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# ARGAMASSA AUTOADENSÁVEL DE ALTO DESEMPENHO PARA BETUMAÇÃO

# SELF-COMPACTING MORTAR OF HIGH PERFORMANCE FOR GROUTING

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**Resumo**

Este artigo tem como objetivo apresentar um estudo de uma argamassa autoadensável com elevada resistência inicial e final para a reparação de estruturas de concreto. O foco desta pesquisa foi a obtenção de um material altamente durável para a reparação de estruturas de concreto, principalmente para o concreto convencional e de alta desempenho. A análise experimental incluiu o estudo das seguintes propriedades frescas: fluido com consistência e capacidade de autocompactação, capacidade para encher os espaços vazios, e a capacidade de passar por obstáculos sem segregar e transpirar. No estado endurecido, também foram avaliadas as seguintes propriedades: resistência à compressão, resistência à tração em flexão, módulo de elasticidade, variação dimensional, resistência de união e resistência ao corte por compressão axial. Os resultados indicam que a argamassa tinha desenvolvido elevada resistência à compressão e à tração em flexão, que é cerca de 140 MPa e 22 MPa, respectivamente. O módulo atingiu 48 GPa, o que excedeu os valores previstos no início do estudo, com a estrutura de material demonstrando muito baixa porosidade e nenhuma segregação em fresco. O desempenho encontrado no material desenvolvido neste estudo pode ser considerado um grande avanço na base de tecnologia de materiais de cimento Portland.

**Palavras-chave**: Argamassa. Autoadensável. Alta durabilidade. Estruturas de recuperação.

**Abstract**:

This paper aims to present a study of a self-compacting mortar with high early and final strength for the repair of concrete structures. The focus on this research was to obtain a highly durable material for repairing concrete structures primarily for conventional and high-performance concrete. The experimental analysis included the study of the following fresh properties: consistency with fluid capacity for self-compaction, the ability to fill up the empty spaces, and the ability to go through obstacles without segregate and exude. In the hardened state the following properties were also assessed: compressive strength, tensile strength in bending, modulus of elasticity, dimensional change, tensile bond strength, and shear strength by axial compression. The results indicate that the mortar had developed high compressive and tensile strength in bending, which is close to 140 MPa and 22 MPa, respectively. The modulus reached 48 GPa, which exceeded the predicted values at the beginning of the study, with the structure of material demonstrating very low porosity and no segregation in fresh. The performance found in the developed material in this study can be

considered a major breakthrough in materials technology base of Portland cement.
**Keywords**: Mortar. Self-compacting. High durability. Recovery structures.

## 1 Introduction

Bauer (2005) defines mortar repair materials are composed of a mixture of binder (cement and additions), aggregates, additives, performance modifiers (polymers, fibers, among others) and water. Mortars for repair are different from traditional mortars, due formulation and specificity. Generally the mechanical properties performances are better than the needs of the masonry and its coverings (TULA; OLIVEIRA; HELENE, 2004).

Gowda *et al.* (2011) study the strength and rheological properties of self-compacting mortars using local materials like rice husk ash and quarry dust getting strength since 5MPa until 39MPa. A self-compacting mortar using fibers was characterized by flow ability, compressive strength, modulus of elasticity, shrinkage, flexural strength tests (DAWOOD; RAMLI, 2011). The properties of self-compacting mortars are influenced by mix and proportions of constituents materials (NEPOMUCEN; OLIVEIRA, 2008 ;TÜRKEL; ALTUNAS, 2009).

Cement-fly ash mortars have better flexural strength performance than others mortar whit same compressive strength (WANG *et al*., 2012). The presence of mineral additions produces an enhancement of compressive strength and a decrease of drying shrinkage (ITIM *et al*., 2011). Moreover, the presence of limestone filler accelerates the chemical shrinkage and the hydration processes in early ages (BOUASKER *et al*., 2008). The addition of limestone filler improve compressive strength in early ages, but at 28 days the natural pozzolan show better properties (GHRICI *et al*., 2007). However, Lawrence *et al.* (2005) observed that at early ages the nature of the mineral admixtures was not exercise significant influence.

