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CONTRIBUTION TO THE ADVANCED STUDY OF HIGH PERFORMANCE MORTAR FOR STRUCTURAL REPAIRS

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Abstract. *Many concrete structures in Brazil and around the world are reaching the limit of their projected useful life, in a cycle of five or more decades of use and operation. In addition to the older structures, there are either structures with reduced service time, and doubtful quality, which already showed several pathologies in such an advanced state that comes to compromise their performance. In according with these needs and looking for contribute to the scientific and technological advancement in industry, this study presents a method for dosing, prepare and application of high-performance mortars for recovery of damaged structures, in addition to suggest procedures to make those repairs, fostering the culture of preventive support and demystifying complexity attributed to such operations. In this case, tests related to mechanical, microstructural and related to durability of specimens molded with silica fume and styrene-butadiene rubber were developed. The results showed us that these ingredients in the composition of repair mortar, caused a significant reduction of the total permeability and a discontinuity of the pore, as well as fostered a higher integrity of the mortar's components, resulting in an expressive expansion of their mechanical skills. This study, which has a highly technological bias, will offer to construction industry a high-performance polymer mortar, with restorative function and most affordable cost, which can be adopted in construction sites, implementing sustainable nature actions and serving the current requirements listed by the literature, related to performance, useful life and repaired structures durability.*

Keywords: *mortar, high performance, silica fume, SBR latex and durability*

1. INTRODUCTION

Many concrete structures in Brazil and around the world are reaching the limit of its projected life, completing a cycle of five or more decades of use and operation. The interaction of these buildings with the environment in this period without proper maintenance, certainly favored the emergence of different types of pathological manifestations that may compromise the physical integrity of these structures and the safety of people who use it. In addition to the older structures, there are structures with reduced construction time, and questionable quality, which already shows diseases in such an advanced state that are compromising its performance. As well as the safety aspect, another point to note, supported by Dal Molin (1988), it is that these problems, when apparent, compromises the user's well-being from the point of view of comfort, health and psychological satisfaction.

In Brazil, preventive or even corrective measures are still in a very early stage, for various reasons, stresses the little importance given to the topic "maintenance of concrete structures and other building systems" in the academies, which confirms the shortage of staff prepared for this. According to Andrade and Fortes (1995) *apud* Pereira *et al*. (2013), the losses with steel corrosion in Brazil, specifically in construction, reaches 15 billion dollars a year or so.

The need for emergency measures to mitigate this problem and the advancement of technology in the industry, various researches have been done by the scientific community to facilitate the restoration of service of structures conditions, extending its useful life.

It is known that the most part of reinforced concrete structures in Brazil is in urban areas and under the effect of marine environments, where high activity of chloride ions attacks the reinforcement through the capillaries pore continuum of structures already compromised due to the penetration of atmospheric gases resulting from urban pollution, which promotes reactions that result in the breakdown of concrete. This is the need to implement measures to decrease the permeability and pore connectivity of the projected parts and, consequently, reduce the deleterious potential of aggressive agents.

Unlike traditional concepts where the technical quality of the structures are measured only for their mechanical strength, aiming the economy, other features becomes to have equal importance nowadays. Currently, performance and durability, focusing on sustainability, are also part of the concerns of modern engineering, supported by the changes in national and international legislation, which aims to aligning the position of the ones involved.

The ABNT NBR 6118: 2014 (NB-1), which deal with the basic requirements for simple concrete structures, reinforced and prestressed, publiched at first at 1978, recently passed (2003 and 2014) by content reformulations covering concepts already absorbed by the international community, but still maturing in Brazil, expanding the classification ranges for the inclusion of high performance concrete (up to C90) and incorporating themes such as durability and useful life of the structures. As long as these new concepts increases the construction costs, the first complaint of construction agents, it aims to present minimum requirements for role-structures of quality assurance of environmental aggressiveness class to which it is submitted.

In Natal / RN, seaside town whose environmental aggressiveness class can be considered level III (NBR 6118: 2014), especially in areas close to the seafront, there are numerous cases of pathological manifestations related to concrete structures, mainly in the hotel chain located along the coastal route, resulting from the high concentration of chloride ions related to the marine environment of the region.

