Characterization of Concrete Repair Mortars

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Abstract: Concrete repair with repair mortars is an usual practice in reinforced concrete structures rehabilitation. The growing number of reinforced concrete buildings with repair needs, allied to an increased interest and investment in rehabilitation market by the engineering industry, indicates an increasing relevance of these materials in the construction sector. The construction materials industry has strongly invested in the creation of repair mortars with optimized properties, mostly with one-component character, and currently it is possible to find a wide range of these products in the market.

The knowledge of the properties of this kind of product is essential to perform a successful repair operation. The objective of this study is to provide a contribution to increase the extension of the knowledge about four repair mortars from different manufacturers that are available in the market. It intended to characterize some properties of the mortars, focusing on those which are more relevant to concrete repair performance.

KEYWORDS: Concrete, rehabilitation, repair mortars, density, consistence, flexural strength, compressive strength, shrinkage, adhesion.

1. Introduction

The construction industry goes through one of the most critical periods of its history, with a financial and economic crisis globally installed and market stagnation with regard to the sale of new buildings. Portugal's situation is a clear example of the survival difficulties of construction companies, and the need to find alternative solutions that may allow inverting the current situation is of extreme urgency.

The rehabilitation of reinforced concrete structures is presented, currently, as one of the most recent and relevant civil engineering challenges. In the last decades, the number of reinforced concrete buildings presenting clear signs of deterioration increased significantly, and it is expected that number to increase in a disturbing way. Therefore, the rehabilitation, mainly the rehabilitation directed to reinforced concrete buildings, reveals a great potential to become a key sector of the construction market.

The reinforced concrete buildings deterioration results from the combination of several factors, which can be related to construction processes, structural conditions or

environmental aggressiveness. These actions, happening alone or combined, lead to impairment of some crucial material properties for the structure's performance.
A large percentage of the deterioration of reinforced concrete buildings is connected to the reinforcement deterioration. The steel corrosion, which is usually caused by concrete carbonation or by chloride attack, leads to loss of bearing capacity and the creation of tensile strains, in a process that may culminate in the collapse of concrete elements.
Regarding the direct attack to the concrete, the most damaging situations are related to sulphate attack, freeze-thaw effect, temperature effect and alkali-aggregate reactions.

The relevance given to the durability of reinforced concrete buildings and its mechanisms of repair has increased in recent decades, mainly due to the growing need and potential of investment in this area. The Academic community, particularly, has devoted increasing investigation efforts to the rehabilitation theme.
This study intents to be an additional contribution to furthering knowledge of concrete rehabilitation techniques, particularly with regard to concrete repair recurring to repair mortars.

In the process of reinforced concrete elements rehabilitation, the use of repair mortars as a replacement of deteriorated concrete is quite usual. The industrial production of repair mortars has evolved significantly in relation to industry dimension and to its technical capacity. Currently, it is possible to find several mortars on the market specifically designed to repair concrete.
A deep knowledge of the repair materials properties is an essential point to ensure the success of a rehabilitation procedure. For each case, it should be chosen the material that better fits to the concrete characteristics with regard to the pathology and composition. Considering the expected growth in the use of repair mortars on deteriorated concrete interventions and the predicted expansion of rehabilitation market, is absolutely essential to have a deep knowledge about available products and its performance when subjected to the different conditions that can occur in the several cases of repair need.

2. Reinforced Concrete Deterioration

The reinforced concrete elements deterioration requires a complex process of evaluation, and often results from the combination of several actions that contributes to the loss of certain material properties. Therefore, except in cases where the preponderance of a particular cause is patent and unambiguous, determinate the circumstances that led to a particular state of deterioration requires a global study exercise that should involve the structural, environmental and utilization conditions of the element.

The global deterioration process of a reinforced concrete element may have its origin in the loss of properties of the concrete or in the reinforcement. However, to both situations cannot be analysed separately since in most cases the deterioration mechanisms of the two reinforced concrete components are connected and produce catalytic or aggravating effects between each other. The deterioration of concrete, which provides mechanical, physical and chemical protection to the reinforcement, leads to an increase of vulnerability of these and creates extremely adverse conditions to the global durability of the system. On the other hand, the steel reinforcement corrosion is quite harmful to the surrounding concrete, due to the tensile strains installed by the volume variation of the reinforcement sections.

