Internal hydrophobization of cementitious materials by using of organosilicon compounds

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Abstract. The low resistance to harmful acting of water confined in porous, cement-based materials is a negative feature. As the consequence of porous structure these materials have not sufficient resistance as some physical and chemical detrimental factors. The objective of this paper was to evaluate the impact of organosilicon admixture based on silane and siloxane on physical properties of cement mortar. Internal hydrophobization can significantly improve the durability of a cement materials. At this paper the results of mechanical strength, absorbability and capillary water absorption of internally hydrophobized cement mortar are presented. In addition, a contact angle test was used to assess the changes in wetting angle of cement paste.

1 Introduction

Cement based materials are one of the most popular materials in building construction. Despite the ecological trend, concrete is still commonly used materials in building industry. To meet the legal requirements and expectations of consumers, cement materials are subject to continuous modifications and improvements. However, this would not be possible without the development and production of new, more effective admixtures. The use of admixtures give substantial physical and economic advantages such as application of cement materials under aggressive conditions like low temperatures. When admixtures are used a several factors must be considered. Among the technological factors on which the effectiveness of admixtures depends, the most important are chemical composition, the presence of other chemical admixtures, the type and properties of mineral additives, aggregates and properties of the cement. The dosage and time of adding the admixture is also important. Each of these factors affects the effectiveness of admixtures, while the interaction between admixture and cement is particularly important [1-3]. The first modifications of cement materials by chemical admixtures (plasticizers as unmodified lignosulfonates) were carried out on an industrial scale in the 1930s. Subsequently at the turn of the 1960s and 1970s, a group of admixtures called superplasticizers appeared. At the beginning of 21st century the ultra-super plasticizers based on polycarboxylether (PCE) and modified with lignosulphonates were introduced. However, the history of using admixtures is much older. Their application began with the development of mineral binders. Already in the 3rd and 2nd century BC natural polymers were used as admixtures to modify the properties of the building materials used at that time [3, 4].

Admixtures are divided according to their ability to receive one, main, intended purpose. In accordance with EN 934-2: 2002 standard the following types of admixtures can be listed: water reducers (plasticizers and superplasticizers), accelerators, set-retarders, aerators, permeability-reducing admixtures. In this paper authors would like to focus on the last one.

Cement based materials used in industry contain pores. This characteristic property may be responsible for the penetration into the internal structure of the material of potentially damaging agents. Water (with contaminations), aqueous inorganic salt solutions or vapor can fill the material pores. It is potentially dangerous, because damage of material skeleton can take place in case of increasing volume of freezing water [5]. Moreover, crystalizing salts can cause damage. Moisture presence can lead to development of the molds and fungus as well. Required durability of concrete or mortar can be provided due to appropriate design of the mix composition and subsequent care during production and curing of material. Admixtures also come in handy. One of the first application used to protect cement-based materials against water ingress were products used externally on an already existing element. As a result of chemistry, engineering and technological development, permeability-reducing admixtures appeared that could already be used during manufacture process. This type of admixture is designed to give the material hydrophobic properties. Name "hydrophobic" comes from Greek. It literally means water (*hydro*) and fear (*phóbos*). In short, hydrophobization is a process of providing surfaces or entire internal structures hydrophobic properties i.e. water repellency. To illustrate this the contact (or wetting) angle is used (Fig. 1). Small contact angle (high wettability, $<90^\circ$) means that the surface is hydrophilic. Large contact angle (low wettability, $>90^\circ$) means hydrophobicity [7, 8].

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Fig. 1. Contact angle on hydrophilic and hydrophobic surface.

