PROTECTION OF FIBER CEMENT BOARDS WITH SILICONE AND ACRYLIC MIXTURES

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ABSTRACT

This paper will explore the benefit of combining silicone and acrylic chemistry to protect fibre cement boards. Silicone impregnation can be formulated with film forming acrylic polymer dispersion for achieving better protection of cement boards, especially against efflorescence. The benefit of formulations combining both technology for protection of the surface or the edges of the boards exceeds the benefit of both individual chemistry. Impact of selected formulations on the surface and edges protection, as well as efflorescence of FC boards will be shared.

KEYWORDS:

Silicone water repellent, acrylic polymer dispersion, efflorescence.

INTRODUCTION

Reinforcement of cement-based materials with various forms of fibre has been common for a long time [1]. The first modern fibre reinforced construction materials were asbestos-cement boards used as flat or corrugated sheets. Asbestos fibres were mixed with a slurry of cement and water to reach a fibre content around 6-18% of the dry formulation in Fibre Cement boards (FC).

FC boards made with asbestos fibres showed good mechanical strength and durability, however, the hazards of asbestos fibre to human health have lead to its ban in construction industry in many countries. Although asbestos is still used in many countries, there is a major global shift away from using asbestos by replacing it with fibres much safer for human health. Alternative fibres such as refined cellulose pulps and synthetic fibres such as polyvinyl alcohol fibres (PVA) or polypropylene fibres (PP) started to be used as replacements in the seventies[2,3].

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

Movement of water within the pores can also lead to transport of portlandite close to cellulose fibres, accelerating their degradation. [6].

Simply stated, cellulose containing board will generally be more susceptible to problems associated with water absorption than asbestos reinforced boards; and this can be a major problem facing manufacturers as they move to replace asbestos by cellulose fibres. Carbonation is another factor which may negatively impact boards durability [4]. When boards absorb too much moisture, many potential problems can occur, such as:

- Reduced Dimensional Stability
- Reduced Freeze/thaw resistance leading to cracking and warping
- Potential for white efflorescence salts affecting appearance
- Reduced durability

Formulations for FC boards vary greatly throughout the world. The fibre source, the cement source and the type and amount of siliceous extenders vary dramatically from plant to plant. Coupled to this is the fact that manufacturers use many different cure processes and post treatments which all mean that each plant will be different and may require slightly different solutions. Different technical solutions can and are being used to combine aesthetic and the need to reduce water absorption.

When FC siding panels are manufactured, they will be sold to the end user either 'raw', primed or post finished [5].

- *Raw*: No post treatment in the factory. All coating takes place on site (or not at all).
- *Pre-primed*: Many manufacturers prime boards with 'universal' primers (typically acrylic based) before they leave the factory. They are then post coated to the desired colour after fixing on site.
- *Sealed:* Silicone based sealers can be used to protect the boards when raw cement appearance is desired.
- *Sealed AND top-coated*: Before painting, some manufacturers pre-seal with silicon-based penetrants before applying the acrylic prime coat and potentially top coat.
- *Integral water repellent:* A last option consist in integrating the silicon-based hydrophober into the board formulation to produce an "integral water repellent". Silicon-based hydrophober is then used as a so-called admixture in the board formulation.

The primary purpose for coating panels is for aesthetics. As long as a coating is fully protective then the water absorption of the board will be reduced through the coated surface. Once the coating fails; so does the protection. Coatings provide little or no protection against ingress of moisture at the edges or the rear surface of the board. By pre-sealing boards with silicone penetrants on the front and rear surfaces as well as the edges prior to coating, then far greater long term protection of the boards can be achieved. If treated in this way; the FC boards and panels have long term protection against water ingress regardless of the life and/or quality of the paint treatment used. If the silicon-based hydrophobe is used as an admixture, the boards can also be cut on the job site without impairing the protection against water penetration. This last option is raising interest amongst the FC manufacturers to further reduce risk of litigation or to eliminate one post treatment step.

One of the purposes of surface protection is to ensure that the visual appearance of cement-based surfaces is retained for a longer period of time. Efflorescence is one potentially deleterious process which can detrimentally alter the visual appearance of FC due to the formation of a white haze on the surface. Efflorescence is due to the movement of water containing dissolved salts through the interconnected pore system from the bulk of the mortar to the external surface. When the water evaporates, the soluble salts will crystallise and leave a white haze on the surface. Primary efflorescence is due to migration of calcium hydroxide produced during the initial phase of cement hydration to the surface. Upon reaction with atmospheric carbon dioxide, it produces water-insoluble calcium carbonate, which is not easily washed or brushed off.
Efflorescence can thus be minimised by reducing the capillary water absorption and transfer of water through the cement matrix. This strategy proved to be not efficient enough in some situations.