The concrete deterioration can occur due to mechanical, physical or chemical actions that, in extreme cases, can lead to the total loss of properties and disintegration of concrete.

The mechanical actions are fundamentally related to situations like impact, vibration, excessive load or excessive deformation. All referred cases cause stresses that will lead to cracking situations, which can make irreparable damages to the concrete properties.

As most relevant physical actions we can include the temperature action, the freeze-thaw cycles and the superficial wear of the concrete. The most disturbing chemical actions are the alkali-aggregate reactions and the sulphate attack. In ordinary environmental conditions, in the absence of extreme temperature ranges, the chemical actions are usually the most worrying to the concrete durability.

The reinforcement durability and deterioration are especially related to the steel corrosion process. The reinforcement steel corrosion is the situation that generates the largest number of deterioration cases in reinforced concrete structures.

The corrosion process is generally a consequence of concrete carbonation or chloride attack. As a result of concrete carbonation, the pH level of the concrete pore structure is reduced, leading to the corrosion of the embedded steel bars and subsequent formation of cracks in the concrete.

The penetration of chlorides, when reaches a critical level, destroys de passive layer provided by the concrete alkalinity. The corrosion process is then possible, leading to the same consequences that were referred to the case of carbonation.

3. Repair Mortars

The selection of repair products must obey to certain criteria required to allow the achievement of satisfactory performance and durability results of the system composed by the original concrete and the repair mortar. The nature of the presented pathology, the concrete properties, its composition and the structural demands should be taken into account for the selection of the repair material, in order to ensure the compatibility between the concrete and the repair mortar.

The structural compatibility between concrete and repair mortars must be analysed according to the guidelines that were set by Emberson and Mays (1990) and referred to by Nsambu (2007), concerning the recommended relations between the mechanical properties of the concrete and the mechanical properties of the repair mortar. It is also quite relevant to ensure the chemical, electrochemical and permeability conditions of compatibility between the different materials, in order to promote a sympathetic performance of the two materials.

4. Experimental Campaign

4.1 Materials

The purpose of this work is to study the properties of some important properties of commonly used repair mortars from four different suppliers. The four selected mortars present one-component character, and the experimental program was planned to allow the study of some important properties in both fresh and hardened state.

It is not possible to proceed to an exhaustive composition analysis of the mortars, since their exact composition is protected by industrial secret. The general presentation provided by the manufacturers indicates the products as controlled shrinkage mortars, holders of high values of mechanic resistance and with excellent performances regarding to adhesion to concrete supports.

The four selected mortars, from now on designed AR1, AR2, AR3 and AR4, possess one-component character, and required only water addition to its preparation. This is an extremely gainful property to the easiness of preparation, alongside the uniformity security on different moments of mixture, with the variation of properties being only dependent of the amount of water added to the product.

Table 4.1 presents some of the main properties of the industrial mortars selected for this study, which are indicated in the product's data sheets.

Table 4.1 – Main properties of repair mortars

Mortar	Compressive Strenght (MPa)	Flexural Strenght (MPa)	Adhesion Strenght (MPa)	Density (kN/m^3)	E (GPa)
AR1	54,2	9,2	2,5	20,5	36,7
AR2	45,0	9,0	1,5	21,0	25,0
AR3	70,0	10,0	2,2	22,0	32,0
AR4	60,0	8,5	2,0	22,5	25,0

For carrying out the “pull-off” tests, there were produced five concrete elements with the dimensions of $75 \times 75cm^2$. The selected concrete presented the following technical features:

- Compressive Strength Class: C 30/37;
- Exposure Class: X0;
- Consistency Class: S3;
- Cement: CEM II/ A-L 42,5R;
- Maximum Aggregate Size: 22mm;
- Mineral Admixtures: Fly Ashes;
- Chemical Admixtures: Pozzolith 540 and Viscocrete 3005.

