PROTECTION OF FIBER CEMENT BOARDS WITH SILICONES AND ACRYLICS: FROM INTEGRAL TO SURFACE PROTECTION

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ABSTRACT

Protecting fiber cement boards against external environment and water ingress is key to the durability and service life of the boards. The market is requesting improved aesthetics which can be achieved by application of paints, typically formulated with effective and durable acrylic polymer dispersions. Matt look or "natural look" boards can be protected as well with silicone water repellents.

Fiber cement board can be protected in the bulk thanks to innovative silicone-based integral water repellents. Different physical processes can be used to ensure retention of the water repellent into the boards, despite the filtration step. These mechanisms of retention are discussed.

Invisible protection can be provided by silicone-based post treatment water repellents. Impregnation hydrophobers are now well known and industrially proven. However, they cannot control completely the onset of efflorescence despite a strong reduction of water penetration.

This paper shares the development of new waterborne hybrid compositions, based on a combination of chemistries (silicone and acrylic technologies) which achieve the invisible protection of the boards with excellent, UV resistant control of efflorescence.

KEYWORDS:

Acrylics, Silicones, Water repellent, efflorescence, fiber cement board

INTRODUCTION

Reinforcement of cement-based materials with various forms of fiber has been common practice for a long time (Johnston, 2001). The first modern fiber reinforced construction materials were asbestos-cement boards used as flat or corrugated sheets. Asbestos fibers were mixed with a slurry of cement and water in so-called Fiber Reinforced Cement Boards (FC).

FC boards made with asbestos fibers showed good mechanical strength and durability, however, the hazards of asbestos fiber to human health led to its ban in the construction industry in many countries. Alternative fibers such as refined cellulose pulps and synthetic fibers such as polyvinyl alcohol fibers (PVA) or polypropylene fibers (PP) started to be used as replacements in the 1970 (Quang, 2010).

The successful replacement of asbestos fibers with cellulose fibers raised new challenges, not only in the way to manufacture the boards but also the properties of the final boards. For example, cellulose-based boards have a higher tendency to absorb water and are more susceptible to degrade due to water absorption.

Cementitious composites based on cellulose fibers often suffer from poor dimensional stability when subjected to changes of relative humidity, limiting their long-term durability (TONOLLI, 2016). Water transport in the cementitious matrix induces cellulose fiber swelling, which may impact the fiber/cement adhesion. This phenomenon triggers the migration of water soluble salts such as Portlandite ($Ca(OH)_2$) to fiber lumens, leading to hardening of the fiber and decreasing of the material ductility (SAVASTANO et al., 2009; MOHR; 2005). This leads to so called fiber mineralization.

Several modifications of the boards formulation have been tested with the objective of minimizing the effects of the degradation of cellulose fibers such as the use of industrial and mineral by-products (FILHO; 2013; MOHR, 2007), the use of cellulose nanofibers from plant fibers or some modification of the curing process including the use of accelerated carbonation (HOYOS et al., 2019; OH et al., 2022). The curing treatment in a CO_2- saturated environment, known as accelerated carbonation, aims at reducing the alkalinity of the cement matrix, making the environment less aggressive to cellulose and increasing the density (by reduction of the porosity and the permeability, improving the dimensional stability of the final product) (FIORONI et al., 2020; PIZZOL et al., 2014).

Boards based on cellulose fibers are therefore more susceptible to problems associated with water absorption than asbestos reinforced boards; and this can be a major problem facing manufacturers as they moved to replace asbestos by cellulose fibers. This is especially demanding for roofing applications where the boards are more exposed to challenging weather conditions. When boards absorb too much moisture, other phenomena can occur, such as:

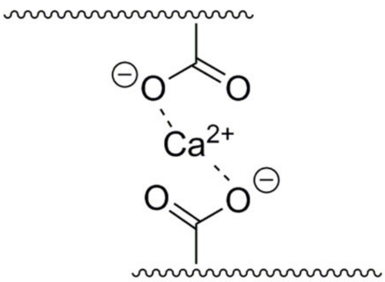
- Reduced dimensional stability.
- Reduced freeze/thaw resistance leading to cracking and warping.
- Potential for white efflorescence affecting appearance or coating durability.
- Reduced durability.

Coatings (formation of a continuous film at the surface of the boards) can be applied to protect the boards as well as to improve aesthetics. Typically, the coatings contain durable all acrylic binder, pigments, fillers and additives necessary for successful coating process and film formation.