Edges of boards are a weak part especially prone to water ingress. Water absorption by the edges can negatively impact the appearance of boards treated with transparent or semi transparent coating. Minimizing water absorption by the edges is then key to maintain appearance and integrity of the boards.

Silane and siloxane are well known and used as hydrophober and consolidant in the field of stone conservation [9]. Combination of organic solvent solutions of silane and acrylic polymer were described in the context of building preservation [10]. Building up on this concept, but adapted for the context of fibre cement protection, blends of acrylic polymer dispersions and silicone water repellent emulsions were developed to be used for FC protection to minimize water penetration and subsequent negative consequence (efflorescence, aesthetic issues, …). The blends mixing an impregnation water repellent and a film forming polymer dispersion were tested to protect either the FC surface or the edge of the boards and results are described in this document.

EXPERIMENTAL

FC sample preparation and product application

Air-cured boards coming from a European manufacturer were used in this study.
All the boards were conditioned in a similar manner by drying them in oven at 50°C during 24 hours and let 1 day at Room Temperature before application of any formulations. Solid particles, dust at the surface of the sample were removed by compressed air.
Non-ionic oil-in-water silicone emulsions based on silane, silicone resin as active material were used in this study.
Water-dilutable acrylic copolymer dispersions were used.
The mixtures tested in this study were prepared by cold-blending the silane/silicone resin emulsions, the acrylic polymer dispersions, and potentially additives such as coalescing agent. These mixtures will be referred as "acrylic/silicones mixes".
Acrylic/silicone mixes were applied with a traditional paint brush. FC samples were weighted before and after each application to calculate loading rate.
Treated boards were left at room temperature during at least 3 days to give enough time for the hydrolysis and condensation reaction of silane and film formation of acrylic polymer to take place.

Deep coating treatment

Deep coating treatment was performed on some boards. Boards were placed together with a clamp and were immersed for 10 min in different dilution of the formulation optimised for edge sealing. They were removed and let to dry at laboratory conditions for 7 days.

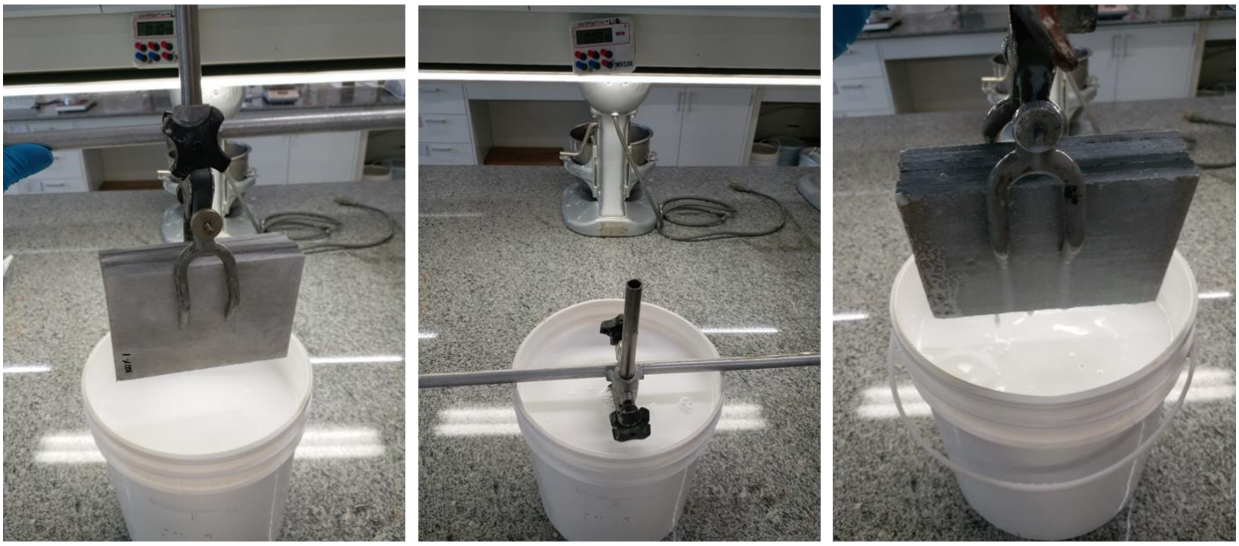


Figure 1 – Deep coating treatment

Determination of water absorption by the edges.