Observing the growth of technology of concretes and mortars in civil construction, it was noted the need to find a product, with performance to meet the needs of repair of concrete, such as high performance concrete (HPC), reactive powder concrete (RPC), prestressed concrete, reinforced concrete. To make repairs, it is necessary to submit a product fast and high mechanical strength (initial and final), self-compacting and quick release. In this sense, there will be a study of a self-compacting mortar of high resistance to initial and final grouting, in order to perform repairs in concrete structures in general.

## 2 Materials and methods

For the development of the experimental program several mixtures were measured in laboratory, and the formulation showed best performance in fresh state was continued in the research.

## 2.1 Study factors

In order to understand the physical behavior and mechanical tests were carried out compressive strength, tensile strength in bending, surface bonding strength, shear resistance in compression, bulk density, consistency index, capillarity water absorption, dimensional change, the modulus of elasticity. The flowchart stage of the study is showed in Figure 1 from which it is possible to get an overview of the study.

Figure 1 – Program study

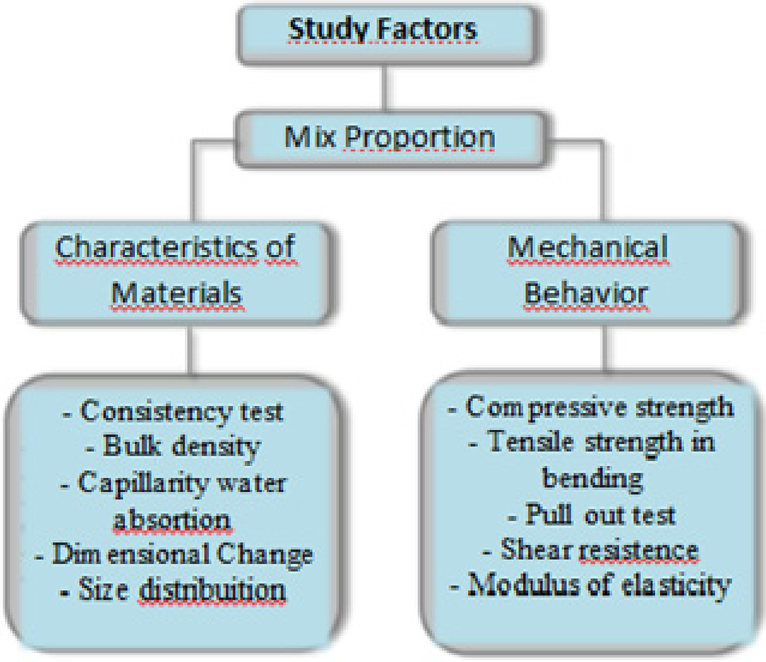



Table 1 presents the size of the samples used.

