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COMPATIBILITY PERFORMANCE AS A FUNDAMENTAL REQUIREMENT FOR THE REPAIR OF CONCRETE STRUCTURES WITH SELF COMPACTING REPAIR MORTARS

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Abstract

Durable adhesion of repair material on concrete substrate requires compatibility between the materials to be bonded. There are four main compatibility components to be addressed in any concrete repair scenario: dimensional, permeability, chemical and electrochemical compatibility. Among those, dimensional compatibility is often prevalent: while a cement-base repair material inevitably undergoes shrinkage, the substrate opposes to its free movement, a situation that can lead to cracking and, subsequently, promote debonding. Besides, an essential requirement for bond development is the creation of the interface itself: the intimate contact between the repair system and concrete substrate is required in order to maximize adhesion. Adequate compaction of the new layer is consequently one of the main parameters that will govern the quality of the bond: sufficient vibration or specific rheological properties for the repair material are needed.

Self-Compacting Repair Mortar (SCRM) can be advantageously used in many repair situations. Limestone fillers seem to offer interesting advantages as addition to these repair materials as they increase the workability of the final product. Several materials have been tested and characterised by means of a physical, chemical and mechanical characterization test program: specific attention has been given to water demand and superplasticizer efficiency.

1. INTRODUCTION

Mechanical interlocking, thermodynamic considerations and electro-physical interactions are the basic mechanisms of the interface stability between concrete substrate and repair material. [1,2]. “Contact” development between concrete substrate and repair material imposes to the latter to have sufficiently low viscosity in order to spread on the surface and penetrate into the capillaries of the superficial concrete layer [3]. This is why contact must happen as soon and as quickly as possible, as viscosity increases with time due to the setting process and evaporation of the liquid phase of the repair material.

Compatibility is a concept that has been specifically developed for concrete repair (Fig. 1).

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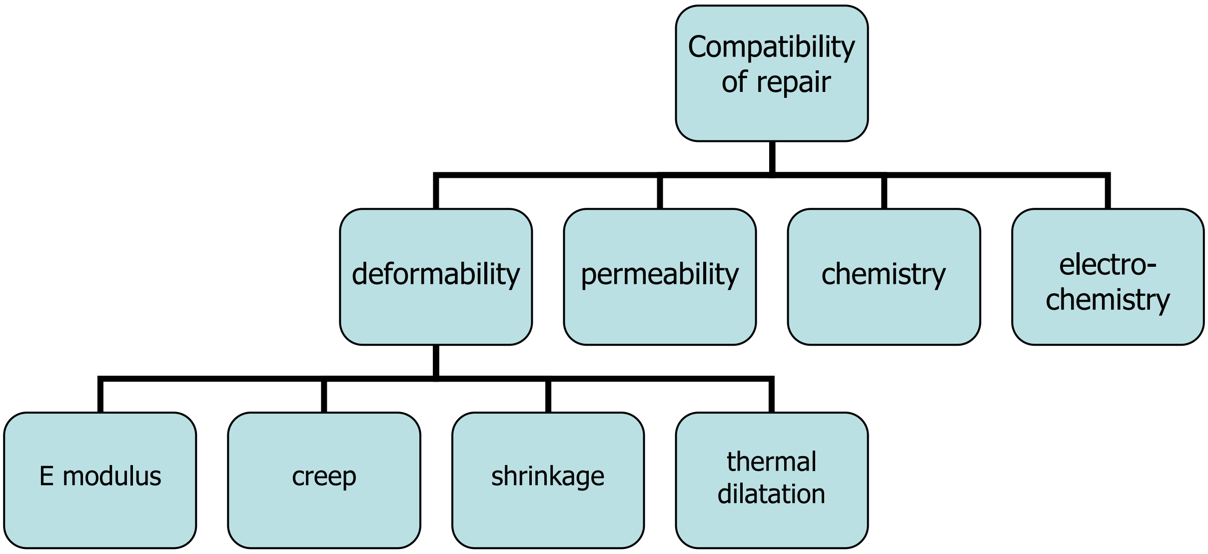

Figure 1: Principles of compatibility for repair materials and systems

Cracking of new material is due to restrained deformation. The new material is submitted to volume changes due to autogenous shrinkage and drying shrinkage which are restrained by a stable substrate (from volumetric standpoint). As the new layer is not able to restrain, internal tensions will appear: if tensile stresses are high than maximum tensile strength of repair material, it will crack. Prediction of this particular type of cracking is a complex task because it also depends on the concrete support characteristics. It is very important to know exactly which parameters can really influence volumetric compatibility between layers.