In local search, at the commercial networks most representative in Natal, it’s possible to notice some difficulty in purchasing products for the manufacture of repair mortars, even in the availability of industrial compounds ready for use, a fact that inevitably increases the costs involved. Thus, suppliers contacts are indispensable, using neighboring urban centers with available representations.

In this context, few studies related to corrosion of steel and structural repair of concrete with pathological manifestations have been realized at the local level. Most of them come from research groups of federal educational institutions.

In the way of these needs and to contribute to scientific and technological advances in the industry, this paper presents a method for dosing and preparation of high-performance mortar for structures recovery with signs of deterioration.

In addition to those facts, this work is justified by the need to foster the culture of preventive maintenance and demystify the complexity attributed to such operations.

The procedures presented here will measure high-performance polymer mortar with restorative function in construction site, providing a significant reduction in costs involved.

This study aims to contribute to the structural repair technology, proposing a specific and comprehensive method that addresses the materials involved and the procedures for execution and control technology.

1.1 Fundamental Properties for repair mortars

Several factors interfere directly in compatibility between the concrete substrate and the repair material to be used. It may be highlighted, among them, the preparation of the concrete surface (substrate), the technique to be applied to the repair procedure, and especially the properties of the repair material.

According to Carasek (1996), properties such as porosity, water suction capacity and surface texture are characteristic of concrete substrates that may interfere with the adhesion of repairing material, especially the first two.

For good anchoring, where the material does not releases the substrate in any position and remain intact and cohesive after application, independent of the intrinsic properties of concrete to be repaired, it is important to make surface treatment of the substrate. The repair material may have a great compatibility grip and durability, but if the substrate is not well prepared, the repair procedure cannot come out as expected.

To assist the connection between the repairing material and the porous surface of the base, a mechanism that promotes increased hydration of the cement particles in the pores of the concrete microstructure should be used, "a bonding bridge", which can be water application, cement cream or another material with similar characteristics.

About the required properties for a good repair material and cement mortar, Souza and Ripper (2009) argue that to have a good durability, must be perfectly known characteristics as mechanical strength, dimensional stability and chemical resistance. Dimensional stability is related to the expansion phenomena, shrinkage and cracking, and chemical resistance, with the ability to withstand various chemical agents, such as sea water, air salinity, atmospheric pollution, among others.

Do and Kim (2012) contributed with a table into four levels that establishes requirements, properties and criteria for the selection of a good repair material, as shown in Figure 1.

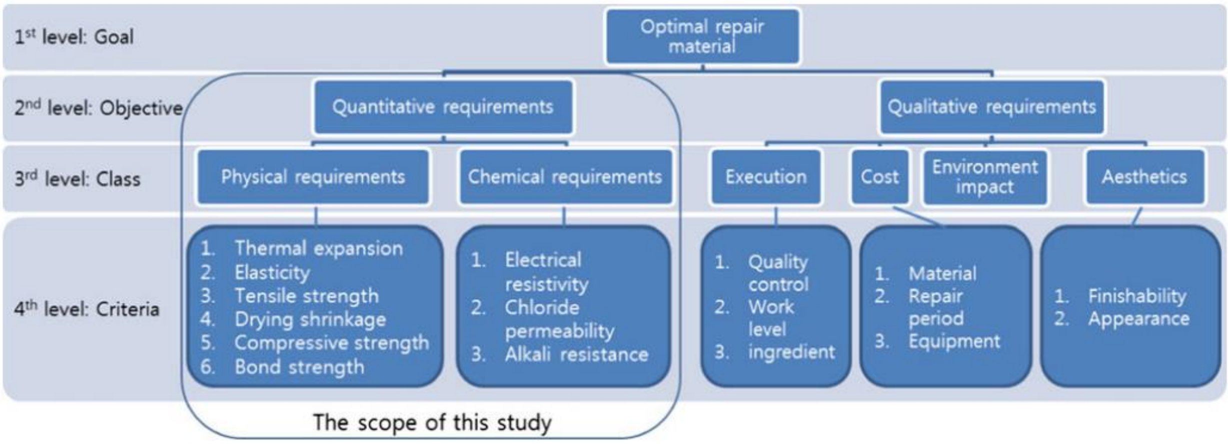

Figure 1. Requirements, properties and criteria for repair material selection
Source: Do and Kim (2012)

Karade, Lakhani and Asthana (2006) conducted a research in order to review the methods used to evaluate the repair materials and suggest criteria for better selection of them. The authors says that for this selection, the dimensional compatibility, structural, permeability, chemical and thermal between the repairing material and the concrete substrate should be considered, according to the needs presented in Table 1.