In order to establish a comparative analysis between the adhesion performance of industrial mortars and a traditional mortar composed of cement and sand, it was applied a traditional mortar, AC, in one of the concrete supports. The referred mortar was produced according to the following relations of composition:

- Water / Cement: 0,45;
- Cement / Sand Ratio: 1:3.

4.2 Experimental Procedure

In order to characterize the repair mortars it was planned an experimental campaign composed of tests on the fresh state and tests on the hardened state of the products. The fresh state properties characterization is extremely important, since it allows obtaining a forecast about the product performance at the application moment, which is absolutely crucial to the later performance at the hardened state.
Thus, there were selected the following proprieties to be evaluated by the experimental campaign tests:

- Density in the flesh state;
- Consistence;
- Compressive Strength;
- Flexural Strength;
- Free Shrinkage;
- Adhesion to Concrete (*Pull-off test*).

4.3 Results

Density

The density of mortars in fresh state was determined using two different procedures. The first procedure consisted of measuring the mass of a recipient with the capacity of 1L in two moments. It was measured before (M_1) and after (M_2) the total filling of the recipient with mortar and the completion of the compression process. The same process was used to the second procedure, but in this case were used the prismatic moulds as reference mass to determine the difference of mass caused by the filling with mortar.

The major difference between the both procedures was the compression conditions, which were significantly more severe in the second case. The values of density were determined using the expression 4.1, and there were determined two different values to each mortar, according to the different procedures (D1 and D2). The obtained values are presented in Table 4.2.

$$\gamma = \frac{M_2 - M_1}{V} \quad (4.1)$$

Table 4.2 – Density tests results

Mortar	Procedure 1 (kN/m^3)	Procedure 2 (kN/m^3)
AR1	22,7	22,9
AR2	22,2	22,6
AR3	22,8	23,0
AR4	22,1	22,7

Consistence

The consistence determination was carried out using a flow table, over that was placed the mortar previously configured by a mould, which was filled in two layers properly compacted. The procedure consisted in jolting the table 25 times during a period of 15 seconds, and measuring the spread diameter in three different directions, D_1, D_2 and D_3. The spread result was determined using the expression 4.2.

$$Espalhamento\ (\%) = \frac{D_{med} - 100}{100} \times 100 \quad (4.2)$$

where:

$$D_{med} = \frac{D_1 + D_2 + D_3}{3} \quad (4.3)$$

In the table 4.3 are presented the results from the consistence tests.

Table 4.3 – Consistence tests results

Mortar	Spread (%)
AR1	89,32
AR2	71,68
AR3	90.32
AR4	69,07

Flexural Strength

The test procedure to determine the flexural strength and the compressive strength of the repair mortars was performed according to the standard NP EN 196-1. The tests were carried out on mortar prisms with 4X4X16 cm^3.

The test campaign involved measurements of the resistance at 3, 7, 28 and 90 days of age. It was tested one prims at the age of 3 days, two prisms at 7 days, 3 prisms at 28 days of age and, finally, 3 prisms at 90 days of age.

The flexural strength tests lead to the results presented in table 4.4.

Table 4.4 – Flexural Strength tests results

Mortar	3 days (MPa)	7 days (MPa)	28 days (MPa)	90 days (MPa)
AR1	2,14	2,72	4,57	7,21
AR2	2,61	5,52	12,58	12,63
AR3	2,63	4,72	7,28	7,94
AR4	3,15	4,78	9,54	9,84

In order to allow a clearer comparative analysis between the resistance evolutions of the different mortars, the evolution model is represented in figure 4.1.

