Coloured Surface Protection: an alternative to mass colouring and an opportunity to meet architectural expectations

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Abstract

Guard Industrie patented technology about colouring GRC enables to offer a credible alternative to mass tinting as it is cheaper to colour the surface rather than using pigments in the mass, it is more durable as it has stable pigments, do not risk to peel off and provide protection against water, stains, chlorides, alkali.... Colouring and protecting the surface gives an added value to GRC panels or elements, it gives full flexibility to GRC manufacturers on colours leaving therefore time to save labour costs and time.

Guard Industries' technology is therefore completing the GRC offer bringing therefore the opportunity for GRC to compete with other materials (standard or high performance concrete, FRP, aluminium…) in the very big market of cladding and architecture materials.

INTRODUCTION

GRC (ultra-high performance concrete) is an artificial white or grey material. There are two ways of tinting this material: mass colouring by adding pigments to it while still wet or applying a coloured impregnating product to it after curing.

Obtaining a successful GRC appearance depends on many factors, including inspection and regularity in choosing the materials, especially the cement.

Mass colouring of GRC is a demanding job, calling for a special choice of cement, granulates, fine minerals and pigments. This makes it rather costly. For instance, a white concrete has to include the use of white cement, free of tetracalcic ferroaluminate (C4AF) and requires the use of white granulates (calcareous or siliceous). Some granulates produce graduated concrete colours but it is the fine particles (smaller than 80µm) that colour the concrete skin.

Stronger colours are obtained by incorporating pigments, usual metal oxides (iron, chrome, titanium, cobalt, manganese) which guarantee a lasting effect.

In addition to being expensive, mass colouring suffers from several drawbacks. To obtain a precisely defined colour (for instance, with reference to an RAL colour chart) requires careful formulation of the concrete down to its very composition. This can be only done by using a mixing plan requiring many experiments. Generally, this preliminary work is not done and the colours are obtained by a trial and error method, until they are approved by the prime contractor. It is true that the initial specifications themselves are rarely quantified.

Mass colouring also offers advantages because any chipping of the material by impact, does not produce any perceptible difference in the colour. The mineral quality of the concrete (its stone-like appearance) is left intact.

An alternative to mass pigmenting is "epidermal" pigmenting obtained by adding a stain to the hardened surface, therefore after the mould release of the facing.

For a long time, colouring was considered more as "re-colouring" because its aim was to correct colour defects. Some products still available on the market are more or less film-forming, like paint, and some even require the prior application of a primer to ensure that the base is uniform, before being treated with the final colour.

Film-forming solutions represent a twofold risk: if the film is too impermeable, it traps moisture inside the material, prevents it from breathing and can cause blistering; from the aesthetic standpoint, a product with any degree of thickness fills the natural grain of the concrete which loses its mineral "signature". When a user looks at a concrete substrate coated with this type of treatment, he sees it as a "plastic" product, especially when the applied product produces a seamlessly uniform colour.

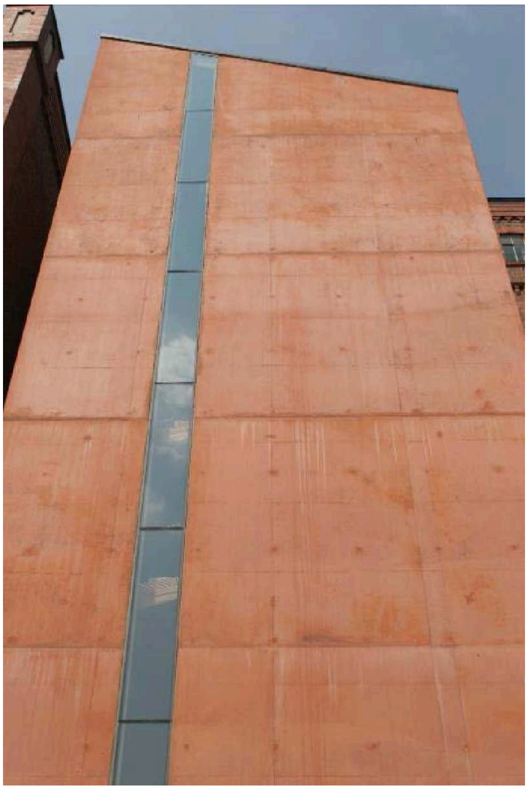

***Figure 1**. GRC Facade*

Alternative colouring products have recently appeared on the market consisting of semi-transparent impregnation products which combine protection with decoration. This article looks at the physical aspects underlying the way these products work, especially with respect to colour. We will look at ProtectGuard Color patented by Guard Industrie and LRVision which has technological and financial advantages to offer.

