ADVANCED AND RELIABLE SOLUTION FOR WATERPROOFING AND CLADDING SURFACES IN WET AREAS

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ABSTRACT

This paper addresses a crucial issue in the construction and ceramic industry: the challenges faced by product manufacturers in developing effective formulations that prevent issues such as detachment of ceramic tiles, which are often wrongly associated with the ceramic sector.

It describes various studies undertaken to create an ideal waterproofing system, fully compatible with ceramic tiling based on experience with an earlier-generation product.

At the same time, it touches on other aspects that represent a risk for tile fixing: waterproofing layers with poor durability, lack of adhesion between materials, low resistance to the phenomenon of alkaline hydrolysis, products applied in the top layer that are difficult to work with, and which lead to installation errors.

1. INTRODUCTION

Watertightness is an essential feature in areas exposed to water and yet problems directly related to water infiltration are still commonplace. These problems not only affect the durability of structures but can also have a negative impact on people's quality of life (1).

In order to provide a definite solution to these challenges, our company has developed its "Laminate No Limits" system. The system consists of a waterproof membrane of a polymer-modified cementitious nature that, when combined with the adhesive, creates a "single body" that excels in terms of waterproofing, adhesion and durability.

The system is designed to provide waterproofing under the tiling. Its main purpose is to protect the substrate on which the tiles are installed and to prevent the problems that arise when tiling in wet areas. This paper addresses these problems in detail, describes the various complications that can occur, such as detachment or breakage of ceramic tiles, efflorescence and general degradation of the ceramic system, and offers an alternative to the traditional system in order to address such challenges.

This is the context in which various research studies were carried out, culminating in the creation of the system developed by Kerakoll, one of the first companies in the building industry to obtain B Corp. certification (2). This paper explains the new system, highlighting its technical characteristics and its impact on sustainable construction.

2. RESEARCH

Using ceramic coverings on outdoor surfaces such as swimming pools, balconies and terraces can present a number of specific challenges and considerations.

In addition to the intrinsic requirement of creating materials that can adhere to each other, the trend in the ceramic market is towards producing larger tiles, thus increasing the technical demands placed on the layers in the system. Consequently, Kerakoll needed to implement research that would provide solutions to the main problems encountered in tile installation in wet areas: waterproofing layer; adhesion of the ceramic system; sensitivity to alkaline hydrolysis; workability of the mixes; complex systems.

a) **Waterproofing layer**: A continuous layer of waterproof material, intended to prevent the passage of water. It may or may not be permeable to water vapour diffusion (3). In wet areas, however, this layer is often not incorporated directly into the system but rather is laid using the traditional method, i.e., under the screed, leaving an exposed tile-fixing surface susceptible to wetting and drying processes that lead to degradation.

Formation of salt efflorescence and mould in joints.

Expansion and breakage due to ice formation.

Screed weakening as a result of water percolation.

***Figure 1**. Illustration of pathologies resulting from water infiltration.*

In construction, the materials and their coverings alone do not suffice to guarantee the necessary watertightness in areas exposed to water (4). That is why it is essential to carry out waterproofing prior to the installation of any cladding (5) and also to ensure that the waterproofing is designed to withstand the stresses it will be subjected to.

One such stress is withstanding water pressure, otherwise it can soon become damaged, entailing costly repairs and premature replacement. The current version of our waterproofing mortar forms a completely waterproof structure that guarantees watertightness up to a pressure of 1.5 bar, while still allowing water vapour to be released from the substrates.

The current formulation has been shown to meet the most demanding standards, including the test set out in EN ISO 7783, a fundamental requirement for CE marking in accordance with EN 1504-2 (concrete protectors), where it has been classified as Class I (Sd<5m) water vapour permeable. Such water vapour permeability is what enables the product to prevent pressure due to the accumulation of water vapour on substrates that are not completely dry, thus impeding tile detachment, efflorescence and a general deterioration of the system.

Regulating the hydration process in cements was a major challenge in the development of the "Kerakoll Polymer" (6). This unique polymer triggers a polymerisation reaction that creates a network of open-pore nanostructures with a maximum size of 40 nanometres. This is 200 times larger than a vapour molecule, thus ensuring the membrane's excellent breathability.

Re-dispersible powder resins are obtained by the spray-dry method (7), drying the polymers in aqueous dispersion by spraying. During production of the polymer powder, anti-caking and anti-heating additives are used to inhibit hydration of the hydraulic binders.

The polymer undergoes a chemical bond formation process known as 'cross linking' (7). In order to activate and complete it properly, the functional groups of the polymer need to be supplied with Ca^{2+} (calcium ions).