Samples of reference and treated FC boards are dried in an oven at 50°C for one day before testing. They are then placed in a vat so that the 0.5 cm of the base of the FC samples are in contact with water (# 2).

At fixed times, samples are removed from water, quickly towelled (#3) in order to weight only absorbed water, weighed and replaced in water (#4). The percentage of water uptake is calculated according to Eq. 1:

$$\text{Percentage of water uptake} = (Wx - Wi)/Wi \times 100 \quad (1)$$

Where Wx is the sample weight after x time in water (in grams) and Wi is the initial weight.

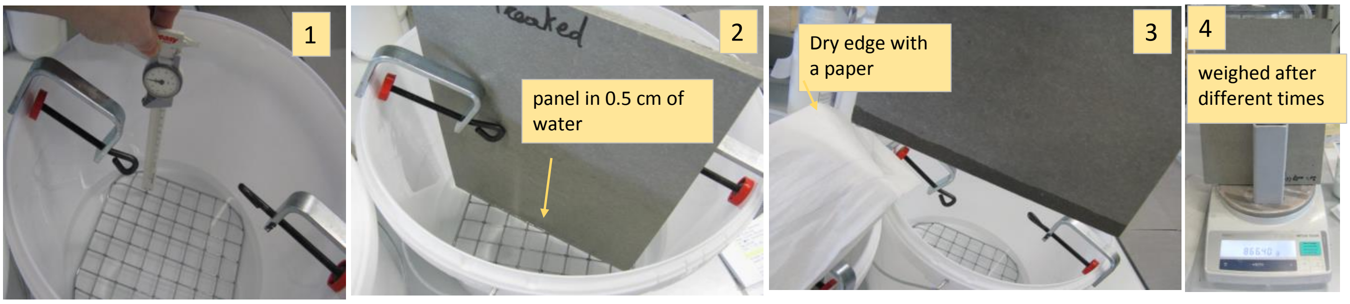


Figure 2 – Measure of water absorption by the boards edges.

Determination of water absorption by the surface with Rilem test using Karsten tubes

Rilem test is a quantitative test to measure the amount of water absorbed by a porous substrate in a time frame.
The procedure implies affixing tightly a Karsten tube on the substrate with a putty. The tube is filled with water through the upper open end. Water absorbed is read on the graduation after different periods of time.

Figure 3 – Illustration of Rilem test (Karsten tube affixed on boards and filled with water)

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. Some methods were described elsewhere [7].

Exposure to water can potentially lead to penetration of water. Application of cold temperature at the top surface of the board can drive precipitation of the calcium hydroxide, leading to accelerated efflorescence process. Two test methods were used in this study.

Forced condensation method

A FC board is placed on top of a cold container (such as the surface of the board is getting colder). The assembly is then placed in a weather chamber at high relative humidity. The cold surface leads to forced condensation of cold water at the surface of the FC.

Forced precipitation

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.

RESULTS AND DISCUSSION

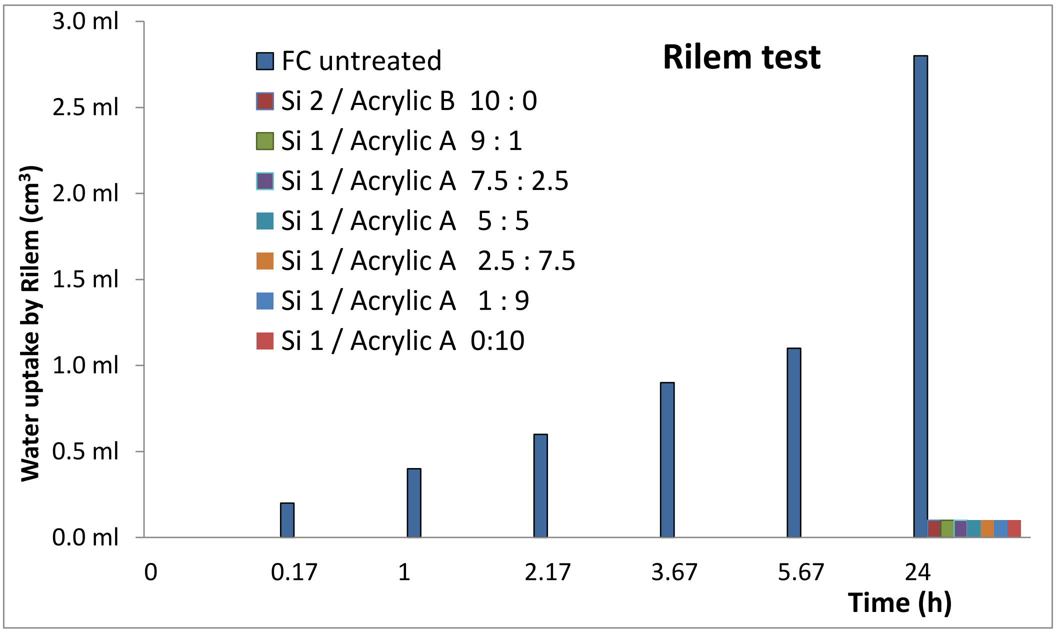
Silicone/acrylic polymer dispersion for boards top surface protection