THE TECHNOLOGICAL ADVANTAGES OF COLOURED IMPREGNATING PRODUCTS

Depending on their responsibilities in the decision-making or implementing chain, professionals may find it advantageous to use coloured impregnating products.

a) Architects

- These products provide protection and colour at the same time. (see Figure 2)
- Colour and opacity are defined in conjunction with the application specialist, depending on the condition of the support and the intended purpose,
- Colouring allows surfaces of different types to be co-ordinated (for instance, walls and floors),
- The process can be considered during the design of the structure, during refurbishment, or as a way of correcting defective workmanship,
- As a non-film-forming treatment it respects the nature of the substrate and contributes to the durability of the materials,
- Semi-transparent treatment makes it possible to use different gradations,
- There is a possibility of using special effects (gloss, metallic reflections, phosphorescence).

***Figure 2**. Colouration and protection of GRC*

***Figure 3**. Metallic effect*

Figure 4. *Play on shininess*

b) Owners and Managers

Owners, whether government, companies or private individuals, are always concerned about the durability of their real estate investment and constructions.

- Water-repellent protection prevents the penetration of runoff water, considerably reducing the unwanted effects of biological colonization,
- Exogenous chemical attacks, often using water as a vector, are neutralized,
- Application of impregnating products, combined with colouring, is a possibility on older structures too,
- It can be applied to refresh colours (in the mass for instance),
- Greasy stains have less purchase and graffiti can be removed more easily

c) Contractors

- Coloured (or colourless) impregnating products protect from runoff water or simply from dirty hand marks,
- A low saturation semi-transparent impregnating product in the greys is an efficient and discrete way of hiding defects to meet some of the demands of specifications concerning facing aesthetics (as long as the consent of the prime contractor can be obtained),

- A coloured impregnating product is applied in one coat, quickly and at low cost, remains totally harmless to the personnel, and causes no upheaval in the engineering schedule, and leaves the site clean.

d) Pre-fabricators

Pre-fabricators are always keen to find innovations which improve their products, whether in terms of their functional (for instance mechanical) properties, the production cost or the aesthetic qualities.

On the last point, a coloured impregnating product can be a novel and economical way of colouring a substrate, while also offering a major technical benefit in terms of protection

- Long-lasting water and grease repellent protection, capable of withstanding high-pressure cleaning,
- A technical alternative to a traditional mass colouring process,
- An economic advantage over mass colouring.

Table 1. *Cost comparison between ProtectGuard Color and a mass coloured GRC concrete for a 10m² surface area*

	GRC tinted in the mass	ProtectGuard Color impregnating product
Quantity of product required	500kg of cement + 15kg of pigments*	1L of ProtectGuard Color per $10m^2$
Price	Cost of pigment = €4/kg i.e. €60 for 15kg	€50 / litre **
Price / m^2	Approx. €6 / m^2	Approx. €5 / m^2

* The quantity of pigments is given according to the quantity of cement. A stronger colour requires on average 3% pigment compared to the quantity of cement.
** Maxi retail price

COLOURED IMPREGNATING PRODUCT PROPERTIES

The properties that coloured impregnating products are required to combine in one require complex formulations with a dozen or so different types of molecules, pigments and additives, mostly coming from nanotechnology.

The effectiveness of these properties must be guaranteed by the manufacturer who is required to run laboratory tests for his own development needs. The resulting performance must be indicated in the product technical data sheets (TDS).

Without going into the scientific aspects involved in the aforementioned properties, we can take a look at the mechanism providing water and oil repellent protection, which in turn gives rise other properties including resistance to biological contamination.