Table 1. Properties and necessary relations between the repair material and substrate

Property	**Relation between the necessary repair material (R) and the substrate (C)**
Mechanical Strenght (compression, tensile and flexural)	R > C
Tensile modulus (compression, tensile and flexural)	R = C
Fluency ratio (for repairs in compressed parts)	R < C
Fluency ratio (for repairs in tensioned parts)	R > C
Water retention	R > C
Adherence	R > C
Thermal expansion coefficient	R = C
Shrinkage index	R < C
Porosity and receptivity	R = C
Performance of fatigue	R > C
chemical reactivity	R < C

Source: Karade, Lakhani and Asthana (2006)

In attention to dimensional compatibility, factors such as shrinkage, expansion or thermal expansion, creep effects and elasticity modulus should be taken into account.

About the structural compatibility, it is expected that the repair materials have greater resistance to compression, tensile and flexural that the concrete substrate, and same elasticity modulus, or so. Complementary to these factors, the adhesion between the two elements determines the performance of the repair material. If the procedure has not been done properly, including substrate preparation, there may be a detachment that certainly compromise the repaired element.

Repair materials shall not show any ill effects to the substrate. To ensure chemical compatibility must be restricted elements containing chloride ions which can promote corrosion of the reinforcement, or sodium and potassium ions, enabling the occurrence of alkali-aggregate reactions. It is important that the mixture can reach the necessary alkalinity for the passivating protective steel.

Several studies have investigated the electrochemical compatibility between the elements in order to prevent that the cementitious repair can cause further deterioration. Ribeiro and Selmo (2010) argue that "localized repairs can lead to the emergence of corrosion macrocells with cathodic area inside repair and anodic area on the reinforcement region under the original concrete, adjacent to the repair." This is why there is a repassivation of the reinforcement with the repair, due to increased alkalinity of the repaired area, as well as the steel loses its cathodic function that the anode area removed by repair gave him. Thus, it is possible that in areas adjunct to repair the steel becomes more susceptible than before.

The penetration of aggressive agents in the structure is not a visible activity, does not compromise the strength of concrete and seems no superficial change, but strongly influence the corrosion of reinforced concrete. The chloride ions that penetrate inside the structural elements are responsible for increasing the electrical conductivity of the electrolyte, facilitating corrosion (MEDEIROS and HELENE, 2003).

The permeability, one of the four known mechanisms penetration, is one of the most relevant parameters to characterize the quality of the concrete and may be described as the resistance or the facility that the concrete is penetrated by a certain substance. It is a parameter that depends on the quality and size of pores, thus strongly depends on the ratio water/cement in the concrete mix. The higher this factor, more permeable concrete will become. The water/cement fator directly influences its microstructure and its network of pores, and the size and interconnectedness of these the main controlling factors of the penetration of chloride ions. The more connected the pores are more easily aggressive agents will percolate the layer cover of concrete.

In general use mortar, to plaster, masonry settlements, floors and tiles, water retention is attributed to a lime. In such cases, the impossibility of cure demains that the lime keep the water in the mortar, providing the cure of the cementitious material.

For structural mortars, which have contact with steel, the use of lime is prohibited, since it, in the presence of water, could cause the process of reinforcement corrosion.

In the need for water retention in structural mortar, the latex polymers of styrene-butadiene (SBR) was employed. This component forms a plastic film that retains water in the mortar, ensuring their healing and curing, even at older ages.