However, the coating can also degrade due to UV-light and exposure to alkaline environment, especially if a low durability binder is used. In addition, excessive water penetration can accelerate afore mentioned degradation mechanisms and can lead to defects to the coated substrate.

Mechanically unstable substrates (following lack of dimensional stability due to water absorption for example) can cause substrate or coating cracking, and in connection with poor adhesion, the coating can flake resulting in a catastrophic failure. Coating blistering is often due to moisture trapped between coating and substrate. In addition, water can transport various species into the coating or coating interface or at the surface of uncoated boards.

Alkaline conditions typical of cement-based materials can degrade coatings by alkaline hydrolysis as well.



A durability study on a model polymer dispersion suggested that the degradation is not only due to alkali, but also because of Ca^{2+} ions. It was suggested that film hardening and Tg change due to prolonged contact with $Ca(OH)_2$ were caused potentially by cross-linking with Ca^{2+} ions. The Figure 1 depicts the suggested mechanism for Ca^{2+} cross-linking (VYORYKKA, 2017).

Figure 1. Calcium ion cross linking with acid groups.

Efflorescence mechanism

White deposit of salts on cementitious surface following transport by water of soluble salts is known as efflorescence and is often responsible for visible surface defects. So-called primary efflorescence occurs during or immediately after cement setting, while secondary efflorescence occurs on already hardened material. Subfloresence describes crystal growth inside a material. Subflorescence crystals are formed when water percolates or rises through a material followed by crystallisation of dissolved salts as the moisture evaporates. Efflorescence requires water soluble salts in the substrate (or alternatively transported from soil etc.), moisture to allow the salt to be dissolved and a path and a driving force to drive the water-soluble salts to migrate at the surface where water can evaporate and leave the salts to crystallize. Figure 2 depicts a schematic diagram on calcium carbonate efflorescence mechanism (DOW, 1983).

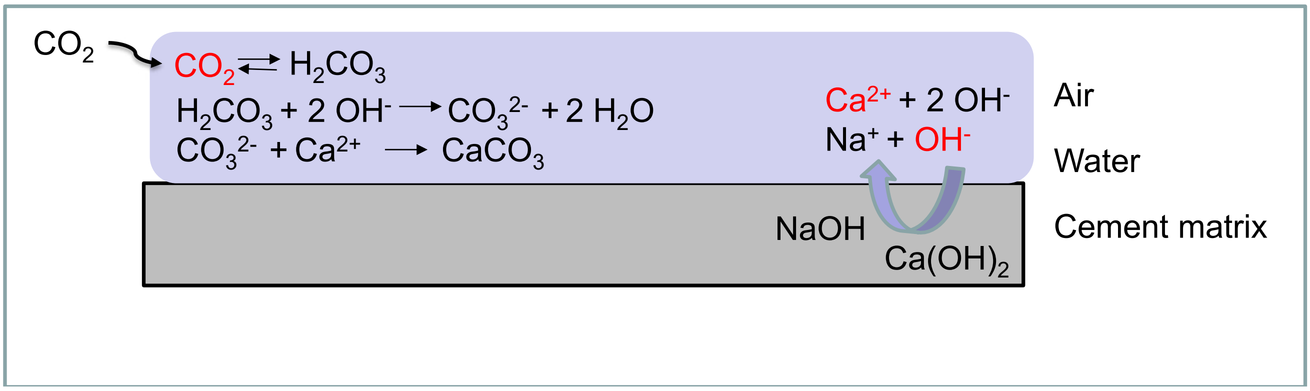


Figure 2. Schematic diagram illustrating calcium carbonate efflorescence mechanism originating from Ca(OH)2 migration to the surface of the cement based material.

Water plays an important role in many of the degradation routes as it can enter the boards or even the coating when the boards are in contact with dew, fog, rain, ground water or moisture from the interior. It is therefore important to minimize the water ingress in the substrate by optimization of the cement matrix and/or by using durable water repellent or film forming coating.

OPTIONS USED TO PROTECT FC BOARDS

In order to protect FC boards and increase their durability, boards can be:

Sealed with impregnation hydrophobers. Silicone based sealers can be used to protect the boards when a matt, “natural” cement appearance is desired. Pre-primed with ‘universal’ primers based on film forming coating (typically based on acrylic polymer dispersions). Boards can then be post coated to the desired colour after being applied on the construction site.

Sealed OR Primed AND then top-coated with a film forming coating. Before painting, some manufacturers pre-seal with silicon-based penetrants before applying the acrylic prime coat and potentially top coat.