In simple terms, hydrophobization can be divided into surface hydrophobization (meaning the application of a hydrophobic coating to the surface or the penetration of the hydrophobic agent into the near-surface layers of the impregnated material) and volumetric/internal (understood as the use of hydrophobic admixtures during production e.g. with batch water or at the end of mixing). In case of surface hydrophobization there are two possible ways to form a protective layer. One of them occurs when the surface applied agent does not fill completely the pores and the capillary. The second scheme is about partial or complete filling of pores and capillaries in the surface layer [7,8]. Surface impregnation requires a considerable work and technical knowledge. It demands paying attention to several factors. The chemical composition, structure and absorbability of the substrate, its humidity and amount of applied hydrophobic product, its properties, concentration, viscosity, as well as the type of solvent have a significant impact on the quality of surface treatment. It should be remembered that salinity of material disqualifies the surface impregnation. The consequence of surface treatment of salinized material may be scaling of surface layers. The effectiveness of hydrophobization is significantly affected by the structure of pores or the amount of moisture in the material (it affects the adhesion of the coatings to the substrate). If there is excess water in the pores, it blocks the ingress of hydrophobic agent. However, the biggest disadvantage seems to be the fact that damage of the hydrophobic coating will cause a reduction in the quality of protection against water or its complete absence [7].

The answer to the above-mentioned disadvantages may be internal (volume) hydrophobization. Of course, it also has its own disadvantages. But, unlike surface treatment, it cannot be damaged by tension or other mechanical forces. Internal hydrophobization, in the presented research, is understood as the process of giving hydrophobic properties to cement based material in its entire volume due to the use of appropriate chemical admixture. The hydrophobic admixture fills both the near-surface pores and the internal pores, creating a homogeneous material [7].

There are different hydrophobic admixtures in terms of the chemical composition and mechanism of action. Namely: stearates (Fig. 2), oleates (Fig. 3) and based on organosilicon compounds (e.g. silanes or siloxanes) (Fig. 4 and Fig. 5). Stearates, as salts of fatty acids, are classified as non-reactive hydrophobizing compounds. The most commonly used are calcium, magnesium,

sodium and zinc stearates. Stearates are only a physical water barrier. The second group of hydrophobic admixtures are oleates classified as reactive substances. The most popular is water-soluble sodium oleate. Hydrophobization occurs as a result of reaction with the lime. Organosilicon compounds (key representatives are silanes and siloxanes) based admixtures are the youngest, but with great potential, generation of hydrophobic agents [7-9].

Fig. 2. Structure of stearates.

Fig. 3. Structure of oleates.

Fig. 4. Structure of silanes.

Fig. 5. Structure of siloxanes.

1.1 Organosilicon compounds

Organosilicon compounds contain, at least, one substituent organic group (e.g. methyl or ethyl group) attached to silicon atom directly through a carbon atom. Silanes and siloxanes do not differ with respect to their acting, but in the structure and size of the molecule. Silanes are monomer, siloxanes are oligomer. The molecular weight of silanes is around 178, siloxanes around 400-600. The great advantage of organosilicon compounds is the creation of a permanent connection with the cement matrix of the finished product as a result of a chemical reaction. As a result of the chemical bonds formed, the surface of the pores becomes hydrophobic, and the penetration of water into the material structure is blocked, while maintaining vapor-permeable abilities. The polysiloxane chain, consisting of alternate located oxygen and silicon atoms (-O-Si-O-Si-O-), is the main structure of agents based on organosilicon compounds. The structure of substituent groups affects the variety of spatial arrangement that can be formed from basic chains. [7-9]. Organosilicon compounds are amphiphilic. It

means that they are intermediate between inorganic and organic compounds. They combine organic action with the chemical properties of inorganic silicon. The organic function of silicon-based agents facilitates reactions with other polymers, including reactions with each other. The inorganic function of silicon allows reaction with many inorganic substrates (e.g. cement phases). The use of only inorganic silicon compounds (water glass or fluosilicates) did not meet expectations. The use of organosilicon compounds, through the use of nanotechnology and obtaining a monomolecular layer (one molecule thick), special coverage results securing materials against water. The impregnation used does not close up pores, present in the material, however, causes that water is not drawn into them as a result capillary effect [10].