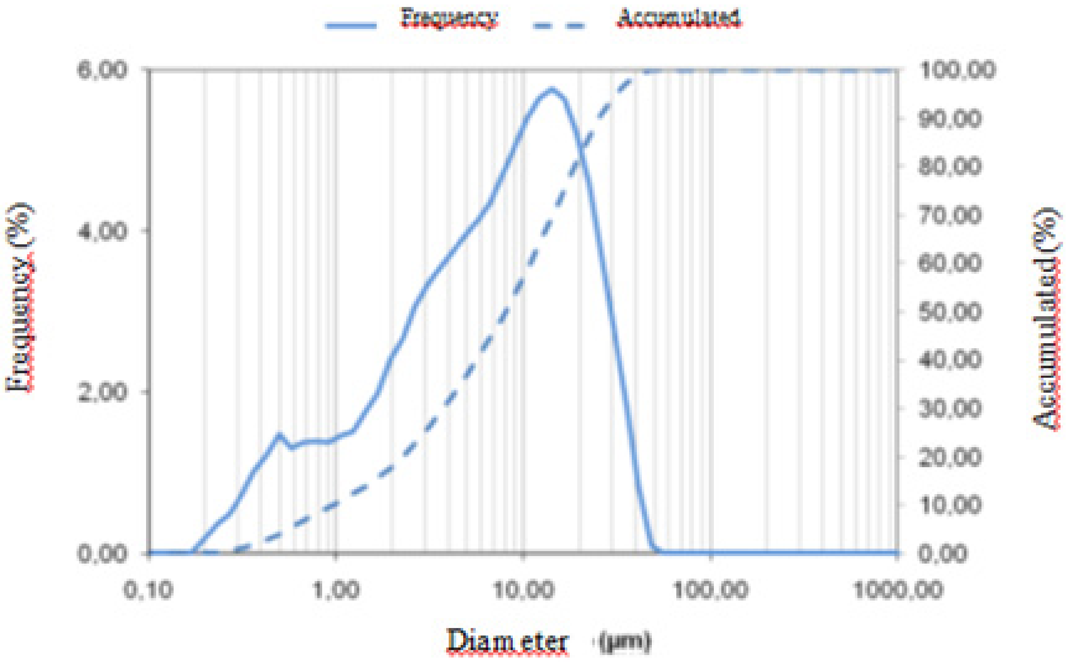
Table 1 – Size of samples

| Test | Samples | Age | Total |
|---|---|---|---|
| Compressive strength – ASTM C 109 | 4 | 12 | 48 |
| Tensile strengthen bending – ASTM C 348 | 4 | 8 | 32 |
| Capillarity water absorption – NBR 15259 | 6 | 1 | 6 |
| Dimensional change – NBR 15261 | 3 | 1 | 3 |
| Modulus of elasticity – NBR 15630 | 3 | 1 | 3 |
| Shear resistance in compression | 4 | 1 | 4 |
| Total samples | | | 96 |

## 2.2 Materials used

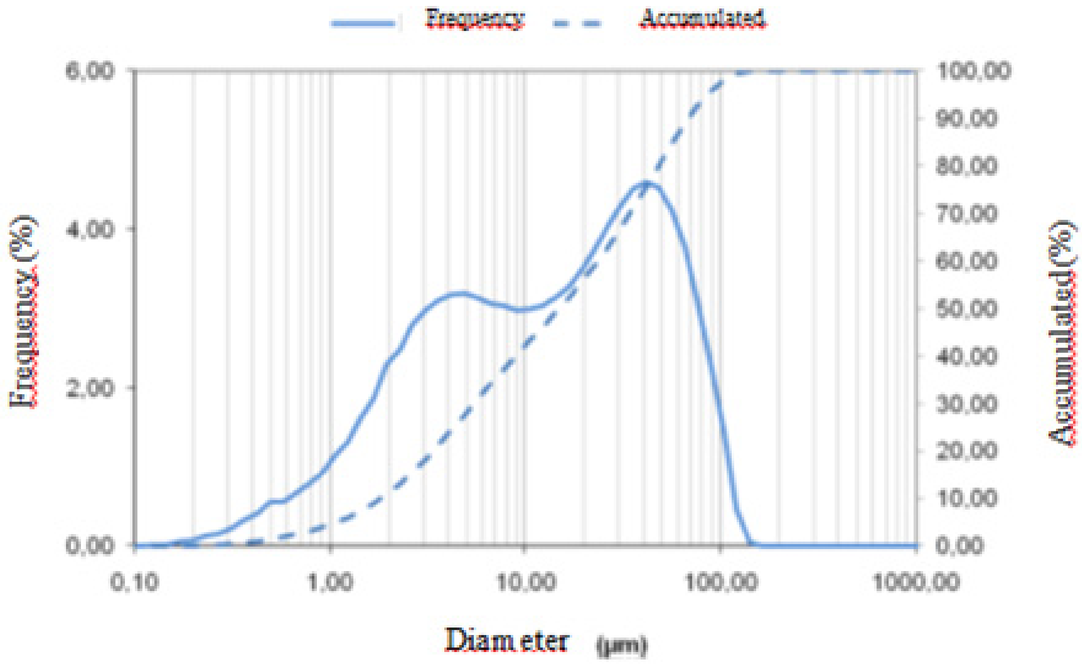
Was used Portland cement of high early strength and Resistant to Sulphates (CPV-ARI RS). This cement has a great fineness, an important characteristic for the self-compacting mortar, since the greater the specific surface area of the grains, the lower the yield tensile and higher viscosity of the mixture. The mechanical strength of CPV-ARI RS answers the questions to achieve high initial resistance and offers a resistance to sulfated environment. The development of high early strength of cement-CPV-ARI RS is achieved by using a different dosage of limestone and clay to produce the clinker and grinding the cement thinner, so that, by reacting with water, it gets high resistance, with greater speed. Figure 2 shows the distribution curve of the cement particles.