Many authors are working on repair topics and, specifically, on the behaviour of the composite concrete/repair material. Common philosophy states that the repair materials must offer the same properties than the concrete substrate: « ***Repair like with like*** » [4]. It should contribute to the durability of the repair operation. However, if this assessment appears to be attractive, it doesn't take into account the "age" of the material. While the "old" concrete is no more sensitive to shrinkage or creep, the "new" repair material will be submitted to stress/strain effects, directly depending on the evolution of material properties from the beginning. The problem has therefore to be considered as a global problem of compatibility between the two materials (mechanical, chemical, electrochemical and permeability compatibility) [5]. Specifically, in order to characterize the potential deformation compatibility between concrete substrate and repair material, five main parameters have to be known: shrinkage, E modulus, creep, restraint and tensile strength. That means that a simple evaluation of axial shrinkage (ASTM C157) is not enough to predict the behaviour of the composite in real situation.

Dry-mixture shotcrete and patch repairs are two classical methods that can be used for repairing these concrete elements [6]. The first method can give high values of adhesion and limit shrinkage by using an adapted W/C ratio and admixtures; the interface between shotcrete and old concrete is usually almost perfect, mainly due to high energy projection. Lacombe et all. [6] showed from SEM analysis that the quality of the bond appeared so good that it was impossible to see the difference in microstructure between shotcrete and old

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concrete. But the main disadvantage of shotcrete in this case is dust and rebound, which are unacceptable for areas like housing and buildings. Patch repairing is very time- and labour-consuming. A comparison of costs shows that Self-Compacting Concrete (SCC) can be an interesting option if it is possible to fix and reuse a mould under the structure [7].

The development of Self Compacting Repair Mortars appeared to be essential for specific applications like balconies, bridge deck slabs and other concrete structure where it is needed to perform thin overhead repairs. It is quite important to define the conditions that are required to assess a good bond between old and new material, knowing that there is no consolidating energy to cast concrete.

2. FRESH STATE BEHAVIOUR

The first way for obtaining a good compatibility is the contact; this will happen if the material is able to spread on concrete surface. One of the influent parameters is the viscosity and the shear level of the repair material. The idea is to develop a product that will be compatible with old concrete and can be cast without any external consolidating system. The SCC (Self Consolidating Concrete) are typically the products that can be used for such application; the only specificity in repair operations is coming from the dimensions of the aggregates which are limited by the thickness of the repair layer. This must be usually less than 20-mm which needs the design of mortar or micro-concrete. As the binder content in SCC is very high (up to 600-kg of powder), it is needed to replace a part of the cement by a mineral addition in order to reduce shrinkage (because of the decrease of the cement content) and to stabilize the product (less sensitive to water content) without loosing workability.

Different additions are commonly used [8] and must be characterized by sieving, shape, specific surface, etc. In order to determine the effect of the addition itself, tests are carried out to evaluate the workability of the basic additions modified products; specific test are needed for mortars. For example, the Flow Through Test (Fig.2) allows the evaluation of the workability of a mortar by measuring after 30 seconds the flow of 1-litre mortar along a specific distance. The distance reached by the mortar in that time is the *flow value*. The maximum distance is also recorded (D_{max}).

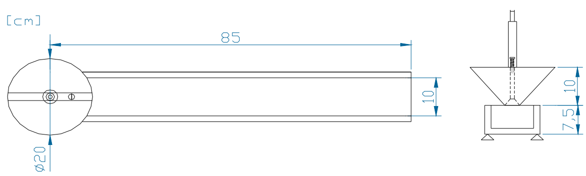

Figure 2: Flow Trough Test device (prEN 13395-2)

The flow is determined after 5 and 30-min, respectively, after the contact between water and powder; the original grouting product (without any addition) and the modified products have been tested.