In our study one of tested admixture is based on silane. Silanes are the smallest molecules with the lower molecular weight (they are monomer). Molecule of silane contain only one silicon atom. A suitable organic (alkyl) group, responsible for hydrophobicity, may be attached to the silicon atom in silane molecule. The longer the chain of attached alkyl group, the better steric protection of Si-O bond. It makes admixture based on silanes unique in hydrophobization of cement-based materials. The most popular silanes, for hydrophobization, in the construction industry are alkyltrialkoxysilanes (e.g. isobutyltriethoxysilane, n-octyltriethoxysilane or iso-octyltriethoxysilanes) [11].

The main ingredient of second admixture used is polysiloxane. Siloxanes are macromolecular, oligomeric polymers which molecules are based on siloxane (Si-O-Si) chains. Siloxanes mostly are modified by methyl groups attached to the silicon atoms. But they can be substituted by other organic groups. Polysiloxanes are the most important group of polymers. Given the hydrophobic properties, they resemble paraffin. The longer the alkyl substituent, the better the water repellency of polysiloxanes. But, in practice, substituents above than propyl are not used [7,11].

When it comes to available scientific literature, there are many publications in the case of surface hydrophobization of concrete (or mortar) by organosilicon agents. It seems that is well-recognized issue. There are significantly less scientific publications about internal (named also as volume or bulk) hydrophobization of concrete. Scientists are trying to add various organosilicon agents as concrete admixtures. Both in the form of emulsions and powders. The impact of using different dosage is also checked. There is even less papers about internal hydrophobization of cement mortars. In 2010 M. Najduchowska and P. Pichniarczyk [12] investigated the influence of hydrophobic agents (among other polydimethylsiloxane (PDMS)) on the properties of cement and gypsum mortars. The impact of silane (n-octyltriethoxysilane) and siloxanes (PDMS) based hydrophobic powder on cement mortar, but with addition of zeolite, examined in 2013 V. Spaeth, J-P. Lecomte, M-P. Delplancke, J. Orlowsky and T. Büttner [13]. N. Milenković at el. [14] at 7th International Conference on Water Repellent Treatment and Protective Surface Technology for Building Materials in Lisbon in 2014 presented the results of non-ionic emulsion of a n-octylethoxysilane used as integral water

repellent. V. Spaeth at el. [15] at 5th International Conference on Water Repellent Treatment and Protective Surface Technology for Building Materials in Brussels in 2008 presented the results of their own research on various forms of admixtures (pure organosilicon compound, emulsion and powder) based, among others, on polydimethylsiloxane and triethoxy(octyl)silane. Naturally, it is not all available scientific literature. Only those are cited which are similar in used compounds and tests to this paper.

As it has already been mentioned, volume treatment has significant advantages compared to surface one. The material is waterproof in its entire volume, which makes it impossible to significantly reduce the protection against water in the case of destruction of its top layer. The objective of the research presented in this paper was to investigate the influence of two different organosilicon admixtures on properties of cement mortar and verification of the possibility of internal hydrophobization by using commercially available admixtures. Our aim is to confirm the correctness and effectiveness of using water-repellent admixtures available on the market and confirmation or undermine the promises of admixture producers. Identification of weaknesses of the above-mentioned admixtures will be eliminated. It allows to create an admixture that would not only reduce the penetration of water in the material but also improve its other properties, or at least, not worsen them. Organosilicon compounds and polymers, due to their structure, seem to be perfect as admixtures for mortars and concretes. Researchers are still looking for the one that will be the most suitable and examine many of them. New papers appear presenting the influence of not previously tested organo-silicon compounds (or already knew but with different substituents), dosed in different amounts, ways or form on the properties of cement-based materials. In our opinion, the interaction between hydrophobic admixture and cement matrix, particularly change of microstructure, and hence change of properties of material, are a significant issue which needs to be considered concerning the strength, wettability and durability of cement-based materials. In order to confirm that used hydrophobic admixtures have an influence on the cement mortar properties, the following test were carried out: mechanical, absorbability and capillary water absorption tests. In addition, a contact angle test was used to confirm the hydrophobic effect.