As part of the research, a mixture of mineral binders was studied for the waterproofing product, capable of satisfying the demand for calcium ions, favouring cross-linking and the consequent creation of a cohesive film that is not subject to hydrolysis and re-dissolution in water, thus affording the material greater durability.

The correct balance between the polymer and the new binder mixture also made it possible to completely inhibit the action of the anti-heat additives in the spraying phase of the polymer emulsion, thus improving cement hydration while maintaining its reactivity unaltered, which translates into faster times to continue with the floor tile installation stage.

This makes the product totally suitable as a waterproofing layer; additionally, it has CM01P marking in accordance with EN 14891 (9), i.e., it is ideal for use under ceramic tiles for laying tiles on outdoor walls, floors and in swimming pools.

- CM: liquid cementitious waterproofing membrane
- 01: with resistance to crack propagation at low temperature (-5ºC)
- P: resistant to immersion in chlorinated water.

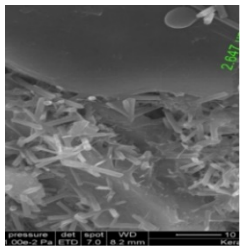
The above is in accordance with Standard EN 138002 (10), where the waterproofing membrane is referred to as a single- or multi-component waterproofing material applied under ceramic tiles, which, when used in ceramic tiling, must be in accordance with Standard UNE-EN 14891 (9).

b) Adhesion of the ceramic system: Achieving adhesion of a ceramic adhesive on a waterproofing mortar can be problematic, as the waterproofing materials tend to generate non-porous surfaces to avoid water infiltration, thus hindering mechanical bonding of the adhesive. On the other hand, it is important to assess what chemical incompatibility both materials may have, as some waterproofing mortars contain components that may interfere with the adhesive's ability to bond.

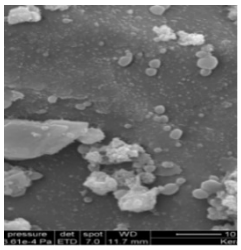
The waterproofing product under study here has revolutionised the adhesion results obtainable with a single-component mortar, thanks to research into the following two features: the binder and the inert components.

I. The binder: a mix of carefully selected mineral binders to provide an ecological, sustainable solution that improves stability, resistance and durability.

This mix allows crystals to grow within minutes of mixing, thus generating early mechanical performance and increased rain and frost resistance properties. The structure formed by the binder reduces water loss and increases workability time (gel effect).



Crystallisation of the Kerakoll binder



Crystallisation of Portland cement

***Figure 2**. Crystallisation of the Kerakoll binder vs that of Portland cement*

When drying times between the first and second coat and the waiting time required for tile installation were compared with the former version of the product and two other competing waterproofing products, it was found that the new single-component version provided significantly shorter waiting times.

Table 1. Comparison of waiting times

Waiting times at 20ºC	**Former version**	**Waterproofing 1**	**Waterproofing 2**	**Current version**
	Two-component	**Two-component**	**Single-component**	**Single-component**
Waiting time between 1st & 2nd coat	≥ 6 hours	4 - 5 hours	2 days	2 hours
Waiting time before tiles can be fixed	≥ 24 hours	≥ 5 days		12 hours

The successful achievement of the binder's early mechanical performance guarantees protection and shortens tile fixing times to facilitate completion of subsequent tasks.

To further enhance the product's durability, it was decided to analyse each component in the formula with a view to increasing end product strength. Rain and frost resistance was thus increased, while waiting times for subsequent work phases were shortened.

The product's strength was significantly improved by increasing the amount of cement and decreasing the calcium carbonate in the formula, bringing it to an optimal level of safety.

II. Inert components: In order to improve mechanical adhesion strength, the particle size curve was modified to increase surface roughness. The difference in the orography between the former and the current versions of the product can be seen below.

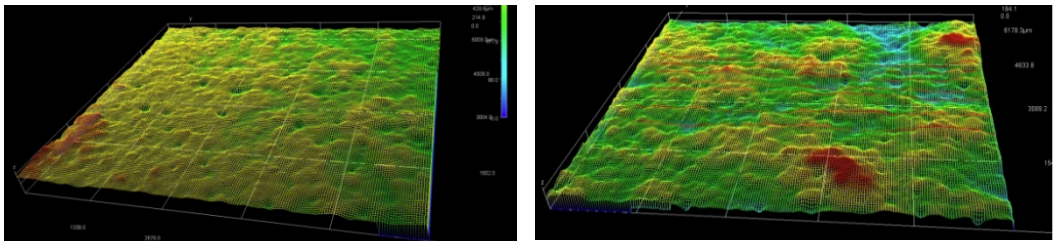


Figure 4. *Previously generated vs current product – Orographic roughness comparison with a modular 3D digital video-microscope system.*

Thanks to the research and steps taken to create an indivisible (laminate) system made up of a waterproofing material and an adhesive, improved adhesion strength results were obtained: initial adhesion was 4 times higher than the minimum required by standard EN 14891 (9).