The “water demand” is another way to determine the rheological characteristics of the mix by the test of “smooth paste” [8]: this last test consists in mixing 400 g of powder with water

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and increasing the water content until the “ball”, formed by the powder and the water, adheres on the sides of the bowl. For this water content, a “specific rheological” state is attempted. The “water demand” is given by the water to powder ratio at this time (W/P). We can also determine the compacity of the mix at this state as the ratio between the quantity of powder (P) and the sum of the quantities of powder and water (W+P) (Fig.3).

Figure 3: Fresh state evolution of cement-modified mixes

The basic grouting mortar is composed of cement, mix of additives (superplasticizer), sand and gravel of maximum 5-mm diameter. The particle size distribution is kept unchanged. The $CaCO_3$ content of the limestone fillers is higher than 98%: it is considered as an inert material [9]. The basic grouting was modified by adding 5 and 10 % (of cement mass), respectively, of each type of addition. Limestone filler is commonly chosen as a very good addition to improve the workability without significantly changing the mechanical characteristics of the mortar. A strategy is to be elaborated to determine the optimum superplasticizer and water contents for several percentages of replacement of the cement by the limestone filler. The mechanical strengths are also determined [8].

Table 1: Physical characteristics of the limestone fillers

	Bulk density (g/cm^3)	Specific surface (cm^2/g)	d_{50} (µm)	Water demand (W/P in mass)	Compacity (P/W+P)
Cement	3.14	5,000	8.4	0.2807	0.5315
LF1	2.71	4,300	13.1	0.2222	0.6242
LF2	2.72	3,200	18.0	0.2251	0.6202
LF3	2.72	5,500	8.3	0.2580	0.5867

The flow is determined after 5 and 30-min, respectively, after the contact between water and powder; the original grouting product (without any addition) and the modified products have been tested.

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Table 2: Loss of workability (%) between original and modified product (5 or 10 % of addition)

Loss of workability after	10 % addition		5 % addition	
	5 min	30 min	5 min	30 min
LF1	13.5	28.7	5.1	8.9
LF2	3.6	14.9	4.3	10.7
LF3	9.9	27.7	2.6	14.3

The loss of workability induced by the addition is estimated from the difference between the D_{max} of the non-modified product and the D_{max} of a modified product (Table 2). When 5 % of limestone filler are added, the loss of workability is quite low.

3. SHRINKAGE AND CREEP PROPERTIES

A large research project [11] has been set up at University Laval in order to compare shrinkage/creep effects on the behaviour of different Self Compacting Repair Concretes (Table 3).

Table 3: compositions of concrete design mixes [11]

Concretes[1]	BAPL1	BAPL2	BAPL3	BAPC1	BAPC2	BAPC3	BF	BO (réf)
Cement	TL[5]	TL	TL	TC[6]	TC	TC	TL	T10
Admixtures	PNS[2]	PNS+Wel.[3]	PC[4]	PNS	PNS+Wel.	PC	PNS	PNS
Binder (kg)	470							
Water (kg)	188							
VMA (ml/kgC)	–	2.1	0.5	–	3.8	0.6	–	–
SP(ml/kgC)	17.5	14.5	8.2	15	12.5	7.0	9.3	5.9
Aggregate (kg)	796	795	796	807	805	807	812,3	783
Sand (kg)	901.4	903	901,4	913,8	911,5	913,8	921	886.6
DEA (ml/kgC)	0.02	0.02	0.04	0.01	0.01	0.04	0.02	0.02
Flow[t.] **(mm)**	660	710	670	700	670	655	Slump 230	Slump 120
Air content (%)	2.6	2.0	2.5	2.4	1.7	2.4	2.7	3.1

[1] W/C = 0.40 ;
[2]Naphtalen-based Superplasticizer ; [3] Welan gum; [4] Polycarboxylate-based Superplasticizer ; [5] GGBS-based cement binder ; [6] PFA-based cement binder.
BAPL = Self-Compacting Concrete (with GGBS); BAPC = Self-Compacting Concrete (with PFA); BF = concrete with high Slump Flow; BO = ordinary concrete

These investigations were undertaken through 4 types of experiments: tensile creep tests, flexural creep tests, drying shrinkage test (ASTM C157) and ring tests (ASTM C1581). These allow the collection of very interesting and accurate information about the viscous behaviour of concretes under tensile load. Six different mixes are here studied: Fig.4 shows shrinkage and creep results. It appears that the 3 SCC with GGBS-modified cement present a similar

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shrinkage – kinetics and amplitude – which is lower than for fly ashes modified cement SCC. This last one offers a low creep potential, in comparison with all other mixes.