Ramezanianpour et al (2006) in their studies, investigated about the compatibility of repair materials in aggressive media in southern Iran, using silica fume mortars and styrene-butadiene latex. The result of this research showed that repaired concrete with cement mortar containing these substances are materials suitable for harsh environmental conditions of the Gulf region. Also add, in its conclusions, that the mixture has a better tensile strength, significant reduction in rates of drying shrinkage (especially in the first five days), improvement in adhesion properties and reduce the formation of microcracks, as well as low rates of permeability to external agents when compared to the reference material.

2. MATERIALS AND METHODS

The experimental campaign begins with the selection of materials that compose the mortar. At first, identifying the options available in the local market were pursued, assessing its properties in the laboratory and adapting them to the needs, when needed. The cement phase is composed of Portland cement, defined on the basis of compatibility with the plasticizer additive, and silica fume, from the manufacture of iron-silicon alloys and silicon metal. The fine aggregate is washed quartz sand, from river, with a maximum dimension of 2.36 mm and composition grain size within the range considered to be usable, of great area, most suitable for what is wanted. two additives are incorporated into the dash: a polymer, based on styrene butadiene, aiming to limit to the maximum permeability of the mixture, and other chemical, water reducer, on the way to promote a reduction in the factor w/c, key to achieving the objectives .

The acceptable range adopted for the factor water/cement, and the relation binder aggregate used (1: 3), was defined based on studies of Lima, Tatsuno and Costa Filho (2010), using as parameter the acceptance of results obtained on consistency test of the mortar index with 250 mm (+/- 20).

Eighty-six specimen measuring 50 mm x 100 mm were cast, distributed among the five traces defined in the research, with the factor w/c variable and relation binding/aggregate fixed at 1:3, with replacement of cement by silica fume 10 %, for some mixtures, according to table 2.

Table 2. Dosage of features for making the specimens

Trace	cement (g)	silica fume (g)	sand (g)	water reducer (g)	factor w/c	SBR (ml)	water (ml)	cure tipe (*)
1	1000	0	3000	20	0,48	100	380	dry
2	900	100	3000	20	0,48	100	380	dry
3	900	100	3000	20	0,42	100	320	parcial
4	900	100	3000	20	0,40	100	300	wet
5 (ref)	1000	0	3000	20	0,42	0	420	wet

Source: Author's archive (2014)

The specimens were subjected to three different curing conditions: dry, air, applying a silicone paint based on silane-siloxane, in order to prevent loss of water to the surface by evaporation or exudation, moist, by immersion, in a suitable chamber, and part dry / part wet, remaining seven days immersed and then subjected to dry healing, in order to promote the optimum conditions for curing mixtures containing Portland cement and latex SBR, according to the recommendations of Ohama (1998).

At three, seven and twenty-eight days, the specimens were removed from the curing conditions that they were submitted and forwarded to mechanical testing of axial compression, diametrical compression traction and absorption by immersion, adopting as a result the average between two Similar values.

At one hundred days, the remaining specimen passed by the air permeability test, considered semi-destructive, by means of a device that uses air suction technique for measuring permeability index, essential to evaluate the prospect of mortar durability (hardened), and propagation of ultrasonic waves, non-destructive testing, which aims to assess the homogeneity of the material, detecting possible internal failures.

3. RESULTS AND DISCUSSION

All dosed samples obtained values of the consistency index within the parameter set at the beginning, of 25 cm +/- 2 cm, which ensured good workability of the mixtures.

Samples containing SBR latex showed a slight increase of consistency with better workability as compared to the other with the same factor w/c, and delaying the start time observed in empirical evaluation.

The results of axial compression tests of the specimen cured with traces as detailed dosages are shown in Table 3.

Table 3. Results of axial compression tests

Trace	**3 days (MPa)**	**7 days (MPa)**	**28 days (MPa)**
1	1,25	1,50	31,10
2	0,75	2,20	40,35
3	-	-	62,80
4	3,15	31,25	54,40
5 (ref)	17,75	20,05	27,10

Source: Author's archive (2014)

It’s importante to notice that the results of mechanical resistance in the early days to the traces containing the SBR latex additive did not follow the standard development of resistance to mixtures with cement used, but achieved a significant advance at a later date. Additional studies should be developed to assess, more specifically, how and why the mortar strength had its strength gain process in the early days, intervened strongly. In the beginning, according Ohama (1998), this observed characteristic is due to the tunneling effect of the grains of the polymer cement during the hydration process, which limits the amount of water in contact with these grains, interfering with the speed of the hydration reactions .