Test in accordance with EN 14891	Standard requirement	Former system	New integrated system
		Two-component + C2 adhesive	Single-component + C2 adhesive
Initial adhesion strength	0.5 N/mm^2	0.8 N/mm^2	2.2 N/mm^2
Adhesion strength after contact with water	0.5 N/mm^2	0.55 N/mm^2	1.1 N/mm^2
Adhesion strength after freeze/thaw cycles	0.5 N/mm^2	0.6 N/mm^2	1.0 N/mm^2
Adhesion strength after heat action	0.5 N/mm^2	1.2 N/mm^2	2.0 N/mm^2
Adhesion strength after contact with chlorinated water	0.5 N/mm^2	Data not declared	0.8 N/mm^2
Adhesion strength after contact with lime water	0.5 N/mm^2	0.6 N/mm^2	1.5 N/mm^2
Adhesion strength after prolonged contact with lime water (28 days)	0.5 N/mm^2	Test not performed	1.5 N/mm^2

Table 2. *Comparison of adhesion strength values*

One of the key advantages of the system is its ability to be applied even over old ceramic tiling without the need for any pre-treatment. This not only simplifies the waterproofing process, but also reduces the costs and time required to carry out renovation or repair projects.

c) **Sensitivity to alkaline hydrolysis:** Alkaline hydrolysis is a chemical process in which alkalis, such as calcium hydroxide (lime), present in the mortar react with water and other compounds, leading to the formation of by-products that can weaken the structure of the waterproofing mortar, causing loss of strength, cracking and detachments, which compromises the waterproofing and integrity of the ceramic system, as well as causing aesthetic damage such as efflorescence.

Figure 5. *Effects of alkaline hydrolysis on ceramic flooring*

The two-component version of the product in question was formulated with acrylic resin, which is not overly resistant to hydrolysis and saponification. This phenomenon appears on site years after installation, so it was only possible to detect it after complaints about the product had been received.

The defect was simulated in the laboratory using an in-house method to analyse membrane durability. The method consists of air curing the membrane for 28 days, then placing it in a 30% sodium hydroxide (caustic soda) solution and leaving it submerged for 30 days. At the end of the 30 days, thermogravimetry of the sample is performed to measure the organic content and the consequent loss compared to an untreated sample.

The in-house method confirms a durability problem which coincides with the complaints received. To solve it, collaboration of the resin supplier was sought in order to modify the resin (main binder in the product) with a view to increasing the raw material's resistance to saponification. A modified resin with the addition of styrene was tested.

The new styrene acrylic resin included in the formulation of the new version significantly improved the durability of the waterproofing in contact with alkaline environments, so the decision was taken to produce the membrane with the new styrene acrylic resin.

The research performed on the former two-component version provided information that was important to the development of single-component waterproofing products. The in-house method created in the previous study enabled us to identify the best resin to use in the project in terms of hydrolysis and saponification resistance (a vinyl acetate, ethylene and vinyl ester resin).

Two-component cement mortars and the current version of the product were subjected to comparative high basicity resistance tests. The old two-component waterproofing mortars degraded in the short term, whereas the new version of the product remained waterproof over time:

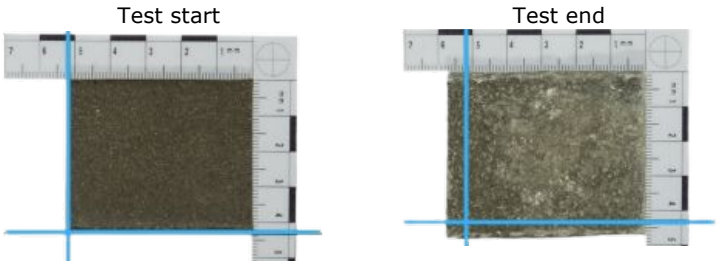


Figure 6. *Two-component cementitious waterproofing*

The two-component mortar sample was subjected to strong, irreversible degradation: surface enlargement is noteworthy, thus compromising the waterproofing, cohesion, adhesion strength and flexibility properties, which can affect the ceramic tiling and lead to detachment.