A last option consists in integrating the silicon-based hydrophober into the boards formulation to produce an “integral water repellent”. Silicon-based hydrophober is then used as a so-called admixture into the board formulation.

The following figure illustrates the different types of protections which can be used to extend service life of FC boards. These options are not mutually exclusive as boards modified with an integral water repellent can be post coated with an acrylic polymer dispersion. Similarly, boards can be sealed with silicone impregnation and then post coated with a coating.

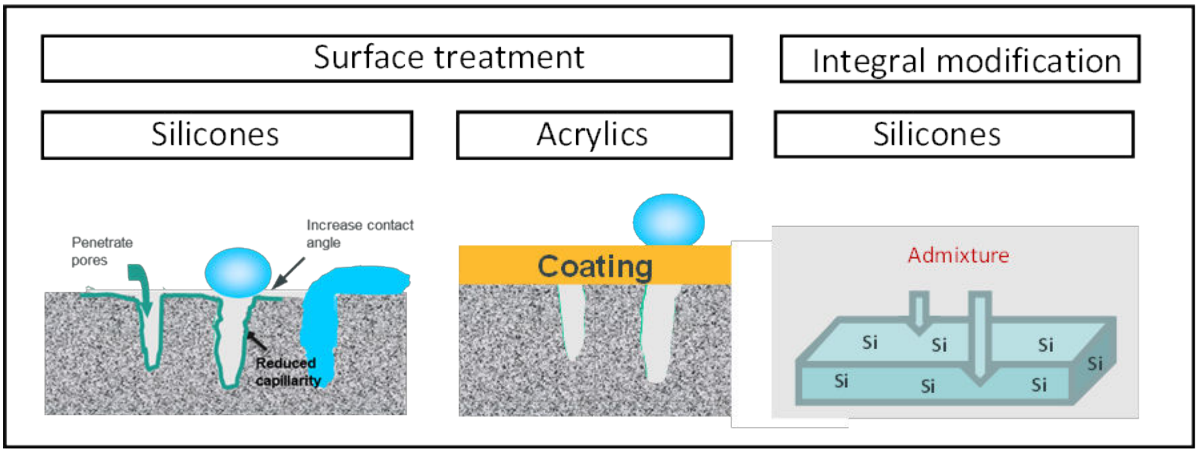


Figure 3: Schematic description of the different type of protection of fiber cement boards.

Modification of FC boards with silicone integral water repellents.

In the process of producing an "integral water repellent", the silicone will become an integral component of the board as it reacts with the cement matrix and therefore forms a water barrier throughout the entire board. One advantage of this approach would be that the FC products would be protected from water absorption from the time they are initially produced and would not depend on a post-treatment or protective coating to provide improved water resistance.

Another useful, and valuable advantage of using an admixture to "build-in" water resistance will be the ability to cut FC products at the location where they will be installed, and still maintain protection that may be lost when using a post-treatment or coating. Extending this logic, the FC products will also retain protection even if sealers, coatings or edge sealants like caulking are damaged or not applied perfectly. In this context, new integral water repellents were developed and commercialized based on liquid silicone resin (LECOMTE, 2012).

One of the challenges to solve to enable the concept of integral modification is to ensure retention of the additive into the board itself despite the filtration step typical in the Hatscheck process. Some physical interactions need therefore to take place to ensure that the additive is not flushed away with water during the final dewatering step.

Liquid silicone resins are very water insoluble. Droplets of the liquid silicone resin will therefore tend to adsorb on available surfaces like the cement particles or the filler. It was observed that a silicone resin (DOWSIL™ Z-6289 Resin) mixed into a mixture of water and cement could not be solvent extracted with hexane, meaning that the silicone resin has adsorbed on the cement particles and probably started to react, ensuring its anchorage to the particles.

This technology of integral modification of fiber cement boards is now industry proven and widely practiced. The water-insoluble, liquid silicone resin like DOWSIL™ Z-6289 Resin requires however some vigorous mixing into the slurry to ensure proper dispersion of tiny insoluble droplets into the slurry. In order to ensure an easy and quick mixing of the silicone-based integral water repellent into the water-based slurry, a new water-dilutable integral water repellent was developed, based on a micro-encapsulated silicone resin. DOWSIL™ IE 6686 Water Repellent has been designed to be water dilutable and easy to mix in a water-based slurry (MILENKOVIC, 2016).