Figure 2 - Particle size distribution curve of the CPV-ARI_RS




Aluminous cement was used to accelerate the handle of the Portland cement. The addition of aluminous cement to Portland cement changes the equilibrium conditions designed by the producer of the cement. The calcium aluminate phase present in aluminous cement reacts with the calcium sulfate present in the Portland cement so that there is deficiency of sulfate on the surface particles of tricalcium aluminate phase ($C_3A$). The early handle is caused by partial hydration of tricalcium aluminate and formation of ettringite by reaction of calcium aluminate and calcium sulfate. The Figure 3 shows the curve of granulometric distribution of the aluminous cement.

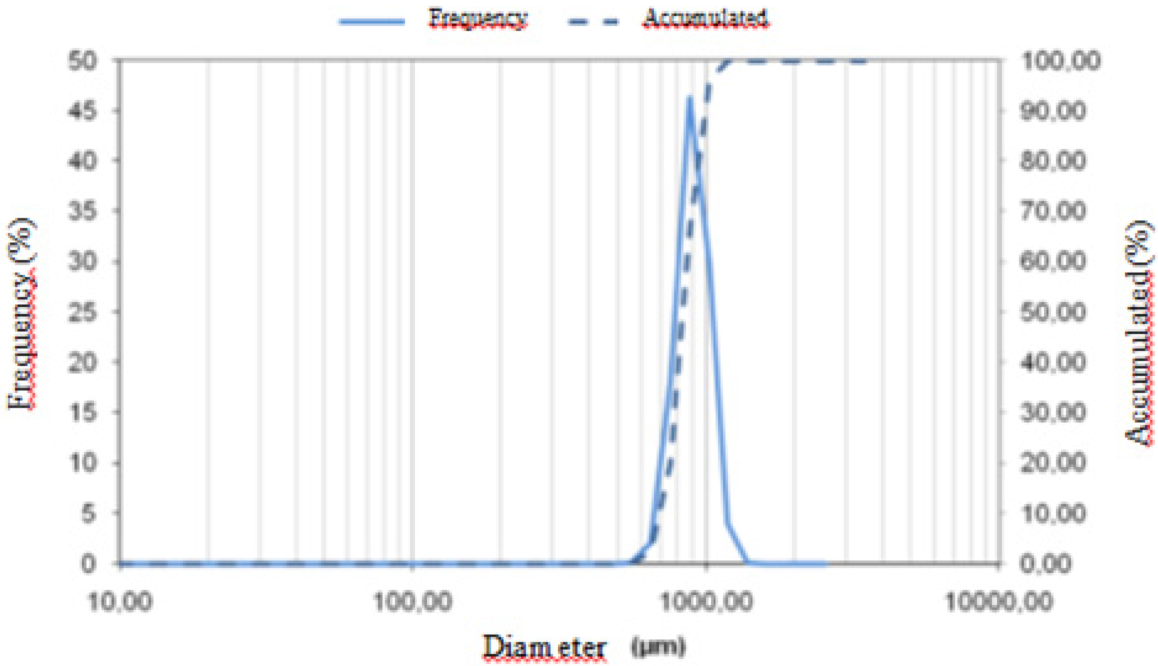
Figure 3 - Particle size distribution curve of the aluminious cement




The choice of aggregates was very important, because of its largest volume in the mixture. The aggregate has a direct influence on physical and mechanical behavior of mortars and high performance concrete: in fresh state, the aggregates have function to contribute in workability and cohesion of the mass, as in the hardened state they can contribute to the resistance, dimensional stability and durability. These properties are acquired due to the mineralogy, shape, texture and grain size of aggregates. In this case we used two types of fine aggregate, with different characteristics, so there would be a better workability in the fresh state, and a low permeability in the hardened state, to prevent voids in the mass and ensure a higher resistance.