a) Water and grease repellency

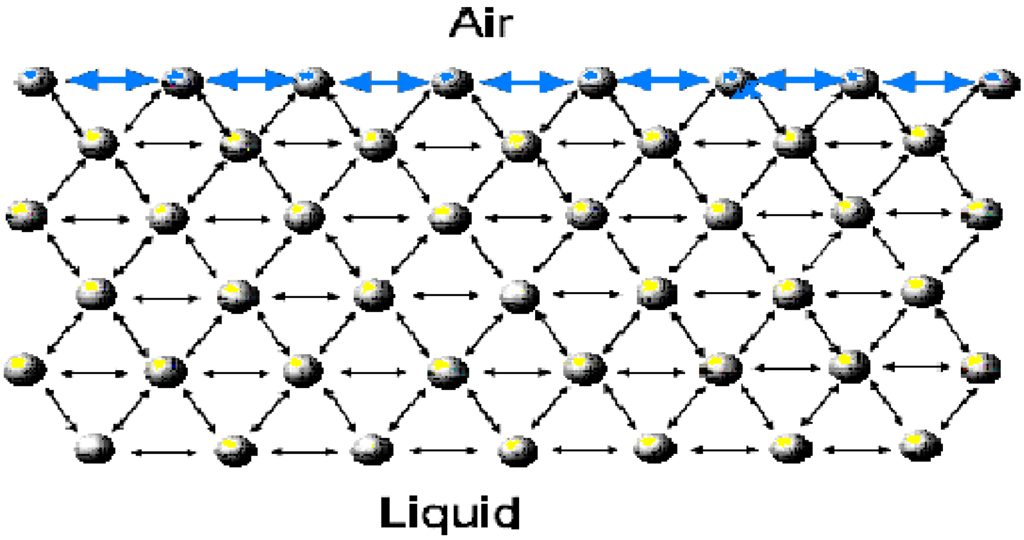

Figure 5. *Interface liquid/air*

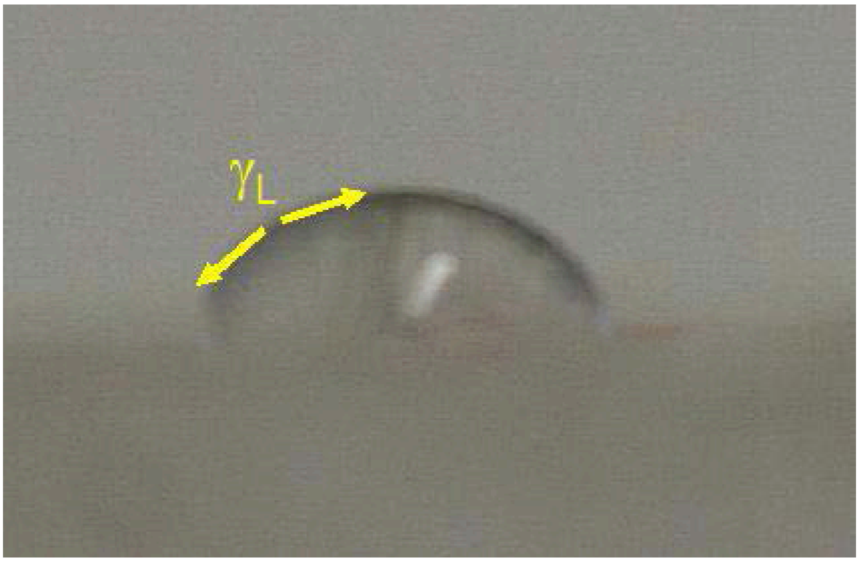

Figure 6. *Picture of interface liquid/air*

Let us take a quick look at the concept of surface tension. In a drop, the liquid-air interface is like a membrane under tension: this is known as surface tension γL.

The applicable unit is the millinewton per metre [mN/m]

Examples (at 20°C):
• water = 72 mN/m
• oil (olive) = 32 mN/m
• petrol = 24 mN/m

→The lower the surface tension the more wetting and penetrating the product is.

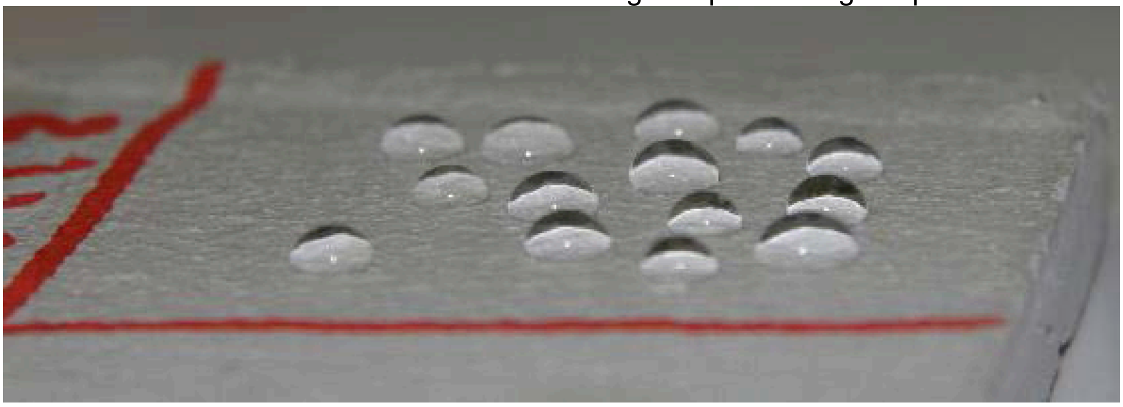

***Figure 7**. Surface of a GRC treated with a water-repellent product*

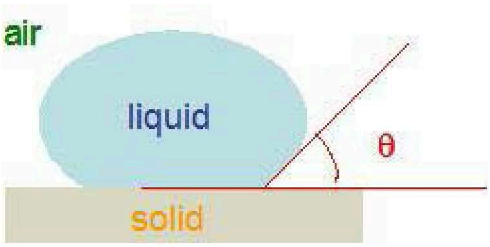

***Figure 8.** Angle of contact*

When a drop comes into contact with a solid, three surface forces at the interface have to be taken into consideration in the balance of the drop: liquid/solid, liquid/gas and solid/gas, the last being the surface energy of the solid.