Being a water-dilutable additive, the retention mechanism had to be based on other physical phenomena. A designed flocculation of DOWSIL™ IE 6686 Water repellent in liquid media with high pH and high calcium content (typical from cement slurry) ensures retention into the board, despite the filtration process (LECOMTE 2018). The silica shell around the active material is also leading to minimum impact on the cement hydration step (CARETTE, 2021).

Surface protection of FC boards.

Sealing or impregnation of FC boards can be achieved with silanes, polydimethylsiloxane, silicone resin or mixture of them. Silicone is a generic term describing polymers encompassing a siloxane backbone (based on the repeating unit: Si-O-Si). Polydimethylsiloxanes or PDMS (illustrated in Figure 4) are the most common siloxane used worldwide, both in terms of volume and application. Terminated by a silanol group (as in Figure 4), they are reactive and can be anchored on construction material matrices.

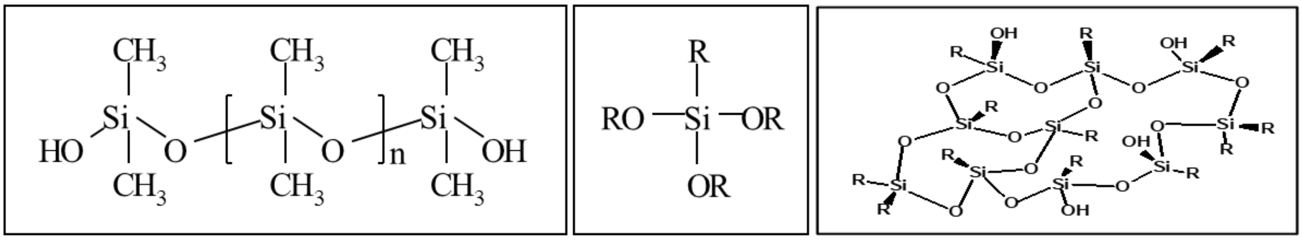


Figure 4 Structure of polydimethylsiloxane, alkyl trialkoxysilane, and silicone resin. R can be ethyl, methyl, phenyl or octyl group.

Silanes are molecules based on one silicon atom which bears four substituents. Alkyl trialkoxy silane shows a good reactivity towards construction materials (reactions during which alcohol is released as leaving groups). The R groups (most often, isobutyl or octyl chain) confer the hydrophobic character to the substrate to which the silane is anchored. Silicone resins are produced by controlled hydrolysis and condensation reactions of silanes and are therefore usually higher Mw molecules.

Water-borne all acrylic dispersions are commonly used in fiber cement coatings as they can provide long lasting protection of the substrate and durable aesthetics. They are co-polymers of different acrylic monomers and made using free-radical polymerization. Emulsion polymerization process allows to manufacture high molecular weight acrylic copolymers resulting in low viscous water-borne dispersions. The type of the acrylic monomers and their glass transition temperature define to large extent the glass transition temperature of the resulting copolymer and its film formation capability. These water-borne acrylics produce homogenous film under appropriate conditions after the water is allowed to evaporate. Excellent film formation is typically a prerequisite to achieve the best performance out of such acrylic dispersion.

Invisible protection and important reduction of water penetration within fiber cement boards can be achieved after application of silicone water repellents. However, it appears that excellent control of efflorescence onset cannot be achieved by the application of silicone water repellents only. Application of acrylic topcoat is certainly an excellent and proven method to control efflorescence onset, but is not invisible, and lead to glossy or shiny surfaces. There was therefore a need for a new invisible protection of fiber cement boards which could both control water ingress and strongly minimize efflorescence onset.

A new acrylic/silicone hybrid has been developed to provide invisible protection to fiber cement boards against water penetration and efflorescence onset. This new hybrid formulation concept has been tested on fiber cement boards. Both unmodified board and boards modified in the mass with silicone integral water repellent have been used for the optimization of the formulation.Efficiency of this new acrylic/silicone hybrid commercialized under the name DOWSIL™ IE-6710 emulsion is reported hereunder.

EXPERIMENTALS

FC sample preparation and product application

Fiber cement boards coming (of density around 1.5 kg/l) from European or Middle East manufacturers were used in this study. All the boards were conditioned in a similar manner by drying them in an oven at 50°C during 24 hours and left 1 day at room temperature before the application of any formulations. Solid particles or dust at the surface of the samples were removed by compressed air. A new acrylic/silicone hybrid (DOWSIL™ IE-6710 emulsion) was used during this study.