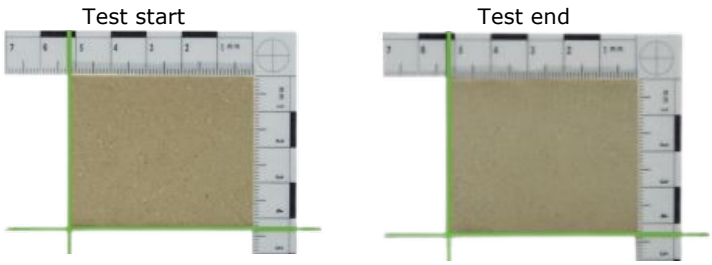


Figure 7. *Single-component cementitious waterproofing*

The dimensions of the sample of current single-component mortar remained intact and the sample preserved its initial guarantees of high-quality chemical-physical performance and total impermeability, even after chemical aggression. The new formulation of the product is designed to resist aggression by alkalis present in floor screeds and tile fixing adhesives. Various laboratory tests have shown that the product is insensitive to the constant presence of moisture in an alkaline environment (pH ≥ 12).

The process of obtaining the current formulation faced major challenges, including finding an adequate balance between cost and quality, increasing the dosage of cementitious material without decreasing elasticity in the waterproofing, as well as achieving a reduction in micronised carbonate which could have generated rheological problems and increased the powder's explosiveness (ATEX).

The waterproofing mortar also resists highly aggressive environments such as swimming pools: it is insensitive to chloride ion (chlorine) attacks, which guarantees waterproof protection for the entire life of the product.

d) Workability of mixes: Thin-set mortars such as two-component waterproofing compounds are difficult to apply, especially at high temperatures, and can call for significant effort by the applier to ensure they are spread evenly over the surface. This can lead to inefficient and uneven application, producing areas with inconsistent thicknesses or even voids, compromising the effectiveness of the waterproofing and the durability of the ceramic system.

The proposal of the current version in addition to offering exceptional workability is to provide variable rheology, so that the product can be mixed with 5 to 6 litres of water to obtain customised consistency, enabling vertical application without the risk of sagging, and horizontal application covering very large areas in a short time while still maintaining performance - a property that distinguishes it from other products in the same category.

The main raw material used to produce the waterproofing product is terpolymer powder, which contains three different monomers: vinyl acetate, vinyl ester and ethylene. The raw material is dosed in high percentages within the recipe and gives the product rheological advantages found in both the application phase and the mixing ratio.

The mixing ratio also benefits from this technical feature of the polymer. The use of this particular vinyl terpolymer has enabled us to increase the mixing ratio range of the premixed powder, so the applier can alter the rheology of the product according to specific requirements or different climatic conditions.

Its workability ensures ease of spreading and levelling, and it has more than double the open time of conventional two-component waterproofing mortars. The high retention power of the resin, very similar to the behaviour of cellulose, allows the finished product to retain large quantities of water and release it slowly into the mix, significantly balancing reaction times and the technical characteristics of the binder material and binding polymers present in the formulation.

Such workability benefits from the retention properties of the resin powder; in fact, the slow release of water into the substrate allows the fresh mixture to maintain its rheological characteristics for a long time, thus increasing the time this new waterproofing product can be worked during the installation phase.

e) Complex systems: The older two-component cement-polymer mortars were originally designed to protect concrete structures under extreme conditions. However, complications arise on site when they are used as waterproofing prior to laying ceramic tiles with cementitious adhesives. This has led manufacturers to recommend complex and costly systems in search of greater compatibility between products and solutions to issues of workability and durability.

As a result of the research carried out, a system has emerged that is composed of a state-of-the-art single-component mortar and a fully compatible adhesive, which meets current technical needs of tile installation in wet areas, and which is also familiar and safe for the applier, a crucial aspect in minimising construction errors on building sites.

Apart from using quality products on site, the necessary measures to reduce any risk of error also have to be taken. It is essential to follow the manufacturer's instructions and to respect fundamental parameters for safe application, such as those established in standard UNE 138002:2002 (9): to apply the waterproofing on the levelling layer and to confirm compatibility among the products used.

In order to waterproof surfaces to be clad with ceramic tiles or vitreous mosaics bonded with cementitious adhesives, it is important that the set of products used should enhance maximum adhesion performance over time and that their compatibility with each other be ensured. In this context, the choice of an integral system, like the one described here, is ideal to meet such requirements:

- The waterproofing mortar develops a fluid and homogeneous mixture, adjustable by varying the quantity of water, to obtain the best workability depending on the conditions on site, ensuring maximum adhesion strength.
- *The adhesive* develops complete wettability of the substrate and the tile, thus ensuring high adhesion strength under shear loading.