In order to test how silicone based water repellent and acrylic polymer dispersions could be combined, 2 different silane/siloxane emulsions and two different acrylic polymer dispersions were used. Two combinations of silicone water repellent (Si 1 and Si 2) and acrylic polymer dispersion (Acrylic A and Acrylic B) were prepared, at different ratio. The different formulations were diluted such as to reach 15% active content and applied on the boards with a brush (150 ml/m2) and let to dry/react at room temperature for at least 3 days.

Table 1: Formulations based on a mix of acrylic dispersion and silicone emulsion tested for surface treatment of FC boards.

	Si (parts)	**Acrylic (parts)**			**Si (parts)**	**Acrylic (parts)**
FRC untreated						
Si 1 + Acrylic A	10	0		Si 2 + Acrylic B	10	0
Si 1 + Acrylic A	9	1		Si 2 + Acrylic B	9	1
Si 1 + Acrylic A	7.5	2.5		Si 2 + Acrylic B	7.5	2.5
Si 1 + Acrylic A	5	5		Si 2 + Acrylic B	5	5
Si 1 + Acrylic A	2.5	7.5		Si 2 + Acrylic B	2.5	7.5
Si 1 + Acrylic A	1	9		Si 2 + Acrylic B	1	9
Si 1 + Acrylic A	0	10		Si 2 + Acrylic B	0	10

Resistance to water penetration into the FC surface was assessed by measured water penetration using the so called Rilem test.



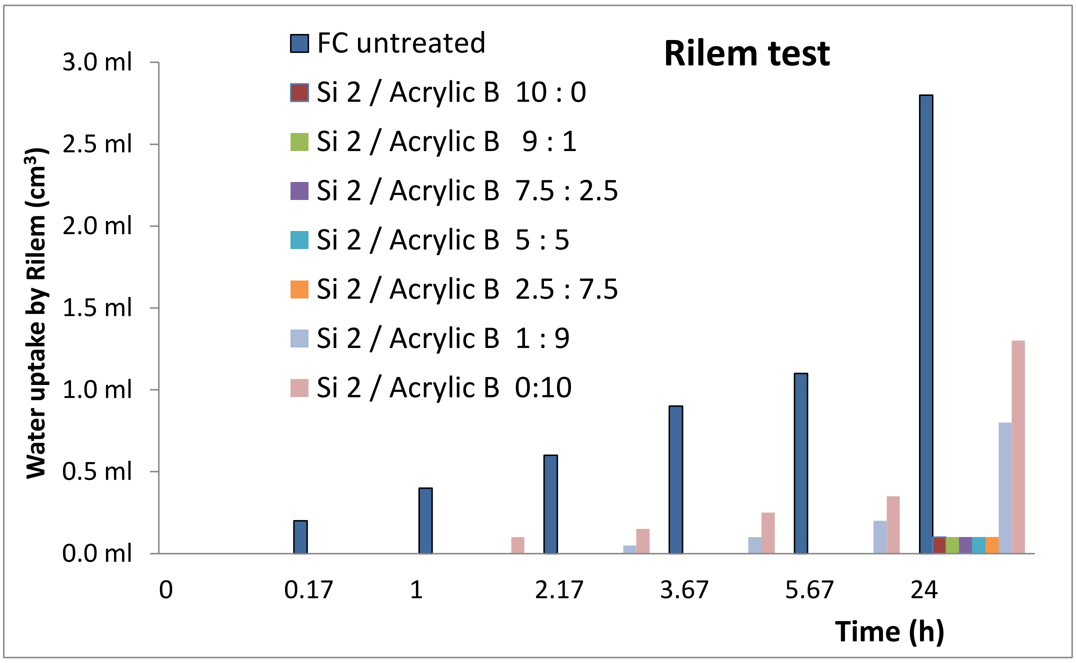


Figure 4. Water absorption as a function of contact time with water of reference and treated FC surface measured with the Rilem test

Water absorption as measured by Rilem test is plot as a function of contact time with water. It is clear that both acrylic or silicone technologies are efficient on their own to strongly minimize water penetration (despite the pure acrylic B which efficiency to reduce water penetration is somewhat lower). It is also clear that acrylic polymer dispersion and silicone impregnation can be mixed in different ratio to obtain the same excellent reduction of water penetration.