The acrylic/silicone hybrid was first diluted such as to reach different active content in the dilution (for example 5, 10, 15 or 20%). Diluted Acrylic/silicone hybrid were applied with a traditional paint brush on the boards. FC samples were weighted before and after each application to calculate loading rate. Treated boards were left at room temperature during at least 7 days before testing to give enough time for the hydrolysis and condensation reaction of silane and film formation of acrylic polymer to take place.

DOWSIL™ IE-6710 emulsion solid content is 50% and the Minimal Film Formation Temperature (MMFT) is below 16°C. Although DOWSIL™ IE-6710 emulsion can be used as such, it has been diluted such as to reach different active contents during this study. DOWSIL™ IE-6710 emulsion has been designed to be used as unique protective agent (to be used alone and not requiring further formulation beside dilution) but it could be used as a surface treatment as well (primer) before application of a film forming top coat.

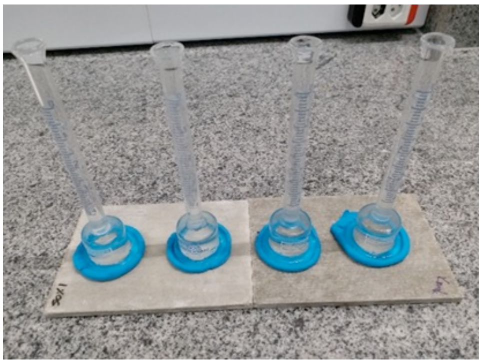


Figure 5 – Illustration of Rilem test (Karsten tube affixed on boards and filled with water0

Determination of water absorption with Rilem test

Rilem test is a quantitative test to measure the amount of water absorbed by a porous substrate as a function of time.

The procedure implies affixing tightly a Karsten tube on the substrate with a putty (see Figure 5). The tube is filled with water through the upper open end. Water absorbed is read on the graduation after different periods of time (Figure 5)

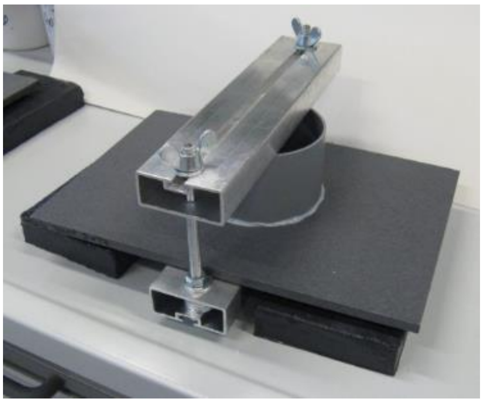


Figure 6 – Illustration of Cobb test.

Determination of water absorption with Cobb test

Figure 6 display Cobb test where a section of cylinder (in this case, PVC pipes) is affixed on the boards with silicone sealant and pressed to avoid water leakage. Boards were weighed before 200 g of water is added into the cylinder.

On a regular basis, water is removed from the cylinder, the cylinder and the boards are quickly wiped and then weighed again to measure the absorption of water by the boards.

The cylinder is then re-filled with water for increased period of time. Water absorption is recorded as a function of contact time with water.

Resistance to dry UV exposure

Boards treated with the new acrylic/silicone hybrid were placed in a dry UV chamber for extended period of time (2000 hours).

UV light was provided with 3 Ultra Vitalux 300 W lamp (see Figure 7). The forced precipitation test method was used to assess durability of the treatment after UV exposure.

Figure 7 : Interior of the dry UV chamber in which the reference and post treated boards were submitted to accelerated ageing under UV light.

Testing resistance to efflorescence

Efflorescence can be accelerated or initiated in the lab by creating conditions leading to penetration of water inside the FC, dissolution of calcium hydroxide (Portlandite), transfer of the solution to the surface followed by precipitation of the salt at the surface of the FC. Exposure to water can lead to penetration of water but is often not enough to initiate efflorescence. Application of cold temperature at the top surface of the board can drive the precipitation of the calcium hydroxide, leading to the acceleration of the efflorescence process.

The following "forced precipitation" accelerated testing method was used in this study.

A FC boards is placed horizontally on a lab bench. Very cold water (either melting from ice or stored in a refrigerator) is applied at the surface of the boards. The cold temperature of water at the surface will force precipitation of calcium hydroxide solution, which would be coming by hydric movement coming from penetration followed by migration to the surface.

Boards are visually observed to highlight onset of efflorescence. In order to highlight the smallest onset of efflorescence, wiping of the boards with a black fabric was carried out, making feasible to observe the smallest precipitation of calcium hydroxide at the surface and which could not be observed visually.