2 Materials, methods and samples preparation

2.1. Materials

The three main types of cement mortars were prepared. Reference composition containing three constituents: cement, water and sand. The other two types of cement mortars were prepared with two different hydrophobic admixtures with three various dosage: 1%, 2% or 3% of water-repellent per cement mass. The mortar compositions are presented in Table 1. Amounts of ingredients shown in Table 1 represent the mortar

compositions per 256 cm³ batch of cement mortar (according to Polish standard PN-EN 196-1). Used admixtures contains, as a main component, various organosilicon compounds. The first one is an emulsion based on poly(dimethylsiloxane) - PDMS. The other admixture is an emulsion of alkyl-alkoxy-silane: triethoxy(octyl)silane - OTES. Both admixtures were supplied by their manufacturers and both were recommended for internal hydrophobization. The PDMS admixture manufacturer assure that thanks to the content of active polymer, which binds to cement components, the admixture ensures hydrophobicity. The emulsion should significantly reduce the water absorption (even by up to 80%), improve resistance to atmospheric and biological factors, reduce the tendency to salt crystallization, mix well with mass, has no toxicological hazards and it is easy to use (product is intended to be used with batch water). The characteristic data of the PDMS admixture are: appearance: milky liquid, pH: 6.5 – 7.0, density: 0.98 – 1.02 g/cm³, content of the active polymer: 70%, type of solvent: water. The other admixture (based on OTES), despite the other main ingredient, has similar description. The manufacturer describes the admixture as a non-ionic alkoxysilane emulsion. He declares that his hydrophobic admixture has extremely strong water-repellent properties and the ability to effectively reduce the absorbability of cement-based building materials. Silanes delivered react with cement and other components during cement binding. The use of admixture during production ensure significant reduction of capillary water absorption, does not affect water vapor permeability, guarantee high resistance to the penetration of water and salt contained in it and resistant to weather conditions and UV radiation. Moreover, admixture is stable over time and resistant to weather conditions. The characteristic data of the OTES based admixture are: appearance: milky white liquid, pH: 4.0 – 6.0, density: 0.94 ± 0.02 g/cm³, content of the active polymer: ~50 %, type of solvent: water. For each type of mortar Portland Cement CEM I 42.5 R was used and the water to cement ratio (w/c) was equal to 0.5.

Table 1. The composition of cement mortars.

	Water repellent agent		
	PDMS/OTES		
	1%	2%	3%
W/C	0.5		
Cement [g]	450		
Water [g]	1350		
Sand [g]	225		
Admixture [g]	4.5	9.0	13.5

2.2 Sample preparations

Prismatic specimens with the dimensions 40×40×160 mm were prepared according to standard EN 196-1. Each batch of mortars were prepared in a laboratory. Dosages of individual components for one mixing (256 cm³) are presented in Table 1. The proper amount of admixture (1%, 2% or 3% per cement mass) were added to the water and mixed. It was particularly important for the PDMS admixture, which has a higher viscosity than the other one. After 24 hours specimens of cement mortar were demolded and stored in water for 27 days. In addition to the impact of hydrophobic admixtures on the basic properties of mortars, their influence on the contact angle was also determined. This study was carried out for cement pastes. They, like mortars, were prepared on Portland Cement CEM I 42.5R with w/c = 0.5. The amount of added admixture had been maintained at 1%, 2% and 3% per cement mass.

2.3 Methods

After 28 days of curing the reference and hydrophobized samples of cement mortar have been prepared for absorbability and capillary water absorption test. Mechanical tests of compressive strength have been carried out after 1, 2, 7 and 28 days of curing according to Polish standard PN-EN 1015-11. The mechanical test was carried out on half of broken prismatic samples with dimensions 40×40×80 mm. To absorbability test three prisms of each type of mortar were used. Before the test specimens were dried, until constant weight. Afterwards mortar prisms were immersed progressively with water. Subsequently the weight of samples was checked, every twenty-four hours, until constant weight was obtained. To capillary water absorption test three halved (40×40×80 mm), prismatic mortar samples (six in total) were used. The same as for the absorbability test, after 28 days of curing, mortar beams were put in an oven and pull out after drying completely. Next sealing agent was applied on the all four side surfaces (40×80 mm) of mortar prisms and after 24 hours samples were positioned vertically and immersed in water to a depth of 1 cm. Weight measurements were made after 10 min, 30 min, 60 min, 90 min, 2h, 3h, 4h and 24h after immersion. The capillary water absorption test was carried out according to standard EN 1015-18. The wetting angle test is about putting drops of selected liquid (water, diiodomethane and propylene glycol) on surface of the cement paste sample. Subsequently a contact angle is determined by using a goniometer (in this study: OCA15EC of the DataPhysics company equipped with a Braun DS-D 1000 SF camera and syringe). Drops of measuring liquid were observed by SCA20 program.

