absorption occurs with a lower slope and the water absorption rates measured on the 1st day are almost negligible.

It is observed that the samples with the lowest water absorption rate in the first 10 minutes are covered with the percentage of PVAc (8%), and it is concluded that there is a systematic decrease in the water absorption coefficients within 10 minutes, 1 hour and 1 day. This phenomenon shows that the abrasion resistance of the hydrophobic polymer coatings was bonding well with the cement mortar surfaces. However, the surface bonding and transition zone between polymer coatings and cement mortar surfaces should be examined in detail with SEM analysis, which will
be carried out in the future studies.

4.3 Contact angle

Within the scope of the experimental study, the measurement of the surface contact angles was carried out on the surfaces of the cube mortar samples using the water dropping method. With the help of the dropper used, a drop of approximately 3 µl of water was dropped onto each sample surface. In order to observe the contact angle and spreading behavior of the drop of water dropped on the surface in more detail, each sample surface was photographed in high resolution. More specifically, detailed images of these photographs were taken to determine the behavior and surface contact angle of the drop on each sample surface and the surface contact angles were determined precisely. The wetting and spreading properties of the coated mortar surfaces were investigated by measuring the surface contact angle of the water using image processing as shown in Fig. 9.

Fig. 10 shows the water-surface contact angle of the uncoated (control) sample and polymer coated specimens. As can be seen, it was not possible to correlate surface angle results with number of dip layers for the specimen groups, since there is no significant relation is observed. However, considering all samples, it is seen that the surface angle is above 70° for all dip numbers of 8PVAc specimen group. In contrast, the average surface angles of the 4PBA specimen group is around 50°.

For some of the selected specimens the surface contact angle images are given in Fig. 11, in order to differentiate between the surface contact of water droplets with each different coating of cement mortars. As it can be observed from Fig. 11(a), control sample showed a very decreased amount of hydrophobicity and the surface contact angle of water droplet is 18.13° which is very low, and the water spread completely on the surface.

Surfaces are defined according to their water-surface contact angle ($\theta_c$) as superhydrophilic and superhydrophobic for contact angles of $\theta_c>130^\circ$ and $\theta_c<10^\circ$ respectively (Simpson et al. 2015, Koch and Barthlott 2009). In this study, while uncoated mortar samples exhibit significant superhydrophilicity due to the hydrophilic nature of cement surfaces and porosity, PVAc or PBA coated samples showed significant hydrophobic properties. It has been observed that the surface contact angles increase with increasing polymer concentration in the surface coating solutions. When the polymer content of PVAc coatings increased from 4% to 8%, a significant increase of about 75% was observed in water contact angle values, which is an indicator of hydrophobic properties (Fig. 10 and Fig. 11). It was observed that there is a molecular attraction between the water and the mortar sample in the samples with small water contact angle and the hydrophobic properties of the coating is low, thus more wetting occurs on the surface.

When we look at samples with a high contact angle, i.e., 4PVAc-2d, 8PVAc-5d, 8PVAc-10d, 8PVAc-20d and 8PBA-5d, we see that specimens exceeds the surface contact angle 70°, and the larger this contact angle indicates that the molecular attraction between the water and mortar sample surface will be weakened and thus wetting will be
very low. When looking at the surface contact angle differences in surface coatings made with different polymer types, regardless of the polymer % content, it was observed that the contact angle values were higher in PVAc surface coatings. Based on this, it is possible to say that PVAc surface coatings have shown more hydrophobic and water repellent properties in cement mortar samples.

As it can be observed from Fig. 12, surface contact angle value increases linearly ($R^2=0.891$) with the percent absorption decrease value, which is indicating increase hydrophobicity. This result is consistent with the results of previous studies in the literature (Arabzadeh et al. 2016, Al-Kheetan et al. 2019c). In addition, water absorption results and surface contact angle results were found to be very consistent for each sample.

5. Conclusions

In this study, the main objective is to evaluate the water repellency of polymer modified cementitious mortars and their applicability. Various polymer compositions with PVAc and PBA were prepared in the laboratory and their hydrophobicity was tested experimentally by surface coating on the cementitious specimens and their efficiency for the protection of the specimens from water absorption and surface contact angles of mortar specimens were studied. The measurement of water absorption amount is based on experimental results of sorptivity test, whereas the measurement of surface contact angles are based on image analysis results of high resolution images from the mortar specimen surfaces, in order to characterize the wetting ability of the surfaces. The results of this study show that the surface coating process applied using both PVAc and PBA polymer coatings reduces water absorption and increases surface contact angles of cement mortar samples and thus increases hydrophobic property. It was found that at different weight percentages, both PVAc and PBA coatings are capable of developing a hydrophobic effect on the cement mortar surface, but with different efficacy in reducing water absorption, which is also in agreement with the previous results of previous studies from the literature (Flores-Vivian et al. 2013, Muzenski et al. 2014, Zhao et al. 2018) Samples coated with 8wt.% PVAc and PBA solutions showed better hydrophobicity due to the increasing density of un-crosslinked polymer chains resulting better hydrophobic surface properties. The water permeation levels were in a narrow range in the mortar samples coated with PVAc-8wt.% for all four dipping numbers while lowest water absorption levels were observed for 2 and 5 dipping numbers in PVAc-4wt.% The enhancement in the hydrophobic properties were much more pronounced in samples coated with PVAc. PBA coatings could not enhance the hydrophobic properties of surfaces as expected probably due to the extraordinary ring-handed spherulite structure of PBA. Surface contact angle results were in good agreement with water intake results for both polymers. When both water absorption and surface contact angle results are evaluated together, we can say that 8wt.% PVAc coated samples show the highest hydrophobicity compared to the others. Therefore, it can be concluded that in addition to the type of polymer surface coating, also amount of polymer coating layers applied (dip number) and polymer weight percentages in the emulsions are of the utmost importance and should need optimisation for successful applications. Findings of this study will help to improve our knowledge of hydrophobic properties of coated cementitious mortars as a construction material and help to develop more enduring/water resistant concrete samples. However, further research is still needed to provide evidence of the hydrophobic performance and effectiveness of polymer coatings on the cement mortar and concrete.

Data availability

Some or all data, models, or code generated or used during the study are available from the corresponding author by request.

Acknowledgment

This work has been financially supported by the Scientific Research Project Coordination Center of Bahcesehir University with the research grant number of BAP.2019.01.02.

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