The specimens for the trace 3 showed the highest levels of resistance to axial compression, even when subjected to dry healing after only 7 days old. High humidity at the earlier ages slows the coalescence process in polymer mix, modified with styrene-butadiene and decreases the permeability of the pulp reduces the water entering the moist healing process, as well as water loss to the environment, which would explain the excellent results obtained in the test.

The reduction in the factor w/c, without prejudice to the pulp consistency index and consequent workability, as well as the healing method adopted in this sample (trace 3) were decisive in the significant increase of mechanical resistance, increasing the rates obtained at trace 2 to numbers 50% higher, at around 60.0 MPa.

The results obtained for the trace 4, although strictly mirrored the procedures adopted for trace 3, with the advantage of adopting a factor w/c a little smaller, were not higher, given the kind of healing adopted, submerged in a moisted chamber during the 28 days of age.

The trace 5 obtained indexes exactly as expected, with standard development of mechanical resistance ratio at choiced reference days (3, 7 and 28). The additions, chemical and minerals, to trace 2, 3 and 4 responded positively to expectations of mechanical improvement when compared to the trace 5, reference.

With the reduction factor w/c in 16.7%, from 0.48 to 0.40 in the trace 2 in the trace 4, was observed a significant increase in ultimate mechanical resistence (after 28 days), with rates 35% larger, approximately. When compared to the trace 5, in reference, the mechanical resistence is increased by 100%, doubling the index.

Table 4 shows the results of tensile resistance tests for diametrical compression.

Table 4. Results of the tensile tests by diametrical compression

Trace	3 days (MPa)	7 days (MPa)	28 days (MPa)
1	0,20	0,25	2,65
2	0,10	0,40	3,65
3	-	-	6,10
4	0,95	2,35	5,55
5 (ref)	1,40	1,95	2,95

Source: Author's archive (2014)

The literature points to an increase in tensile resistence index by up to 40% when added the SBR latex in trace composition. This is due to the formation of an interpenetrating network polymer films with high tensile strength, in addition to acting as wax in the capillary pores by reducing the capillary suction.

Unlike the observations of Ohama (1998) and Rossignolo (2003), the tensile resistance results obtained, as shown in Table 3, showed no change of standard in terms of proportion to axial compression (approximately 10%) when compared to the results of reference (trace 5). On the other hand, they exposed the same retardation conditions in the gain of resistance at early ages, as the axial compression results.

The use of mineral and chemical additions, including SBR latex, amplified tensile resistance of the specimens up to two times more than the reference index (trace 5), which in itself already qualifies the study.

Table 5 shows the results of water immersion absorption test.

Table 5. Results of water immersion absorption test

Trace	Absorption index (%)	Empty index (%)
1	6,89	14,21
2	6,78	13,58
3	8,53	14,32
4	5,34	8,44
5 (ref)	8,10	12,44

Source: Author's archive (2014)

The samples of trace 1, unlike the others, presents no silica in its composition, but has had additive SBR and silicone paint (waterproofing of the peel) after undercut, for the dried curing process.

The samples of trace 3 have the microsilica in it composition and had the addition of the additive SBR, but passed through moist curing for the first 7 days and placed in dry healing after this, however without the silicone paint that the samples trace 1 and trace 2 were submitted, which may explain, in part, this greatest result.

The samples of trace 4, which achieved the lowest levels of absorption by immersion and gaps, and count with the sílica fume and SBR in its composition, had their factor w/c quite small in relation to the trace 2, which allowed a reduction in bit rate over 20%, compared to the index of samples of the trace 2, which counts even with the application of an external waterproofing layer of silicone.

Regarding samples of the trace 5, the reference, the tested models of trace 4 showed gaps ratio and water absorption by immersion 30% lower, approximately, which corroborates with the parameters presented in the literature on the waterproofing microsilica action, physically acting through the filler effect, and chemically, the additional C-S-H formation, besides the waterproofing promoted by impregnating of the látex SBR on the mortar pores.