Table 2: Surface modification and efflorescence of FC boards treated with different formulations based on a mix of acrylic dispersion and silicone emulsion. Colour coding. Surface appearance and gloss (the darker the stronger the surface modification, rating). Efflorescence: the whiter, the higher the efflorescence observed after the efflorescence test). Rating is "0" for no modification or surface appearance, "+" slight surface modification, "++" : clear surface modification.

	15% active content		**Darkening**	**Gloss**	**Efflorescence**
	Si ratio	**Acrylic ratio**			
FRC untreated			0	0	++
Si 1 + Acrylic A	10	0	0	0	++
Si 1 + Acrylic A	9	1	0	0	++
Si 1 + Acrylic A	7.5	2.5	+	0	+
Si 1 + Acrylic A	5	5	++	0	+
Si 1 + Acrylic A	2.5	7.5	++	++	+
Si 1 + Acrylic A	1	9	++	++	+
Si 1 + Acrylic A	0	10	++	++	+

	15% active content		**Darkening**	**Gloss**	**Efflorescence**
	Si ratio	**Acrylic ratio**			
Si 2 + Acrylic B	10	0	0	0	++
Si 2 + Acrylic B	9	1	0	0	++
Si 2 + Acrylic B	7.5	2.5	+	0	+
Si 2 + Acrylic B	5	5	++	0	+
Si 2 + Acrylic B	2.5	7.5	++	++	+
Si 2 + Acrylic B	1	9	++	++	+
Si 2 + Acrylic B	0	10	++	++	+

Some modification of the FC surface appearance was visually observed after application of the different acrylic/silicone mixes. It was observed that at application of mixtures containing higher content of the acrylic polymer dispersion lead to some darkening of the surface and to some gloss.

Modification of the boards surface appearance are reported in table 2 using a colour coding : the darker the table cell, the stronger the darkening of the surface or the higher the gloss (also noted "++" in the table).

Resistance to efflorescence was assessed both by the "forced condensation" and "forced precipitation" test method. Efflorescence was visually assessed. Results of the forced precipitation tests are reported in table 2 using a colour coding: the whiter the cell, the stronger the efflorescence (also noted "++" in the cells to indicate strong efflorescence or "+" to indicate only small efflorescence)

It is observed that FC boards which are impregnated with silicone based water repellent, despite very low absorption of water, are still showing strong traces of efflorescence when tested according to the ”forced precipitation” efflorescence test. Efflorescence was as much or, even more visible than with the un-treated boards.

Dow and Glasser[8] proposed that formation of efflorescence is controlled by several processes, assuming water has already moistened the surface. They consist in the dissolution of salts (alkali or calcium –or others), dissolution of carbon dioxide into water and its conversion to aqueous species, diffusion of the reactants through solution and precipitation of calcium carbonate. Efflorescence at the surface will then appear after a cycle of dissolution of the salts at the water/pore surface interface, dissolution of carbon dioxide at the water/air interface (favoured by the presence of alkali in the water phase), diffusion of salts near the surface and precipitation of the poorly water-soluble calcium carbonate. The full cycle is “self-perpetuating” which means that the length of time the liquid water persist, will increase the amount of efflorescence which can be observed at the surface.

It is observed experimentally that when boards treated with a silicone water repellent only (Si 1 + Acrylic A 10/0 for example) are wet, water is standing for a longer period of time at the surface of the boards. Efflorescence is generated when salts dissolve in the pore water and migrate to the surface. But the pores must not be completely filled with water. Thin water films along the pore walls are enough to allow these reactions to occur[7]. It is hypothesised that this increased contact time with water at the surface of the boards is leaving more time for even slight penetration at the surface of the pores, followed by dissolution and migration of the salt to the surface. This hypothesis is graphically illustrated in the following figure (Figure 5).