We can demonstrate that the liquid does not wet the solid (the angle of contact is greater than 90°) when the liquid/solid surface tension is greater than the surface energy:

$<$ ↔ surface not wet

The role of a decorative water/oil repellent impregnating product applied to a GRC is to decrease the surface energy (and not block the pores). This produces a beading effect. Protection efficiency can be checked using a goniometer.

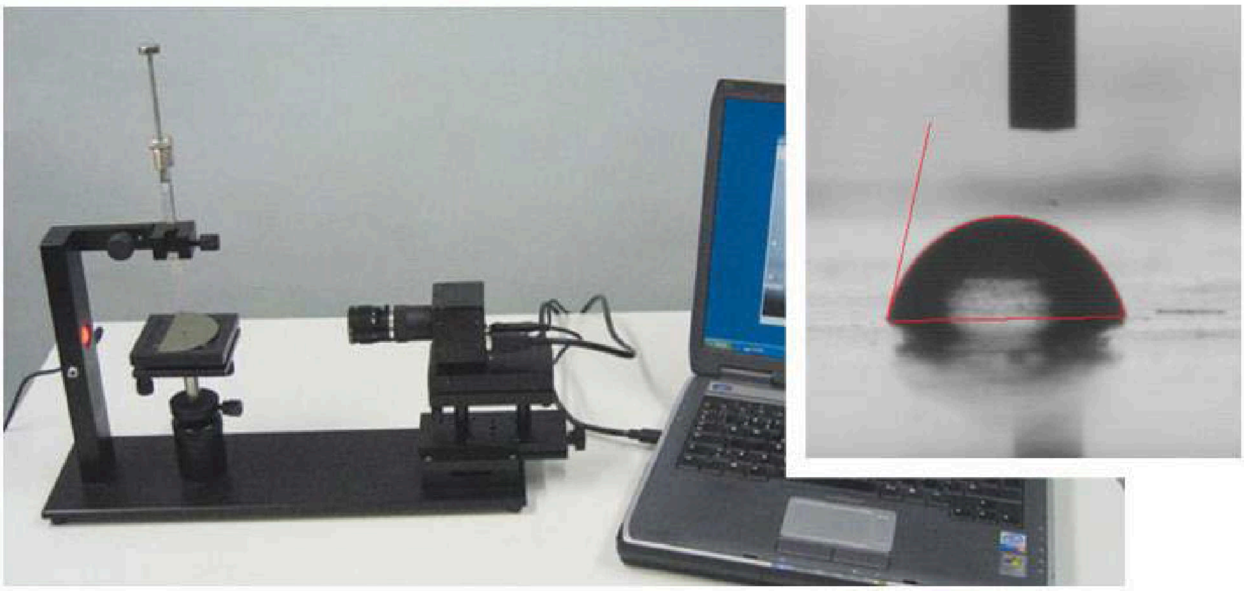

Figure 9. *Goniometer*

More simply, the angle of contact between the surface of the treated concrete and drops having different surface tensions can be evaluated by eye.

To achieve this, a mixture of water with different concentrations of isopropanol is used; it is also possible to use aromatic hydrocarbons (n-hexadecane, n-dodecane, n-, n-octane, heptane, in decreasing order of surface tensions).

b) Algae colonization

Figure 10. *Test of colonization by algae*

The LMDC laboratory (Laboratory of materials and durability of construction) carried out a study defining an accelerated-ageing apparatus for concrete walls regarding the risk of colonization by algae.

The simulation system optimizes humidification cycles with artificial sunlight to accelerate the proliferation of the microorganisms.

It involves inoculating two algae families:

- chlorophycea bloom which develops quickly under favourable humidity conditions,
- algal cyanophycea which have better tolerance of dry periods.
-

Tests reveal that the porosity and roughness of the material are the leading factors boosting biologic development on cement substrates.

The amount of contamination is quantified as the surface area of the concrete covered by the algae. Quantification is carried out by image analysis.

***Figure 11**. Test of colonization by algae on GRC samples*

A test of this type revealed the beneficial effect of a water repellent impregnating product, having a twofold action:

- reduction of moisture in the pores by water repellent action
- action of any biocidal agents contained in the formula

c) UV ageing

Polymer chains are liable to break down under the ultraviolet rays (UV) of the sun which, by adding energy to the atoms (of silica for instance), causes the electrons to make quantum leaps, breaking the covalent bonds linking them to water repellent organic radicals.