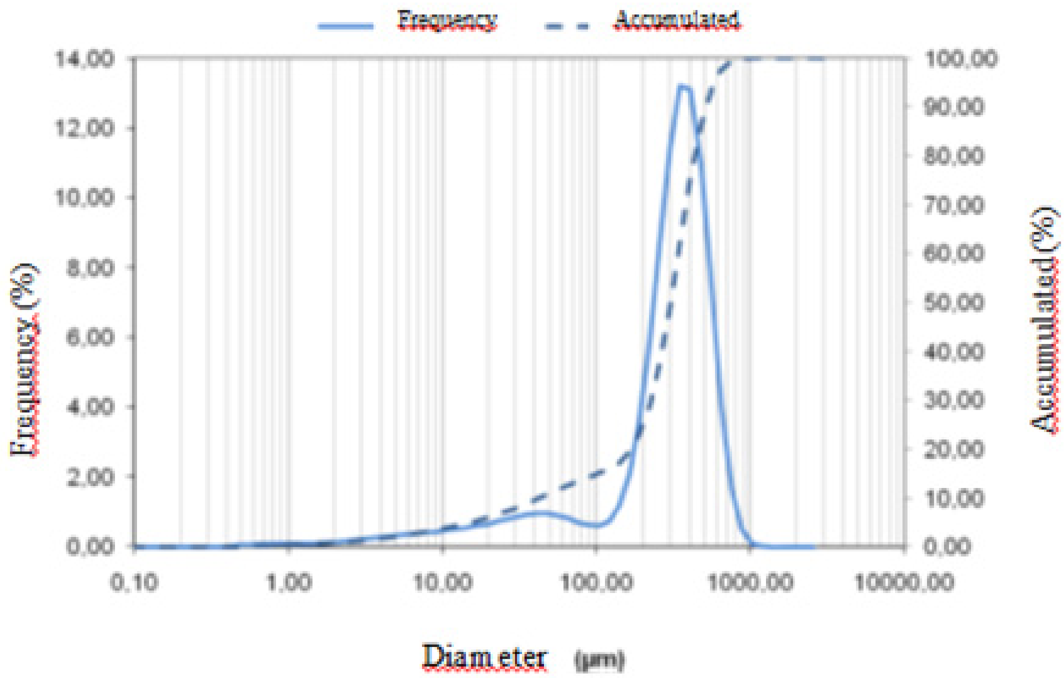
The medium sand used was of artificial origin, crushed limestone, passing through mesh 1.4 mm, triangle grains shape and rough texture. A representative percentage of sand is essential to give volume in the mixture, decrease cost, and assist in the physical properties of the mortar. The Figure 4 presents the particle size distribution of artificial sand used.

Figure 4 - Particle size distribution curve of artificial sand




The fine sand used was natural quartz, passing the mesh 0.425 mm, with 8% of fine material, the shape of the grains rounded and smooth texture. There was the addition of sand smaller to fill the macroscopic voids of the medium sand and facilitate the "rolling" of the grains among themselves, leaving a mass greater fluidity and workability. Figure 5 shows the particle size distribution of the sand.

Figure 5 - Particle size distribution curve of natural sand



The use of mineral additives in the mixture is crucial to ensure a better packing between the particles and increase the compactness of the system, resulting in a more dense mixture, cohesive (without exudation or segregation) and greater fluidity, while the capillary permeability and porosity are reduced. Consequently these factors influence in a mortar of high performance and high durability.

As the silica fume a very thin material, when dosed in a quantity limit may have pozzolanic reactions, due to chemical reaction with calcium hydroxide (released in the hydration of cement) forming silicate stable that has cementitious properties but a large amount can be considered as an inert material. The introduction of the silica in the mixture was essential to ensure a filling between the particles and help the rheological behavior of mortar.