Table 6 shows the results of air permeability tests.

Table 6. Results of the air permeability tests

Trace	Time of elevating internal pressure of the specimens cavity by the *porosyscope*, of -55 KPa to -50 KPa			protective quality of the mortar (*device manual*)
	specimen-01 (seg.)	specimen-02 (seg.)	average (seg.)	
1	78	72	75	Not so good
2	383	404	393,5	Good
4	1028	1013	1020,5	Excellent
5 (ref)	105	113	109	Reasonable

Source: Author's archive (2014)

Confirming the results obtained from tests for absorption, described earlier, samples from the dosages of trace 4 had permeability condition incomparable to others, demonstrating integrity of the models virtually with no connection of pore and likely fill the gaps with products of complementary hydration, from silica, and polymeric film derived from the polymer particles used.

Samples from trace 1, although they have the same water/cement ratio and cement/aggregate applied to the samples of the trace 2, shows poor permeability index, precisely because they didn't have the properties of microsilica in its composition.

The samples of trace 5, although did not have any agents that promote reduction in permeability rates, had their factor w/c greatly reduced, which benefited the test result, achieving "acceptable" levels.

The trace 3 has not been tested, regarding their permeability conditions in numerical unavailability of specimens.

The results of ultrasound waves propagation speed tests are shown in Table 7.

Table 7. Results of wave propagation speed of ultrasonic testing

Trace	**Velocity of linear propagation between the two transducers**			**Mortar quality (CANOVAS, 1988)**
	specimen-01 (km/s)	**specimen -02 (km/s)**	**average (km/s)**	
1	4016	4032	4024	Good
2	4184	4184	4184	Good
3	*the test for the specimens of trace 3 wasn't made*			
4	4566	4566	4566	Excellent
5 (ref)	4464	4464	4464	Good

Source: Author's archive (2014)

The results obtained in the test, when compared to the index presented by Canovas (1988, apud Reis, 2001), attest to the uniformity of the specimens tested, especially the samples for the trace 4 which, again, the best combination of assay, as regards its physical integrity.

4. CONCLUSIONS

On the results presented, it is concluded that:

a) The use of microsilica together with the styrene-butadiene latex, in the composition of the repair mortar met the expectations in regard to reducing the total permeability and discontinuity of pores, as well as stimulated a better integrity of the constituents of mortar, translating into an significant expansion of its mechanical capabilities.

b) the results of axial compressive resistance tests attest to the positive assessment of the proposed mortar (trace 3), promoting a composite with about 60 MPa compressive resistance, reaching levels around 2.3 times stronger than the mortar reference (trace 5).

c) contrast to the results achieved by Ohama (1998) and Rossignolo (2003), developed resistance to draw, although achieved mechanical capacity two times higher (trace 3), as compared to the reference mortar (trace 5) had no different proportion of the standard index in comparison with resistance to axial compression. Kept ratio of approximately 10%. According to the literature, the latex SBR choice would increase this proportion up to 20% on average.

d) about the plasticity and workability of the mixture with the SBR latex in agreement with the results obtained by Ohama (1995) it was possible to confirm the increase of this ratio, when compared to traditional mortars. In accordance with the studies of Torgal and Jalali (2009), it was also observed a delay in the start and end handle, and limited growth of mechanical resistance in the early days, caused possibly by encapsulation of the cement particles, slowing the gain of mechanical resistance at early ages.

e) As for the results that shows the resistive capacity to aggressive agents that attack the armor, could be seen an almost impermeable state of mortars that used the SBR latex and silica fume (trace 4), demonstrating integrity of the models practically no pore connectivity and probable filling the gaps with additional hydration products from the high pozzolanic silica and the polymer film derived from the polymer particles used. The air permeability analysis, by Figg's method could prove the excellent quality of the concrete.

f) microscopy tests allowed to observe the microstructure of the dense samples (trace 3), high density and homogeneity of the cement paste matrix surrounding the aggregate without distinction in the interface region also confirmed by the test of velocity propagation of ultrasonic pulse.

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