It is observed that un-treated boards are absorbing water more quickly and more deeply into the board. It is hypothesised that this transport phenomena of water is transporting the salts inside the boards or to the back of the FC board (Fig 5),

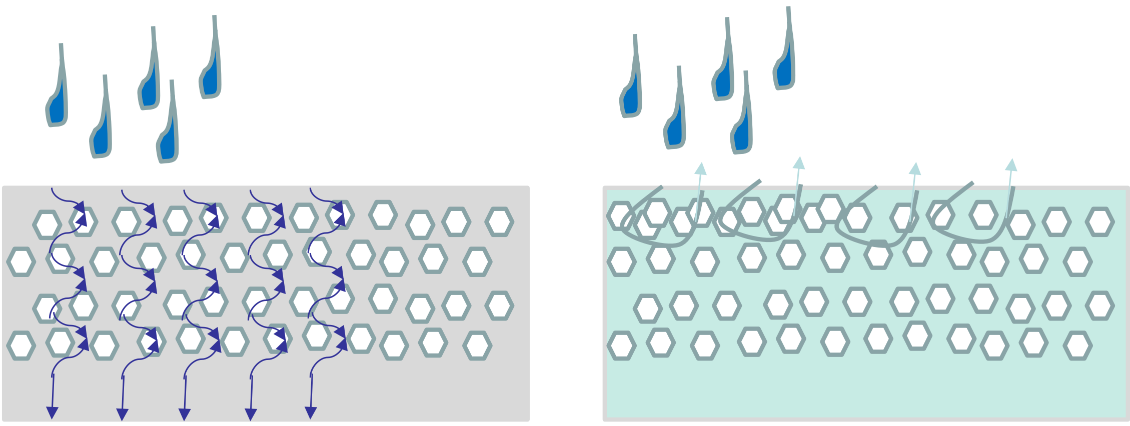


Figure 5: Illustration of the hypothesis suggested to explain the strong efflorescence observed with boards treated with silicone water repellents.

Combination of impregnation silicone-based water repellent and film forming acrylic polymer dispersion appears to be a promising technical option to treat the surface of FC boards, which needs to keep a ‘natural look’ and yet demonstrate an improved resistance to water penetration and efflorescence. Based on Dow and Glasser’s model[8], these acrylic/silicone mixture must minimize one or several of the processes required for the efflorescence to occur.

Silicone/acrylic polymer dispersion as edge sealer

The edge of FC behave differently that the top surface, as the edge is showing the different layers to the external environment. Quick preliminary tests showed that the formulations optimised for the surface protection were not necessarily efficient for the protection of the edges.

Efficiency of silicone water repellent emulsion with acrylic polymer dispersion as edge sealer for FC was assessed by applying a selected formulation (named here *formulation A*) to the edges of the boards with a small brush. The silicone emulsion used in Formulation A was based on a mix of silane, silicone resin and siloxane. The oil-dilutable acrylic copolymer dispersion used in *formulation A* was used in combination with a coalescing agent to insure good film formation on the edge of the boards. *formulation A* was diluted such as to reach 20% active content and applied on the edges with a brush such as to reach a loading of 60g/m².

Absorption of water by the edges was assessed both visually. Boards treated on the surface with a transparent, non water-absorbing film forming coating were treated on the edges by the selected formulation.

Absorption by the edges was assessed by placing the boards vertically in a plastic basin, partially filled with water, such as 0.5 cm of the boards are immersed in water. Appearance or weight of the boards was analysed as function of time (see fig 6).