3. CONCLUSIONS

- The study conducted on the former two-component version of the product provided important information for the development of single-component waterproofing products. The need was detected to ensure the waterproofing layer is resistant to the effects of alkaline hydrolysis and saponification, as this is a phenomenon that can only be identified on site after a number of years, with a view to extending the ceramic system's service life and reducing its carbon footprint.
- Our research has led to a single polymer that triggers a polymerisation reaction, forming a network of open-pore nanostructures in its membrane. This distinctive feature ensures excellent breathability, which in turn prevents problems associated with the accumulation of water vapour on substrates that are not completely dry, thus avoiding problems of tile detachment, efflorescence and a general deterioration of the system.

  In addition, research into the best blend of mineral binders for the current version of the product has significantly improved the material's durability by creating a cohesive film that is not susceptible to hydrolysis and re-dissolution in water.

  As a result of studying the behaviour of the polymer in combination with the new binder mixture, it was determined that the cement hydration process was improved while its reactivity remained unaltered, which translates into faster tile installation times. These characteristics give the product excellent performance and ideal tile fixing times, as certified by its CM01P marking in accordance with EN 14891.
- The result of modifying the particle size curve and increasing surface roughness in the new version of the product produced exceptional adhesion strength values, four times more than the minimum required under EN 14891.

4. REFERENCES

[1] *FACTORS AFFECTING WATER-TIGHTNESS IN WET AREAS OF HIGH-RISE RESIDENTIAL BUILDINGS.* M.Y.L. Chew, Nayanthara De Silva. 375-383, s.l.: Architectural Science Review, 2011.
[2] B CORP CERTIFICATION. [Online] B Lab., 2023. https://www.bcorporation.net/en-us/certification/.
[3] Normalización, Asociación Española de. *UNE 138002:2017. Reglas generales para la ejecución de revestimientos con baldosas cerámicas por adherencia.* Madrid: s.n., 2017.
[4] *UNE 138002:2017. Reglas generales para la ejecución de revestimientos con baldosas cerámicas por adherencia.* Madrid: s.n., 2017.
[5] *Waterproofing of Concrete Foundations.* Paula Mendes, J. Grandão Lopes, J. de Brito, and João Feiteira. 2, s.l.: Journal of Performance of Constructed Facilities, 2012, Vol. 28.
[6] *INFLUENCIA DE LOS ADITIVOS POLIMÉRICOS EN LA ADHERENCIA TRAS INMERSIÓN EN AGUA.* Juliana de Oliveira, Denise Antunes da Silva. 86-96, s.l.: Qualicer, 2006.
[7] *The function of polymer dispersion powder in cement based dry mix products.* BONIN, Klaus. Germany : Wacker Polymer Systems GmbH & Co. KG, 2005.
[8] *Cross-Linking and Structure of Polymer Networks.* MacKnight, Karel Dusek and William J. Washington, DC: American Chemical Society, 1988.
[9] Normalización, Asociación Española de. *UNE-EN 14891:2017 Membranas líquidas de impermeabilización para su uso bajo baldosas cerámicas colocadas con adhesivos.* Madrid: s.n., 2017.
[10] *UNE 138002:2017. Reglas generales para la ejecución de revestimientos con baldosas cerámicas por adherencia.* Madrid: s.n., 2017.
[11] Asociados. *UNE 138002:2017 Reglas generales para la ejecución de revestimientos con baldosas cerámicas por adherencia.* 2017.
[12] *The Analysis on Mechanism and Application of CementitiousCapillary Crystalline Waterproofing Coating.* Guo-Zhong L, Wei-Xuan Z, Li-Juan Z, Xiu-Jua. 156-161, s.l.: Proceedingsof the International Conference on Mechanics and Civil Engineering (ICMCE 2014), 2014.
[13] *The Effect of Crystalline Waterproofing Admixtures on the Self-Healing and Permeability of Concrete.* Anita Gojević, Vilma Ducman, Ivanka Netinger Grubeša, Ana Baričević and Ivana Banjad Pečur. https://doi.org/10.3390/ma14081860, s.l.: Innovative Materials in the Building Industry: Reducing Building Energy and Minimising Environmental Impacts, 2021.
[14] *Push-out and bending tests of steel-concrete adhesively bonded composite elements.* Jurkiewiez Bruno, Tout Firas, Ferrier Emmanuel. 111717, s.l.: Engineering Structures, 2021, Vol. 231.
[15] *Core-Shell Morphology of Redispersible Powders in Polymer-Cement Waterproof Mortars.* Stefano Caimi, Elias Timmerer,Michela Banfi,Giuseppe Storti and Massimo Morbidelli. 1122, s.l.: Polymers, 2018.