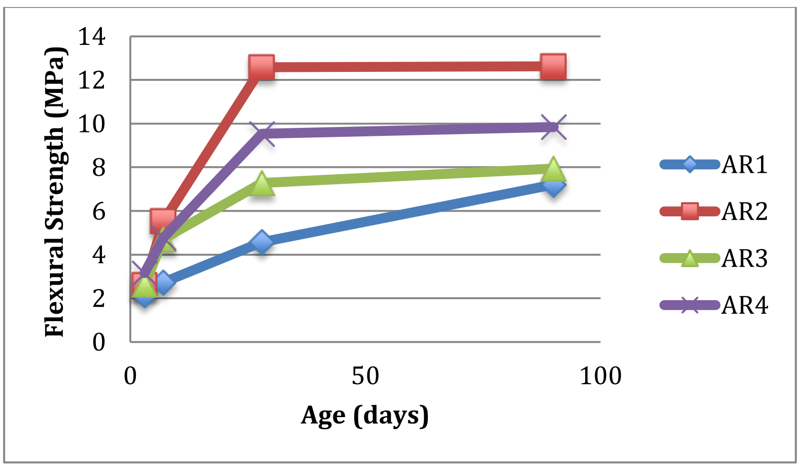

Figure 4.1 – Flexural Strength evolution

Compressive Strength

In table 4.5 are presented the results obtained in compressive strength tests, and the mortar's evolution model is represented in figure 4.2.

Table 4.5 – Compressive Strength results

Mortar	3 days (MPa)	7 days (MPa)	28 days (MPa)	90 days (MPa)
AR1	23,98	38,39	75,60	86,93
AR2	21,12	40,85	82,05	105,82
AR3	20,67	44,12	49,10	55,17
AR4	24,31	46,20	69,03	84,80

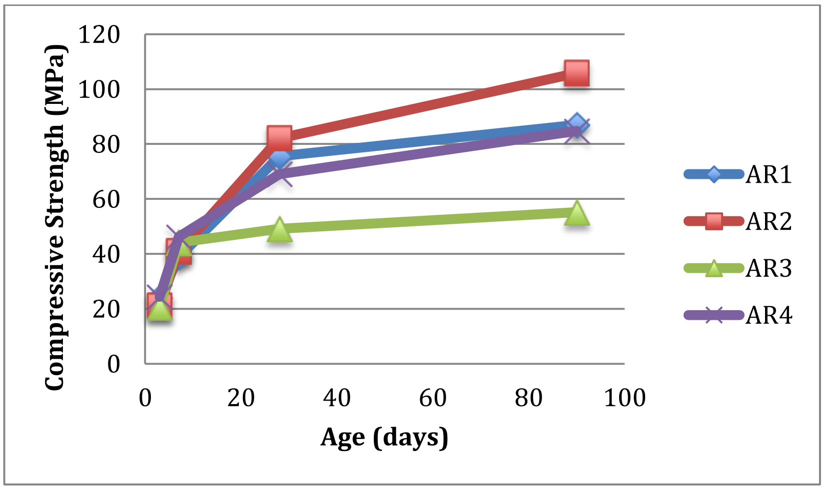

Figure 4.2 – Compressive Strength evolution

Shrinkage

The shrinkage evaluation of the repair mortars was conducted according to the stipulated procedure in the specification E398 from LNEC, and the shrinkage values were determined to the ages of 3, 7, 28 and 90 days.

The specimens used to evaluate this specific property were made in prismatic moulds with 4x4x16 cm^3, equipped with steel studs that remain embedded in the top of the mortar prisms after the moulds removal.

The results obtained with the described procedure are summarized in table 4.6, and the shrinkage evolution during the test period is represented in figure 4.3.

Tabela 4.6 – Resultados dos ensaios de retracção ($\mathcal{E}_{cs} \times 10^{-3}$)

Argamassa	3 dias	7 dias	28 dias	90 dias
AR1	-0,13	0,31	0,83	0,94
AR2	-0,44	0,27	0,85	1,04
AR3	-0,13	0,25	0,69	0,75
AR4	-0,65	0,56	1,19	1,48