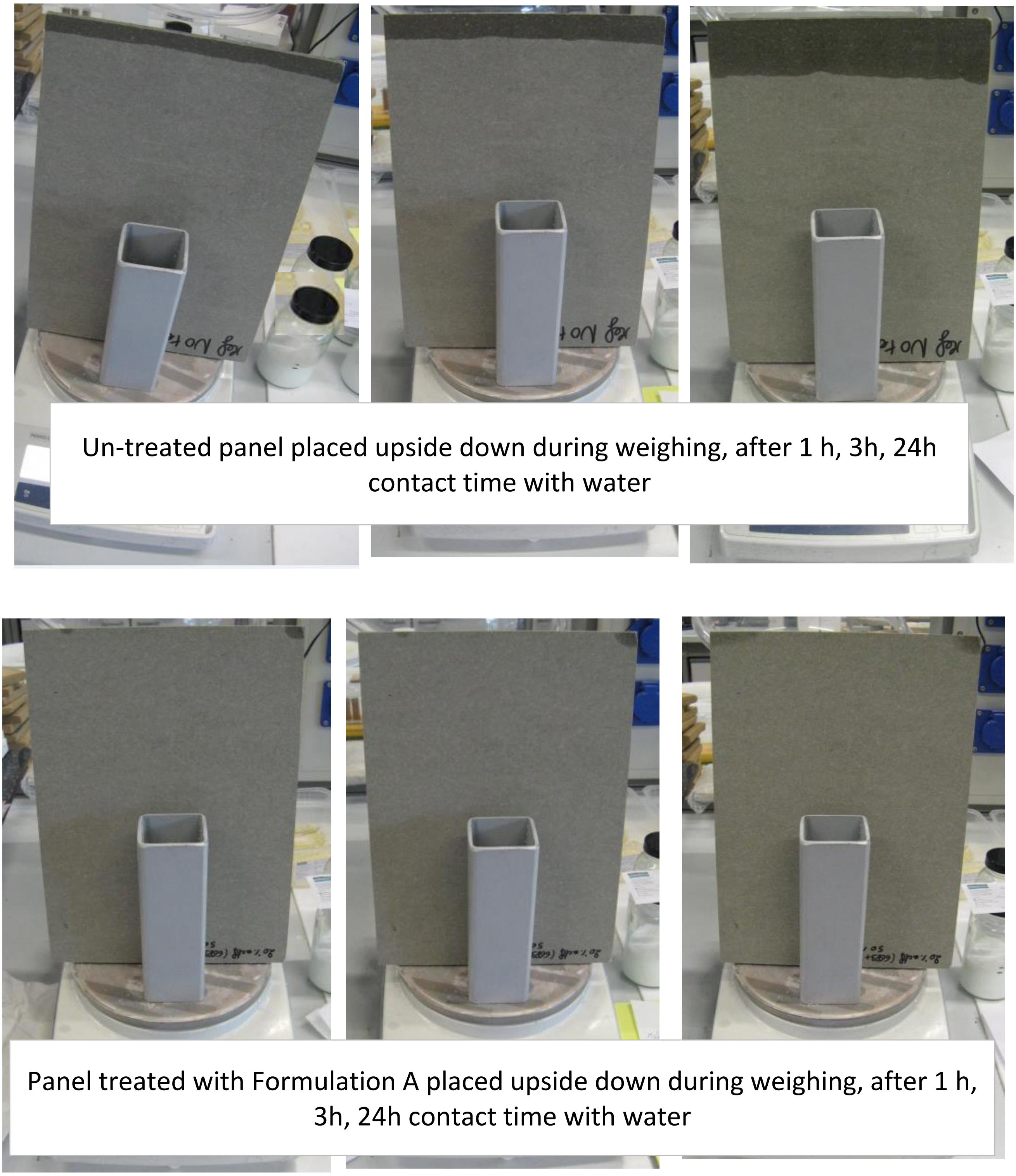


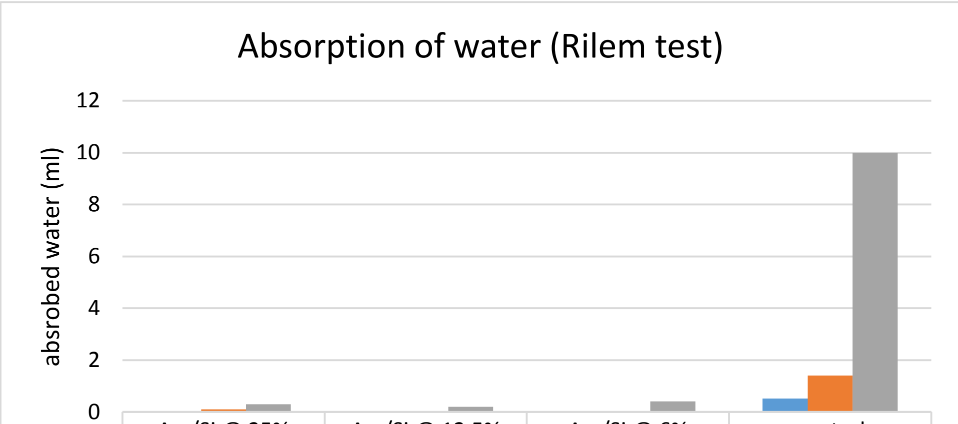
Figure 6 Illustration of absorption of water by the edges for reference and boards treated with Formulation A diluted @ at 20% active content and applied at +/- 60 g/m².

After 24 h contact time with water, the reference boards absorbed 1.3-1.5% of water vs the dry board weight. In the same conditions, the boards treated with the selected edge sealer formulation absorbed 0.03-0.10% of water (vs dry board weight). Efficiency of the selected edge sealer formulation to minimize water penetration could be demonstrated both by water absorption measurement and visual observations.