As a general rule, impregnation products have good resistance to UV radiation because they line the pores of the material. Only the molecules remaining at the surface are exposed to this risk of degradation. However, we need to quantify the scale of the phenomenon, again using an accelerated test referred to as photo ageing.

Figure 12. *Accelerated UV ageing machine*

Preferably, this test is performed to standard ISO11341, the benchmark for varnish and paint.

Samples of the material, treated with the impregnating product and untreated, are exposed to the light given off by a xenon arc lamp whose emission spectrum is close to that of the sun in UV, visible and (IR) infrared light.

The chemical change in the component materials is measured by infrared spectrometry, or more simply, the change in the customary properties (colour, water repellent capability) is measured. Natural photochemical phenomena are simulated in this way; temperature and humidity are controlled in real time by a sensor-controlled flow of moist air.

The standard requires programming a succession of cycles with alternating dry and wet (by immersion) periods, or the completion of the test in a dry situation alone.

However, the standard steers clear of proposing any simple correlations between accelerated and natural ageing because of the great number of parameters influencing the degradation process.

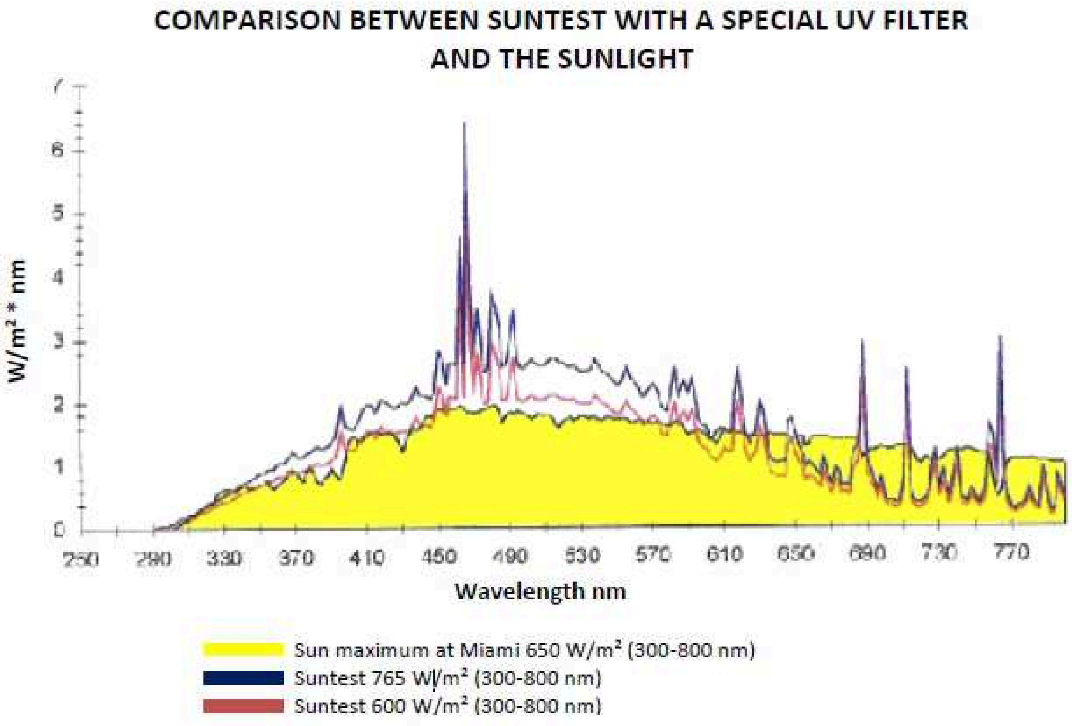

Figure 13. *Spectrum of artificial light vs sunlight*

A simple energy breakdown is not enough on its own to assess the order of magnitude of the acceleration factor. For instance, in Zurich, the mean daily solar irradiation over a year works out at 2.979kWh/m²/day; if we compare this power to that of an artificial sunlight test (650W/m² typically, i.e. 15.6kWh/m²/day) we would obtain a sunlight factor of 5.24.

We also have to allow for the temperature; chemical reactions, especially photochemical reactions, have a kinetic action that doubles with every 10°C temperature increase. Accordingly, in Zurich where the mean temperature is 10.3°C, chemical reactions take place 16 times slower than in an artificial sunlight enclosure where the temperature is held at 50°C (on a black body) or above. The acceleration factor is now 5.24 x 16 = approximately 84.

This means that 1000h of accelerated testing would correspond to an equivalent theoretical period of 84,000h, which is 10 years or so. In reality, the ageing multiplication factor depends not only on the geographical area in question, but also on the type of material being tested and the type of impregnating product. Accordingly, a 1000h actually corresponds to a period of between 4 and 10 years, depending on the case. Only an outdoor test allows the accelerated and real kinetics to be.