Figure 8 is illustrating the test. Parts A and B of the board are treated with DOWSIL™ IE-6710 emulsion. Part C is not treated. Picture 1. Board with ice applied on the board. Picture 2: boards after a few hours, after melting of the ice. Picture 3 : board after a couple of days, showing efflorescence onset on the untreated part of the board.

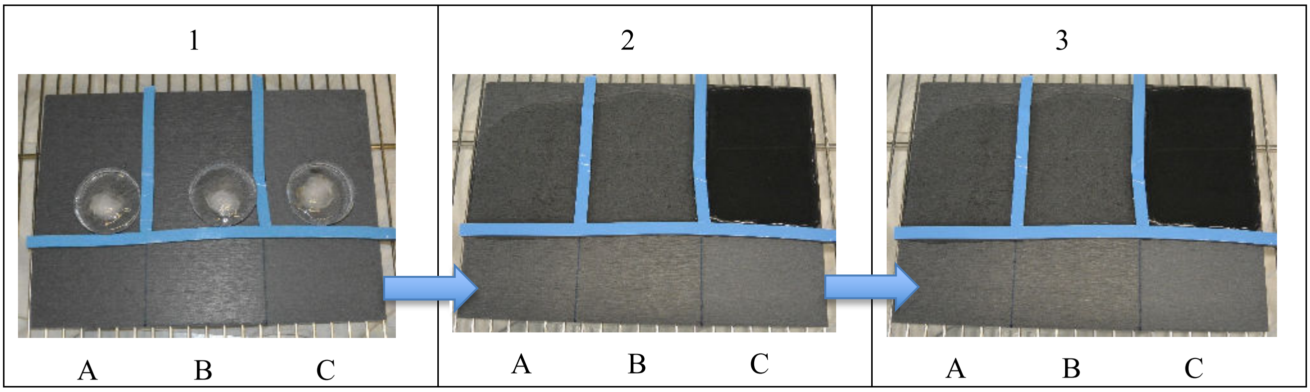


Figure 8 : Pictures illustrating the efflorescence test.

RESULTS AND DISCUSSION

A new acrylic/silicone hybrid formulation (DOWSIL™ IE-6710 emulsion) was developed as post treatment for cement-based materials.

Water absorption of post treated concrete blocks

This new formulation was first tested to seal a standard, commercial concrete flagstone.

All surfaces of concrete blocks were post treated with 200g/m² of diluted DOWSIL™ IE-6710 emulsion (such as to reach 7 and 14% active content).

Post treated concrete blocks were tested according to EN 13580, meaning they were immersed under water such as to ensure access of water to the bottom surface and to have 3 cm of water on top of the blocks.

Water absorbed by the blocks are measured after 1 and 24 hours immersion. Percentage of absorption is referred to the dry weight of the blocks. Figure 9 is showing the water absorption by the post treated blocks after 1 and 24 hours immersion. The results show the high efficacy of the DOWSIL™ IE-6710 emulsion in reducing water absorption.

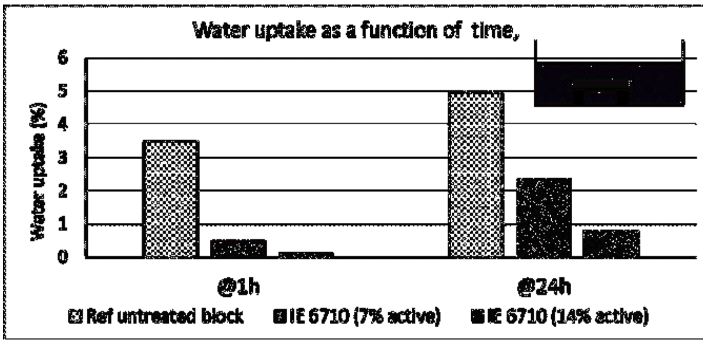


Figure 9: Absorption of water of reference and post treated concrete blocks under immersion as a function of time (blocks were treated with 200g/m² of diluted DOWSIL™ IE-6710 emulsion at 7 and 14% active content.

Water absorption of post treated fiber cement boards tested by Cobb test

A set of FC boardsproduced through an Hatschek process (air cured, 8 mm thick, no post treatment) were treated by brushing with different dilutions of the new acrylic/silicone hybrid. Post treated boards were tested with a Cobb-test. This test is somewhat more demanding than Rilem test as higher hydrostatic pressure is applied at the surface of the treated boards.