Some conclusions can be drawn:

- there is no relationship between high creep potential of SCC and VMA type or content;
- naphtalen Sp could induce higher creep for SCC;
- carboxylate Sp could promote drying shrinkage, which can induce tensile stresses;
- GBBS cements with naphtalen Sp seem to offer good balance between creep and shrinkage.

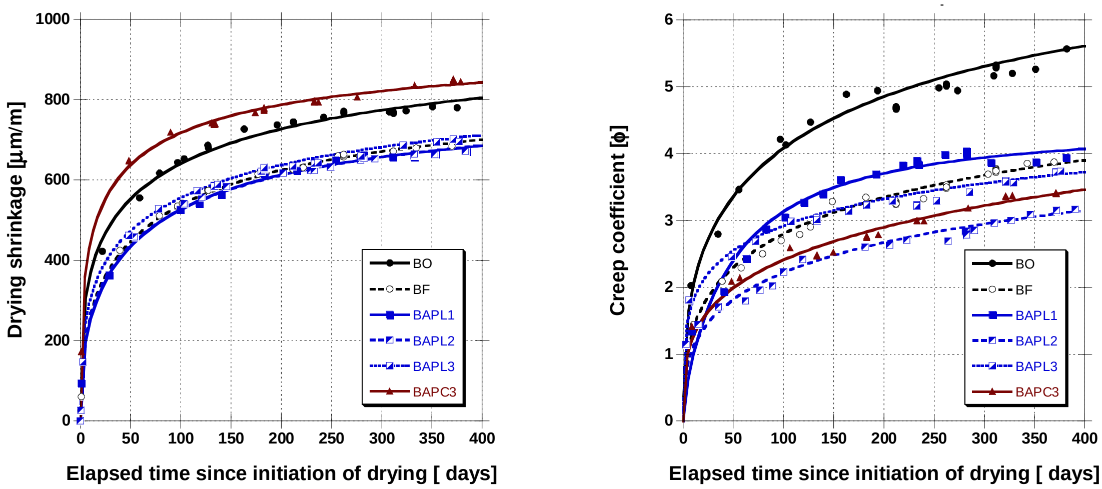

Figure 4: Drying shrinkage and direct tensile creep test results

4. HORIZONTAL APPLICABILITY TEST

It is not easy to know if the selected material will be really adequate; this is the reason why we tried to develop applicability tests that would be easy to use as well as very selective. This test program has been organised for the particular situation where the repair material is an SCRM. Guidelines and standards have been developed in Belgium for classical hydraulic binder-based repair systems agreement, but it was necessary to adapt the tests and the requirement to Self-Compacting Repair Mortar and Concrete [12]. The usual requirement for repair mortars are based on minimum values for adhesion: 1.5 MPa for non-structural and 2 MPa for structural repairs.

The repair product is flowed or pumped under a concrete slab in horizontal position (fig.5). A concrete slab (500 by 1000 mm) is prepared and sandblasted in accordance with prEN 1766 (concrete MC(0.45) which corresponds to 395 kg/m³ cement content and W/C = 0.45). Three holes with a diameter of 50 mm are cored on the medium axis at 250, 500 and 750 mm from the edge, respectively. These holes are closed with PMMA plates that are glued to the concrete with silicon. The concrete slab is held in position and separated from formwork with wood pieces.

Mortar or concrete is flowed through 30 x 50 mm hole from one extremity of the slab; the same hole on the other part of the slab is used as breather (Fig.6). The final thickness of

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repair material is 30 mm. Formwork is made of polyethylene plates. Slabs are dried before application. Applications are realized at 25 ± 2 °C and 50 ± 5 % R.H. After 48 h, the forms are removed and the repaired slabs are stored in environmental conditions and at 20 ± 2 °C for 7 days and 60 ± 5 % R.H. for additional 21 days.