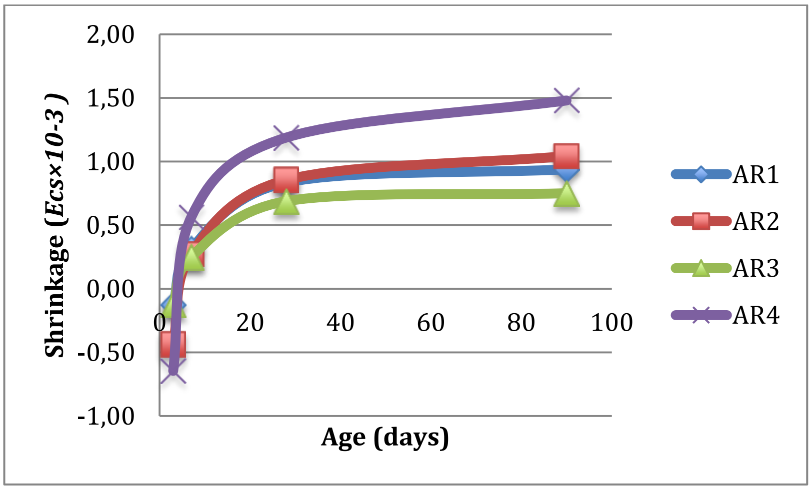

Figure 4.3 – Shrinkage evolution

Adhesion

The adhesion performance of the repair mortars to the concrete elements where they were applied was evaluated though the execution of "pull-off" tests. The adopted procedure followed the instructions contained in the sheet test FE Pa36 from LNEC, and consisted in the application of a tensile force perpendicular to the surface, in order to pull a prepared element off the system, measuring the maximum strength applied at the moment of the system failure. The failure can occur in concrete, in the mortar or in the interface area between the two materials, where the adhesion must be created.

The tests results are presented in table 4.7.

Tabela 4.7 – Pull-off tests results

Mortar	Failure Area	Adhesion Strength (MPa)
AR1	Interface	0,499
AR2	Interface	0,499
AR3	Interface	1,151
AR4	Interface	0,468
AC	Interface	0,235

5. Discussion

As revealed by the mortar density tests, we clearly obtain higher values using Procedure 2 which can be explained by two distinct aspects. The first concerns with the different compression process used in both procedures, which seems to be the most relevant factor. Using greater compression intensity in Procedure 2 allowed us to have a clearer air void decrease. The second possible explanation to the difference in values obtained can be associated with the excess of mortar inside the mold, which could have increased the density.
When looking at the Consistency Scattering Tests we can distinguish two pairs of results, AR1 and AR3, and the mortars AR2 and AR4. The tests indicate a 20% difference between the above-mentioned pairs, which could be experimented when handling the mortars after their mix, casting and appliance on the concrete. However the resemblance shown by AR2 and AR4 mortars does not reflect their real workability performance. Handling the AR4 mortar, especially when applying over the concrete for the Pull-off tests, revealed to be fairly complicated. Although it did not possess the workability performance of mortars such as AR1 and AR3, AR2 proofed to be a rather simple mortar to apply.
The mortars mechanical resistance to Flexural Strength presents fairly different results. Results indicate that AR2 has significant higher values when compared to the mortars, around 3 MPa when compared to AR4. AR1 and AR3 have similar results although they turned out short relatively to the manufacturer indications.
All four mortars presented distinct resistance progress. Even thou AR2, AR3 and AR4 had a similar resistance evolution, all three mortars had different final resistance Flexural Strength values, obtaining a 90% resistance after 28 days. On the other side, AR1 saw its final resistance evolve around 60% in a period between the 28th and 90th day.
Concerning the Compressive Strength, all mortars in study revealed distinguish results in a range over 50MPa, between the lowest and highest result. Mortars AR1 and AR4 had a similar performance, both on the final resistance and the progress to it, even overcoming the values stated on the manufacturers technical sheet. AR2 Compression Strength results were extremely high when compared to the other mortars and to what the technical sheet mentioned.
On the same comparison mortar AR3 did not reach the expected Compressive Strength value, revealing to be the lowest result in the study. This unexpected variation can be explained due to the specimen preparation methods or the tests themselves being fairly different from the ones executed by the manufacturer.
Through the careful Shrinkage Test results analysis we were able to verify that all mortars showed expansions at the 3rd day measurements, which derived from the curing in the first 48 hours. AR3 presented less shrinkage compared to the other mortars while AR4 had the biggest shrinkage percentage. AR1 and AR2 evolved in a similar expansion while the shrinkage effects were noticed.