Figure 10 shows the absorption of water of reference and boards post treated with DOWSIL™ IE-6710 emulsion.

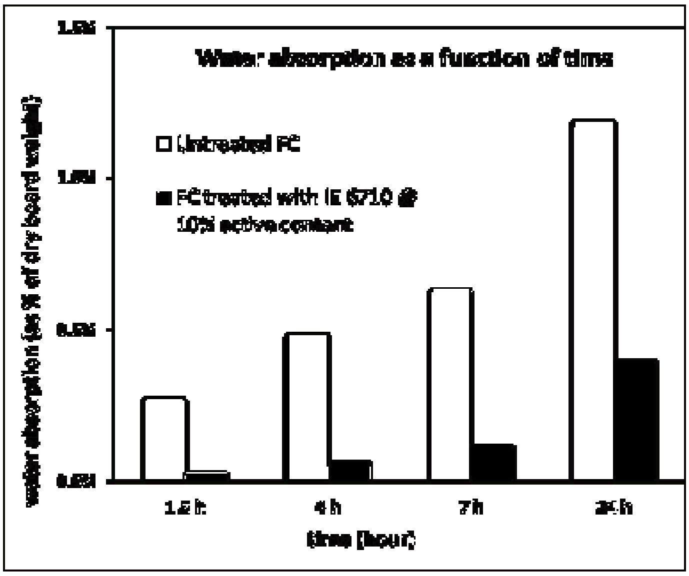


Figure 10: Absorption of water assessed by Cobb test of reference and post-treated board with 150 g/m² of DOWSIL™ IE-6710 emulsion diluted at 10% active content.

Water absorption of post treated fiber cement boards tested by Rilem test

A set of FC boards, produced through an Hatschek process (air cured, 9 mm thick, no post treatment) were treated by brushing with different dilutions of the new acrylic/silicone hybrid. The hybrid formulation was diluted such as to reach 5, 10 and 15% active content. 100g/m² of diluted formulation was applied on each board.

Water absorption by the top surface was assessed by using Rilem test as a function of time and is reported in Figure 11.

A very significant reduction of water penetration as tested by Rilem test is observed, even when the boards are treated with the most diluted mixture.

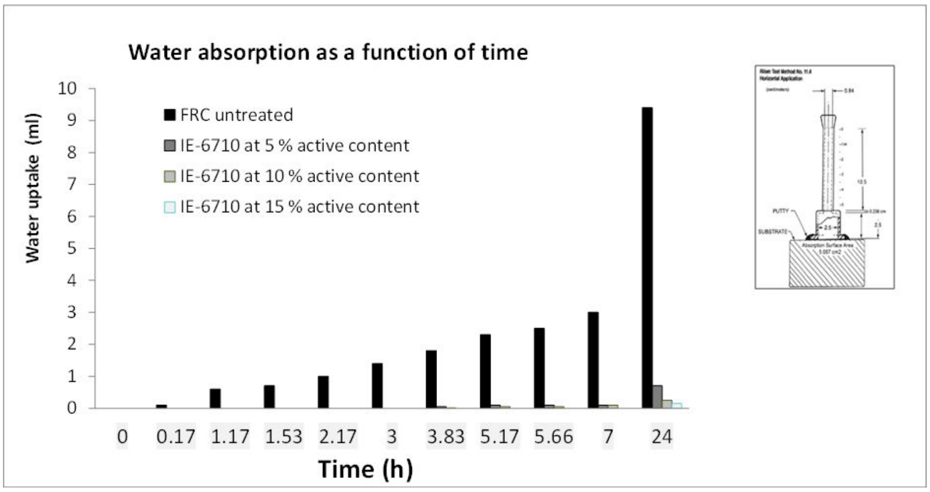


Figure 11. Absorption of water assessed by Rilem test of boards treated with different dilution of formulation DOWSIL™ IE-6710 emulsion.

Resistance to efflorescence.

Another set of untreated FC boards, produced through an Hatschek process(air cured, 9 mm thick), post treated by brushing with different dilutions of the new acrylic/silicone hybrid. The hybrid formulation was diluted such as to reach active content of 10, 15 and 20% active content. 100g/m² of dilute formulation was applied on each board.

Boards were placed horizontally on a lab bench. Large ice cube were placed on the boards, left to melt and wet the surface of the boards. Water is left there till complete evaporation and drying of the boards. Surface of the boards are visually inspected after evaporation of water.