3 Results

3.1 Air content in fresh mortar

Aeration of fresh mortar was measured according to standard EN 1015-7. Air content in fresh cement mortar is determined by the pressure air measurement method. A specially intended test device is used. A sample of fresh mortar is placed in the cylindrical container of the device and then tightly closed with the cover. Then, using the valves the space under the cover (above the mortar) should be filled with water until all the air above the mortar is removed. Using appropriate valves, air must be forcibly driven into the sealed device, and then equalize the pressure and read the air content. The results shown in Table 1 are the average of two measurements.

Table 1. Air content in fresh mortar.

Water repellent agent	Amount of admixture	Aeration [%]
Reference	0%	10.5
PDMS	1%	26.0
	2%	26.0
	3%	26.0
OTES	1%	11.0
	2%	11.5
	3%	13.0

3.2 Mechanical tests

Results shown in Table 3 the average value taken over six, halved samples left after flexural strength test. Both admixtures decrease mechanical strength of cement mortar. But this is definitely more noticeable in the case PDMS admixture. It decreases the mechanical properties by almost 50% in comparison with reference sample. Smaller, but still apparent, impact on compressive strength has OTES admixture (by 15%). It is noteworthy that the addition of 1% silane-based admixture does not decrease significantly compressive strength after 1, 2, or 7 days of curing.

Table 3. Results of mechanical tests after 1, 2, 7 and 28 days of curing.

Water repellent agent	Amount of admixture	Compressive strength [MPa]			
		1 day	2 days	7 days	28 days
Reference	0%	14.40	23.04	31.16	45.25
PDMS	1%	5.03	8.76	10.47	25.84

	2%	3.83	8.31	9.02	23.53
	3%	3.65	9.07	11.91	22.16
OTES	1%	13.17	22.34	32.71	38.35
	2%	8.27	18.22	28.72	38.19
	3%	7.05	17.18	27.59	36.36

3.3 Absorbability test

Absorbability test shows first differences between used waterproofing admixtures in terms of hydrophobic effect. Cement mortars admixed triethoxy(octyl)silane has definitely lower water absorption. Addition of 3% of OTES provide decrease in absorbability from 7.6% to 2.2%. No significant effect of 1% and 3% in absorbability reduction for poly(dimethylsiloxane) admixture is quite striking. It might be due to the irregular distribution of the PDMS admixture in the mixing water, and later in the mortar itself, due to its viscosity. The amount of three beams may also be insufficient.

Table 4. Results of absorbability test of hydrophobized cement mortar.

Water repellent agent	Amount of admixture	Absorbability [%]
Reference	0%	7.6
PDMS	1%	6.3
	2%	3.7
	3%	6.5
OTES	1%	3.9
	2%	2.3
	3%	2.2

3.4 Capillary water absorption test

This test revealed the biggest differences between both hydrophobic admixtures. Besides the fact that both of them decrease capillary water absorption coefficient only silane-based one do it perfectly. Already addition of 1% of poly(dimethylsiloxane) admixture decrease capillary water absorption coefficient by half. The lowest value was obtained for amount of 3% of triethoxy(octyl)silane-based admixture. Also, the lowest of mass changing was observed for specimens admixed OTES admixture.

Table 5. Results of capillary water absorption test of hydrophobized cement mortar.