Water absorption (Rilem test)

Another set of FC boards, produced through an Hatschek process, air cured, 6 mm thick, with no post treatment and kindly provided by Infibra were treated by deep coating with different dilutions of *Formulation A* (although optimised for edge sealing, it was tested here for surface treatment). Water absorption by the top surface was assessed by Rilem test. Absorption of water as a function of contact time with water is reported in figure 7.

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 (see figure 7).



	Acr/Si @ 25%	Acr/Si @ 12.5%	Acr/Si @ 6%	control
1 h	0	0	0	0.5
4 h	0.1	0	0	1.4
24 h	0.3	0.2	0.4	10

Figure 7. Absorption of water assessed by Rilem test of boards treated by deep coating with different dilution of Formulation A.

Blocking of boards treated by deep coating

Deep coating is an easy and quick treatment method for FC boards. However, presence of acrylic copolymer dispersion, which are film forming in the acrylic/silicone mixture, could results in some sticking of the boards treated by this method. In order to assess potential impact of deep coating with acrylic/silicone mix on boards adhesion, a stack of boards (same air cured boards provided by Infibra) was treated altogether with *Formulation A* (optimized as edge sealer) and let to dry/react for 7 days. Impact of the deep coating with *Formulation A* on the ease of “unpacking” was assessed. Treatment of the edge with concentrated formulation A (@ 25% active content) lead to serious difficulty to de-stack the boards. Using diluted Formulation A such as to reach 12% active content or below for the deep coating step could mostly be made by hand, or could require some help of a tool (illustrated in fig 8).

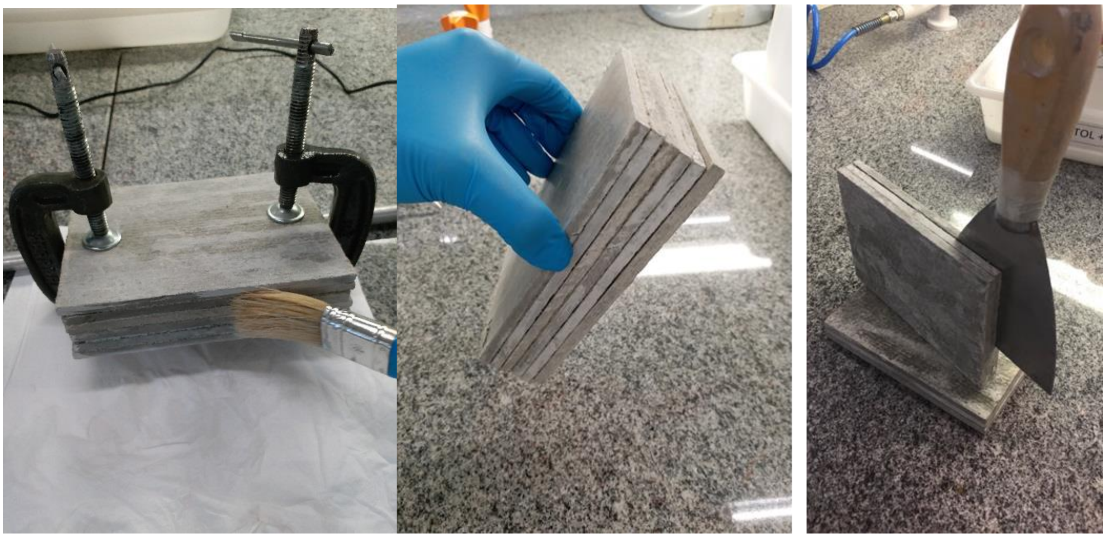


Figure 8. Edge of a stack of board treated with formulation A. Impact of the treatment on stacking of the boards was assessed by evaluating the ease of separating of the boards.

CONCLUSIONS

This work illustrates how impregnation, silicone-based water repellent and film forming, acrylic polymer dispersion can be mixed together to formulate new surface treatment. When the surface treatment is applied on FC, it enables to control water penetration and onset of efflorescence and yet with no modification of the board appearance.

A hypothesis trying to explain why FC treated with highly efficient Silicone based impregnation water repellents is still showing strong efflorescence is proposed. It suggests that treated FC boards leaves more time for water to (even slightly) go into the cement matrix, dissolve calcium hydroxide and migrate back to the surface.

This work illustrates also how silicones and acrylic can be formulated as FC edge sealer. It is observed that the type of formulation which can be designed for top surface treatment is somewhat different than to treat the edge sealer.

It is believed that a better understand of silicone and acrylic starting materials is key to successfully formulate highly efficient surface protection for FC boards.

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