Figure 12 is showing dark grey boards after efflorescence accelerated testing (reference board : A, board treated with diluted version at 10% active content= B, @ 15%Active content = C and 20% active content = D).

A large surface area is covered with white precipitate at the surface of board A. No white precipitate is observed at the surface of boards B, C and D. Application of the acrylic/silicone hybrid is clearly protecting against the onset of efflorescence.

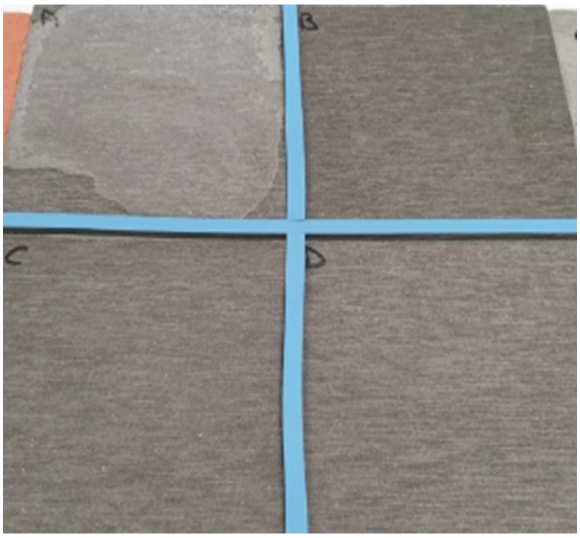
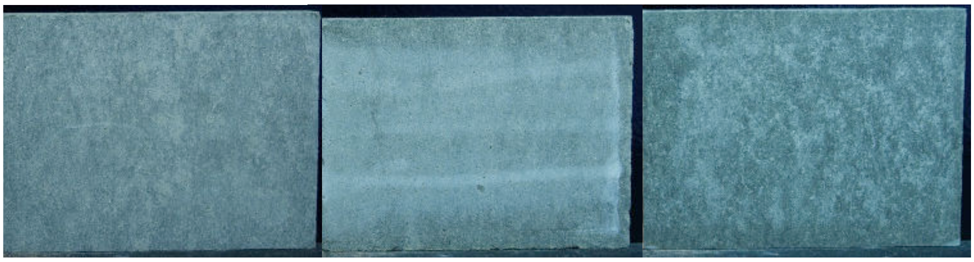


Figure 12: visual observation of reference (A) or treated FC boards (treated with DOWSIL™ IE 6710 emulsion diluted at 10%Active content = B, 15% active content = C and 20% active content = D) after the accelerated efflorescence test

Accelerated ageing under UV exposure.

Boards post treated with the new acrylic/silicone hybrid formulation were aged for extended period of time under dry UV light before being submitted to the accelerated efflorescence test. Excellent control of onset of efflorescence could still be evidenced after UV exposure as long as 5000 hours.

Another set of boards modified with an integral water repellent (DOWSIL™ Z-6289 Resin) and surface treated with 100g/m² of a dilution of DOWSIL™ IE-6710 emulsion at 7.3 % and 14.4% active content were aged for 2000 hours in a QUV and visually assessed to identify efflorescence onset after ageing. Clear onset of efflorescence is observed on the reference boards which is modified in the mass with an integral water repellent but not post-treated (picture B). Good protection against efflorescence is observed on the boards which are modified in the mass with an integral water repellent and are post treated with the acrylic/silicone hybrid (picture C, Figure 13).



A : before ageing	B: reference board After 2000h QUV	C : post treated board after 2000 h QUV

Figure 13 : Picture of fiber cement boards treated in the mass with DOWSIL™ Z-6289 Resin before ageing (picture A). Board not post-treated after 2000 h QUV (picture B). Board post treated with DOWSIL™ IE-6710 emulsion after 2000 h QUV.

This set of results shows that the post treatment of fiber cement boards, whether modified in the mass with an integral water repellent or not, is leading to strong reduction of efflorescence onset including after extended accelerated ageing under UV light or after QUV ageing.

CONCLUSIONS

Providing long term protection of fiber cement boards can be achieved thanks to the use of different technologies. This set of data is illustrating that combination of acrylic and silicone technologies enables to provide invisible protection of the boards which protect efficiently against water penetration and efflorescence onset. Hybrid technology enables board protection by different mechanisms of action. Silicone water repellents reduce the affinity of treated boards for water through chemical modification of the pores surface, while acrylic chemistry is forming physical film blocking the ingress of water. The technologies complement each other to achieve invisible, but still long-lasting protection.

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