Water repellent agent	Amount of admixture	Capillary water absorption coefficient, $\frac{kg}{m^2 * min^{0,5}}$
Reference	0%	0.206
PDMS	1%	0.115
	2%	0.106
	3%	0.098
OTES	1%	0.042
	2%	0.023
	3%	0.020

Fig. 6. Mass changes of cement mortar samples during capillary water absorption test.

3.5 Contact angle test

Wetting angle test were carried out for cement paste with w/c ratio equal to 0.5. Contact angle is considered as measure of hydrophilicity and hydrophobicity. It is commonly accepted that if the contact angle at which a drop of water contacts with the surface is less than 90 degrees, the surface is hydrophilic. When it exceeds 90 degrees, the surface is referred as hydrophobic. Despite what authors wrote above it is noticeable that addition of PDMS admixture hinders the wettability of the sample surface. Contact angle decrease form 14.59° to 64.04°. The best hydrophobic effect is observed for 3% of silane-based admixture. The contact angle is 106.91° and it deserves to be called superhydrophobicity.

Table 6. Results of contact angle test for water.

Water repellent agent	Amount of admixture	Contact angle
Reference	0%	14.59°
PDMS	1%	53.68°
	2%	43.64°
	3%	64.04°
OTES	1%	65.93°
	2%	86.36°
	3%	106.91°

Fig. 7. The surface of reference sample of cement paste with drop of water.

Fig. 8. The surface of cement paste with 3% of PDMS with drop of water.

Fig. 9. The surface of cement paste with 3% of OTES with drop of water.

4 Discussion

This set of results illustrate very well the influence of silicon-based, hydrophobic admixtures on cement mortar properties. The decrease in compressive strength caused by both the silane-based and siloxane-based admixture is immediately noticeable. The larger drop in mechanical strength was observed for the content of 3% of poly(dimethylsiloxane) based admixture than 3% of the triethoxy(octyl)silane one. Comparing the results of compressive strength of cement mortar, after 28 days of curing, siloxane-based admixture reduces mechanical strength by more than 50% and silane-based one by less than 20%, compared to reference samples. Both values are significant and not acceptable. Interestingly, Najduchowska and Pichniraczyk [12] did not observe any deterioration of mechanical properties of mortars. The addition of 2% PDMS based admixture did not affect the compressive strength, and the addition of 5% of admixture even caused an increase in strength. Spaeth et al. [13], who used silane and siloxane based hydrophobic powder as admixtures, noted increase in compressive strength of mortar for silane powder and mix of silane and siloxane. While the reduction in mortar strength occurred for PDMS powder. Milenković et al. [14] noticed a decrease in compressive strength of cement mortar by 18% for addition of 2% of silane emulsion. Spaeth et al. [15] also observed a decrease in comprehensive strength for silane and PDMS emulsions. It is reasonable to expect that hydration of cement is slowed down by the addition of organosilicon admixtures. Such a conclusion is also made by Spaeth et al. [15]. Triethoxy(octyl)silane, as monomer, must undergo a hydrolysis reaction first. Subsequently, the reactive silanol groups (Si-OH) can attach to the cement phases (with ethanol release). These silicon-based compounds interact or react with the cement phases (like alite, belite or tricalcium aluminate) or CSH phase making material hydrophobic. The addition of hydrophobic admixture based on organosilicon compounds leads to a decrease of the interaction of cement phases with water, and hence to interfere with the increase in mechanical strength of cement-based material. In case of poly(dimethylsiloxane) the similar reaction, as for silane, is expected. PDMS is a polymeric compound. So, the hydrolyse reaction has not taken place. It seems

most probable that when the PDMS attached the cement, the $-CH_3$ groups are detached, which attach the hydrogen atom (a methane molecule is formed), causing excessive aeration of the mortar. Thus a decrease in mechanical strength. Aeration of fresh reference mortar is 10.5%, and mortar with poly(dimethylsiloxane) 26% for each dosage of admixture. In case of OTES based admixture, the aeration was 11%, 11.5% and 13% respectively for 1%, 2% or 3% of addition of admixture. Moreover, it should be remembered that ingredient in admixture in addition to the main silicon-based, there are other agents, such as surfactants, emulsifiers etc., which we know nothing about and they can also affect the properties of mortars and concretes.