COLORIMETRIC FORMULATION

Until now, we have only considered impregnation products from the standpoint of the functional protection properties.

Now let's take a look at the decorative aspects. Not from the artist's point of view, but with the intention of shedding (a little) light on the physics behind the colour and its transparency.
An impregnation product is not a paint. Although it is designed to attenuate defects and improve the uniformity of a coat of colour, it must do so in a particularly subtle way. It is not designed to cover the concrete with an opaque film at the risk of masking minor irregularities in the texture which form the inherent charm of the material.

Figure 14. *Several colours on GRC*

This means that an impregnating product has to be somewhat transparent (to a level to be defined). Accordingly, the final appearance of a wall coated with coloured impregnating product will depend on:

- the condition of the substrate before covering (grey level, initial colour gradations, consistency),
- the pigment formulation of the impregnating product, of course,
- the application technique used, and therefore the quantity of product applied.

But the visual effect will also depend on:

- the light (morning/evening, artificial, combined),
- the observer - and we all know about human subjectivity,
- the context (other walls, floors etc.).

Therefore, we have to bring in a few concepts of colorimetry.

Colour of semi-transparent coats

In schematic terms, a coloured impregnating product consists of a binding base with properties of fluidity and wettability propitious to the impregnating of a porous substrate, and incorporating pigments giving it its colour.

Essentially, colour is a matter of the interaction between a material and the light, so most of the pigments must stay at the concrete-air interface, that is, the surface.

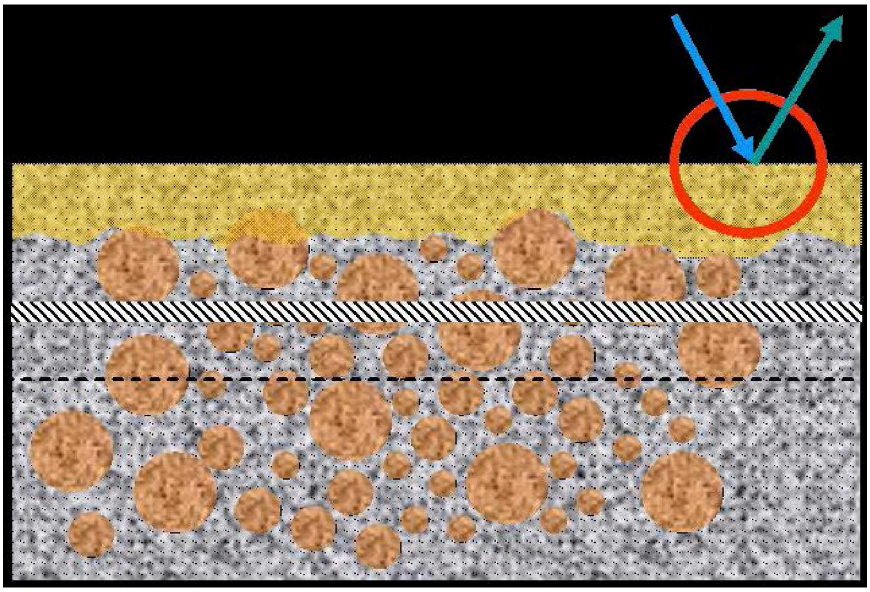

***Figure 15**. Impregnating product on GRC*

This gives us a picture of an impregnated GRC exposed to the action of light.

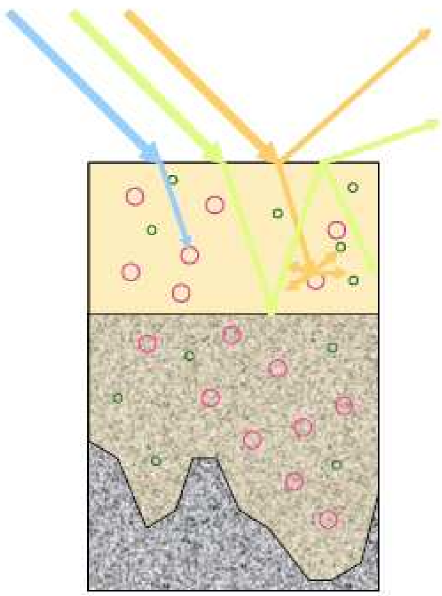

***Figure 16.** Interaction of light with GRC*

The paths of the beams of light go through several modifications as they pass into and reflect back out of the semi-transparent coat:

- reflection on the surface,
- absorption by the pigments,
- diffusion by the pigments,
- reflection from the surface of the porous substrate,
- various refractions,
- various internal reflections.