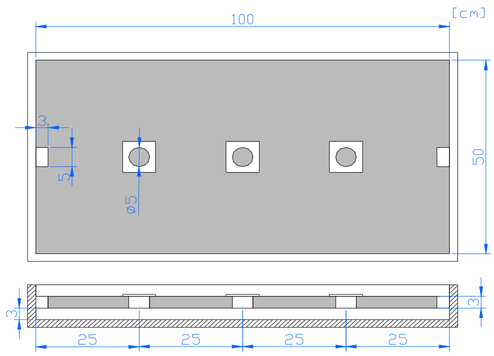

Figure 5: Description of the applicability test system for repair SCC

Observations after the application consist in visual inspection of the surface of the new layer and of the slices obtained after sawing the slab in the two main directions (Fig.6). They show air bubbles entrapped along the interface (Fig. 7).

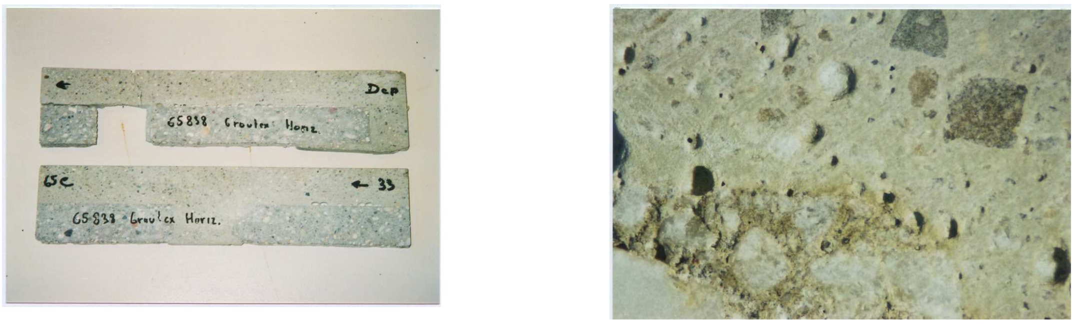

Figure 6: Slices perpendicular to the interface [12]

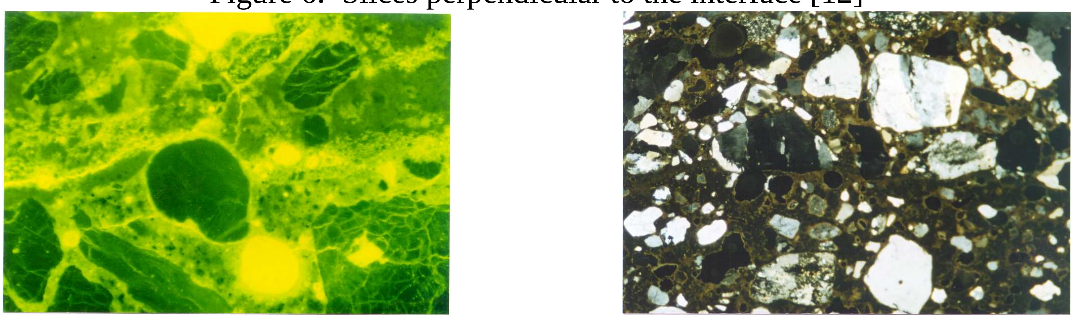

Figure 7: Air bubbles entrapped along the interface and /or inside the SCRM [12]

First results on Self Compacting Repair Mortar with limestone fillers show a good adhesion on the concrete substrate even if some air bubbles are still entrapped at the interface.

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5. CONCLUSIONS

The following conclusions may be reached from the present investigations concerning the behaviour of Self Compacting Repair Mortars and Concretes:

- Compatibility is quite easy to define but complex to evaluate. Creep and shrinkage behaviours seem however to provide very interesting information about the influence of parameters like VMA, Sp content and type;
- The use of limestone filler can be a good solution to replace a part of the cement in mortar composition. If the superplasticizer and the water contents are adjusted, the loss of workability can be minimised;
- The applicability test gives interesting information on the effectiveness of the products to be used for overhead applications. The difficulties we met during the applications are very instructive and clearly show that more research has to be conducted to elaborate final products.

Moreover, some problems like air bubbles cannot be deduced from classical test. It is absolutely needed to impose applicability test to be sure that the contact between repair material and concrete substrate really exists.

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