Comparing the results in all 4 mortars to the ones obtained by Ribeiro (2004) and Nsambu (2007) in similar mortars, we can observe a considerable results resemblance, exception made to the AR4 mortar.

The results obtained by the above mentioned authors in the traditional cement + sand mortars Shrinkage Tests, when compared to the more commercial mortars tested, reveal invariable lower test results which refutes the supposed advantage commercial mortars had in that chapter.

The performance results obtained revealed to be quite inferior to the ones expected in all four mortars. Only one test showed a Tensile Strength over 1MPa and all the repaired concrete elements showed fracture along the mortar/concrete interface, which indicates a deficient adherence.

Since all relevant indications by the manufacturer where applied, namely the ones concerning the preparation and appliance of the mortars, convenient concrete roughness preparation and humidity, one can infer that the problem could have been caused by poor support concrete. The mentioned support concrete for the mortars in test presented itself with an excess of water in its composition. This, if confirmed, could have led to the formation of an excessively porous concrete. The concrete's potential excessive porosity can be one the relevant factors, if not the most important one, in the slender adherence between the two materials. Ruduit (2009) indicates that the high porosity percentage on concrete elements might lead to the excessive mortar's water absorption by the concrete, leading to an incomplete cement hydration over the interface, therefore creating a fragility point.

6. Conclusions

Over the extensive bibliography analyzed and the interpretation of the test results obtained, some relevant conclusions were gathered on the tested mortars:

- The mortars' density is slightly inferior when compared to the concrete's, which means that the mortars' density is 94.3% of the concrete's;
- Consistency Scattering Tests reveal that the mortars are easy to handle during its processing and appliance. However, although AR1 and AR3 presented a greater workability, the AR4 mortar had a fairly less workability when compared to the AR2;
- The AR2 mechanical flexural strength turned out to be greater than the other mortars studied, overcoming significantly the manufacturers technical sheet;
- The AR4 mechanical flexural strength also slightly overcame the manufacturers technical sheet mentioned values;
- AR1 and AR3 mechanical flexural strength only reached approximately 80% of the value mentioned by manufacturers technical sheet;
- AR2, AR3 and AR4 had a similar resistance evolution, all three mortars had different final resistance Flexural Strength values, obtaining a 90% resistance after 28 days;

- The AR1 mortar saw its final resistance evolve around 60% in a period between the 28^{th} and 90^{th} day;
- AR2 Compression Strength results were extremely high when compared to the other mortars and to what the technical sheet mentioned;
- Mortars AR1 and AR4 had a similar result on the Compressive Strength tests. However, the AR1 mortar overcame the value stated on the manufacturers technical sheet by a wider margin than the AR4, which also overcame its theoretical value;
- The AR3 mortar had the lowest compressive strength results of the four, reaching only 70% of the value stated on the manufacturers technical sheet;
- It was clear that the AR4 mortar had the highest percentage of shrinkage, developing wider volume variations, when compared to the remaining mortars studied;
- The AR3 mortar was the most stable one with the lowest shrinkage percentage, of which AR1 and AR2 had intermediate test results, slightly closer to the ones AR3 had;
- Through the comparison of the shrinkage test results of all the four mortars with the traditional cement + sand mortars, subject to the same curing process, it can easily be said that the mortars tested in this study had considerably better qualities;
- All the results obtained in Pull-off tests, trying to characterize the adherence conditions between the mortar and the concrete were considerably lower than the ones expected.
- The fracture system between the mortar and the support concrete occurred invariably at the interface between those two materials, which meant that both materials had a greater Pull-off resistance;
- The concrete's porous structure dimension, which was supposedly too high due to the excess of water (this concrete characteristics were observer during the entire study), could have been responsible for the inability of strong adherence between the concrete and the mortars in study;

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