Each pigmented particle diffuses but above all absorbs the light energy, meaning that the transparency of the impregnating product depends on the charge of pigment (called the "grade").

In a model like this, a semi-transparent coat is characterized by two quantities (defined for each wavelength of the visible spectrum):

S(λ) the diffusion coefficient　　　　**K(λ)** the absorption coefficient

In reality, we have to consider more the flux (at least six) and consider other factors like the roughness of the porous substrate, but it is helpful to use a simplified model to illustrate the formulation process.

The overall properties of an impregnating product depend on the optical properties of each of its components (pigments and binder);

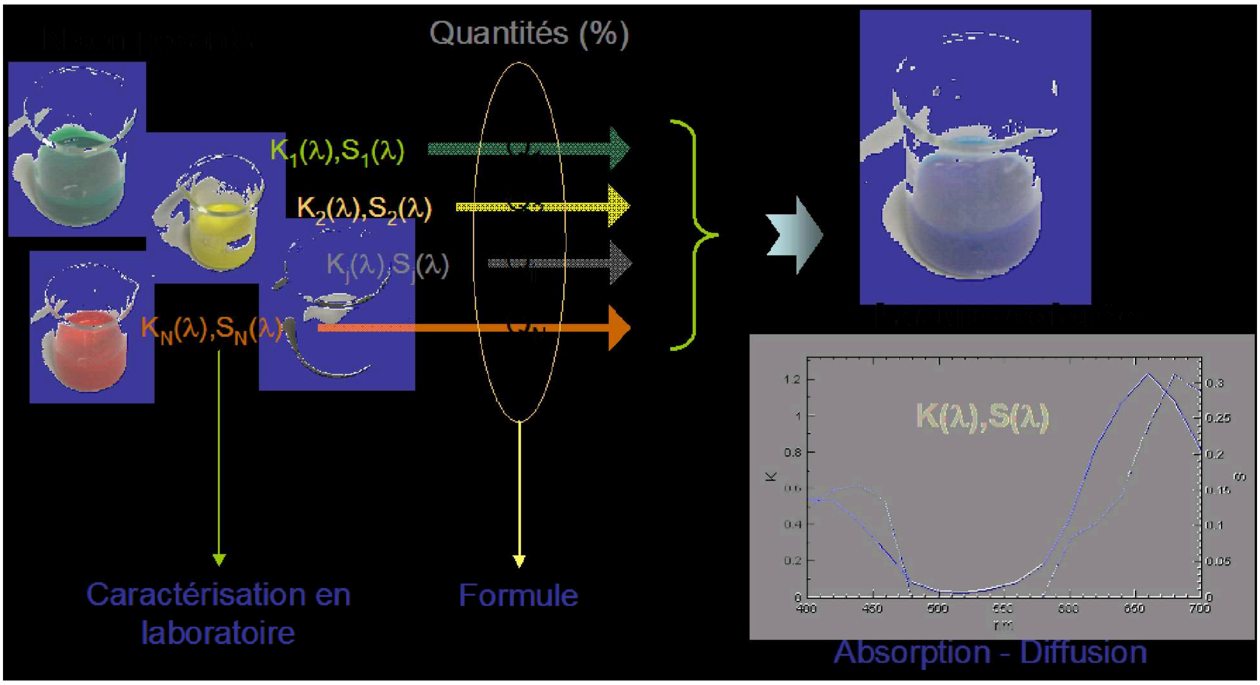

Figure 17. *Formulation of a coloured impregnating product*

The optical properties of the ingredients must have been identified in the laboratory.

If the formula of the impregnating product is known (the quantities Qi of each of the ingredients), then we can calculate the resulting properties of the product.

In reality, the problem is different if the architect imposes the colour on the treated concrete wall; the inputs are then the colour of the substrate before covering, its colour after covering, and we seek the quantities Qi (the formula).

Figure 18. *Problem of the formulation of a semi-transparent product*

We need to emphasise two points concerning coloured protective impregnating products:
a) they are not paints: the result depends on the initial condition of the substrate and the transparency of the impregnating product

b) colouring must not be carried out to the detriment of the protection function. Accordingly, the quantity applied (approximately 120 to 200 g/m² depending on the substrate) must not depend on the colour.

Transparency is characterized by means of clarity measurements L using a spectro-colorimeter on a "contrast card" to which a controlled quantity of the impregnating product has been applied.

If an impregnating product is considered as a means of correcting the appearance of a concrete wall with colour defects. Transparency is a way of adjusting the intensity of the defect-attenuating effect (by reducing contrast).

To summarise, the process of formulating a coloured impregnating product can be depicted as follows.