Both admixtures give a noticeable hydrophobic effect in the form of decrease in capillary water absorption. The addition of admixture based on PDMS successfully reduces capillary water absorption coefficient from $0.115 \text{ kg}/(\text{m}^2\text{min}^{0.5})$, by adding 1% of poly(dimethylsiloxane) admixture, to $0.098 \text{ kg}/(\text{m}^2\text{min}^{0.5})$ for cement mortar containing 3% of PDMS one. OTES based admixture decrease capillary water absorption coefficient by almost 90% (from $0.21 \text{ kg}/(\text{m}^2\text{min}^{0.5})$ to $0.02 \text{ kg}/(\text{m}^2\text{min}^{0.5})$) compared to reference sample ($0.21 \text{ kg}/(\text{m}^2\text{min}^{0.5})$). In all four cited papers [12,13,14,] authors noticed decrease in capillary water absorption. Spaeth et al. [13] the best results achieved for silane/siloxane mix, but they also perceived that silane powder gave better results than siloxane admixture.

While the results of absorbability for triethoxy(octyl)silane-based admixture are quite predictable (an increase of dosage causes a decrease in absorbability from 7.6% for reference sample to 2.2% for addition of 3%), the ones for siloxane-based not. The addition of 2% of poly(dimethylsiloxane) admixture leads to the lowest value (3.7 %) of absorbability. It can be caused by not homogeneous distribution of the admixture in the mortar samples (closer to the surface) due to the admixture viscosity. The number of tested specimens could also be insufficient. Najduchowska and Pichniarczyk [12] noted a slight decrease (from 7.8% for reference sample to 6.5%) in absorbability of mortar containing 2% of PDMS admixture. It is similar to our observation made for addition of 1% or 3% of poly(dimethylsiloxane) based admixture.

As assumed, the contact angle gave the final evaluation of the admixture effectiveness. In this respect, a silane admixture was better. It was revealed that it can be classified as superhydrophobic admixture. The surface of reference sample become relatively easily saturated with water (the contact angle is 14.59°) while the average wetting angle of mortar with 3% of OTES admixture is 106.91° (surface is hardly wettable).

The presence of non-polar, organic groups, such as methyl groups ($-CH_3$) in case of poly(dimethylsiloxane) and octyl groups ($-C_8H_{17}$) in case of triethoxy(octyl)silane are responsible by internal hydrophobization of cement mortar and ensured noticeable hydrophobic effect. As the capillary water absorption and absorbability test, as well as contact angle one, proved the longer alkyl chain of octyl group provided better internal hydrophobic effect by greater decrease in capillary water absorption and

absorbability of cement mortar and significant increase in contact angle of cement paste. In case of polymer-based admixture it is related to the steric effect. The octyl ($-C_8H_{17}$) groups take more space (have a larger size) than methyl ($-CH_3$) moieties.

5 Conclusions

In view of the obtained results the following conclusions were drawn:

- The addition of the organosilicon admixtures to cement paste and mortar with batch water in an amount of 1 - 3% of the cement mass have a major impact on the basic properties of hardened mortars such as strength, absorbability and water absorption caused by capillary adsorption.
- Both hydrophobic admixtures give a noticeable effect as treated internally by decrease the capillary water absorption and increase the contact angle. But the admixture based on triethoxy(octyl)silane give better results in this case.
- Unfortunately, in both cases, a decrease of compressive strength is visible. For poly(dimethylsiloxane) admixture a decrease of mechanical strength of cement mortar is by average of 50%.
- Both admixtures ensure an increase in wetting angle. The OTES based admixture is more effective than PDMS one in case of capillary absorption.

As the consequence of using organosilicon admixture internal hydrophobization is provided, but it has its own restrictions. First of all, the hydrophobic effect hinges on the type of silicon-based compounds and present of non-polar, organic groups attached to silica atom. The early results are very promising. However, the issue of internal hydrophobization definitely requires more studies and research.

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