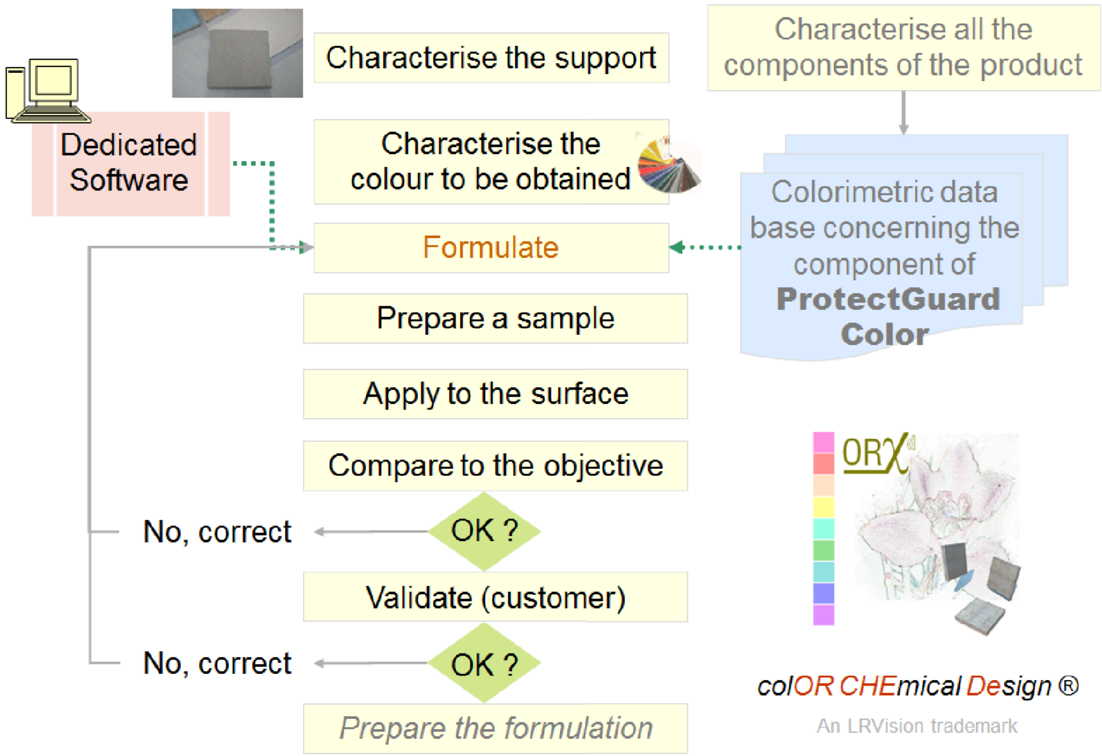

Figure 19. *Flowchart for the formulation of a semi-transparent product*

Naturally, if colour control to this extent is not essential, the prime contractor can also choose an impregnating product from the manufacturer's or dealer's catalogue.

CONCLUSION

Coloured impregnation products are a credible alternative to the mass colouring of architectonic concrete. Not only do they allow the graduated decoration of concrete walls, but they can also ensure water-repellent or stain-repellent protection.

These are semi-transparent products whose colorimetric formulation depends on the substrate before treatment, as well as the results to be obtained. Tailor-made formulation therefore means using suitable physical and IT tools.

In addition to their colours, impregnating products offer new capabilities like fluorescence, metallization, and gloss finish. They open up a new range of creative possibilities for the architect.

	MASS COLOURING	PROTECTGUARD COLOR
Colour stability	**Bad** (efflorescences, impact of the UV rays on the silicium atoms…)	**Very good** (mineral pigments, removal of efflorescences before application ; the protection avoids them…)
Colour homogeneity	**Depends on the batch, the operator,** the way of mixing…	**Very good** - Ready to use product (no mixing needed)
Colour choice	**Difficult to obtain** the target-colour : a new concrete formulation is necessary for each colour sample	**Easy** The colour formulation is obtained thanks to a software. Possibility to apply several samples at the same time on concrete : Possibility of tests on site
Water resistance	**None**	**Protection against water :** protection against bacteria and algae colonisation
Stain resistance	**None**	**Protection against pollution, stains & graffiti**
Colour possibilities / Special effects	**Limited**	**Possibility of** custom-made colours, several opacities and finishes (glossy, flat) Possibility to apply colours with **metallic effects**
Reversibility	**Not possible to change the colour of concrete**	**Possibility to reapply** another colour after sanding or use of a chemical remover
Correction of surface defects	**Impossible**	**Possible** Just by applying ProtectGuard Color on the surface
Maintenance	**Only cleaning**	**Possibility to refresh colour of concrete**
Ease of use	Need to clean between 2 batches, concrete mixers, trucks…	Easy and ready to use, minimum equipment, just need to rinse the HVLP
Price	About 6 € / m²	About 5 € / m²