The filler is a material obtained by fine grinding of limestone. It is a chemically inert material, which has as function a physical behavior in mortar, because of its size, can fill small voids, makes for better workability, reduces capillary permeability, but if used in large quantities can cause cracks in the mortar.

The use of additives was essential to obtain high resistance due to decreased water/cement ratio. For this case we used a next-generation superplasticizer, the most advanced technology of polymers. These types of additives generally contain chains based on polyethylene glycol. The optimal dosage of additive found in mortar was one that required a low w/c ratio, in order to achieve high mechanical strength, and showed good flow condition in the fresh state.

Other additives have been used also, where the throttle grip additive is an essential component of this mixture as it is a formulated product for speeding up the handle and increase the initial and final resistance of the concrete, providing rapid repair of the structure. The use of retarder handle was required to achieve a higher workability time, retard the increase in heat of hydration and increase the time of application, without losing the properties of the mortar in the fresh state (fluidity and viscosity). The addition of anti-foam in this formulation is to help unite air micro bubbles inside the mass to facilitate expulsion of them out of the mortar thus avoiding air gaps pores, which results in a greatly reduced permeability and mechanical strength.

## 2.1 Characterization of mortar

The definition of the trace was performed according to the compatibility of the materials and the proportions was determined according to the performance showed that the fresh state mortar, being measured, the consistency index, and visually resistance to segregation and exudation. Table 2 shows the mix proportion of mortar studied.

Table 2 – Mix proportion the mortar studied

| Materials | Mix proportion |
|---|---|
| Binder | 1.00 |
| Fine aggregate | 1.07 |
| Mineral additives | 0.11 |
| Chemical additives | 0.06 |
| Ratio water/cement | 0.27 |

For the mortar defined in Table 2, tests were conducted on fresh and hardened for the purposes of characterization. Was being tests by Flow Table workability and cylinder 3x5, bulk density in fresh and hardened, entrained air content, particle size complete mortar, compressive strength, tensile strength in flexion, surface bonding strength, shear strength by axial compression, modulus of elasticity, absorption of water by capillarity, dimensional change and determination of the heat of hydration.

## 3 Results and discussion

### 3.1 Characterization of the mortar in the fresh estate

The characterization of the mortar in the fresh state is classified by the consistency index, density of mass, and viscosity.

Was defined the ratio water/cement (w/c) so that the mixture present a consistency of around 400 mm with the method of Table Flow and 115 mm with the method cylinder 3x5. Because it is a mortar "self-compacting" was necessary to obtain a fluid consistency and a high viscosity for not segregate materials. The test results of consistency by Flow Table and the 3x5 cylinder are shown in Table 3.

Table 3 – Test of consistency

| Time (min) | Flow table – NBR 13276 | 3 x 5 cylinder |
|---|---|---|
| | Consistency (mm) | |
| 0 | 444 | 144 |
| 5 | 442 | 136 |
| 10 | 420 | 130 |
| 15 | 405 | 115 |
| 20 | 380 | 90 |

The workability of the mortar is allowed to be measured 20 minutes due to present an abrupt decrease in the consistency index of about 25 mm. This period was observed also that the viscosity of the material tends to increase, even with a high degree of consistency. After 20 minutes the increase in viscosity hinders the handling of the material, so 15 minutes was defined as the time limit for handling and application.

The Table 4 shows the characteristics of compactness of the materials, methods in this step were used to evaluate the density of mass, content of incorporated air and the density.

Table 4 – Characteristic of compactness

| Characteristics | | Test Method | Results |
|---|---|---|---|
| Bulk density | Fresh state (g/cm³) | NBR 13278:2005 | 2.36 |
| | Free state (g/cm³) | NBR 14086:2004 | 1.20 |
| | Hard state (g/cm³) | NBR 13280:2005 | 2.39 |
| Specific mass (g/cm³) | | NBR NM23:2001 | 2.82 |
| Content of incorporated air (%) | | NBR 13278:2005 | 0.99 |

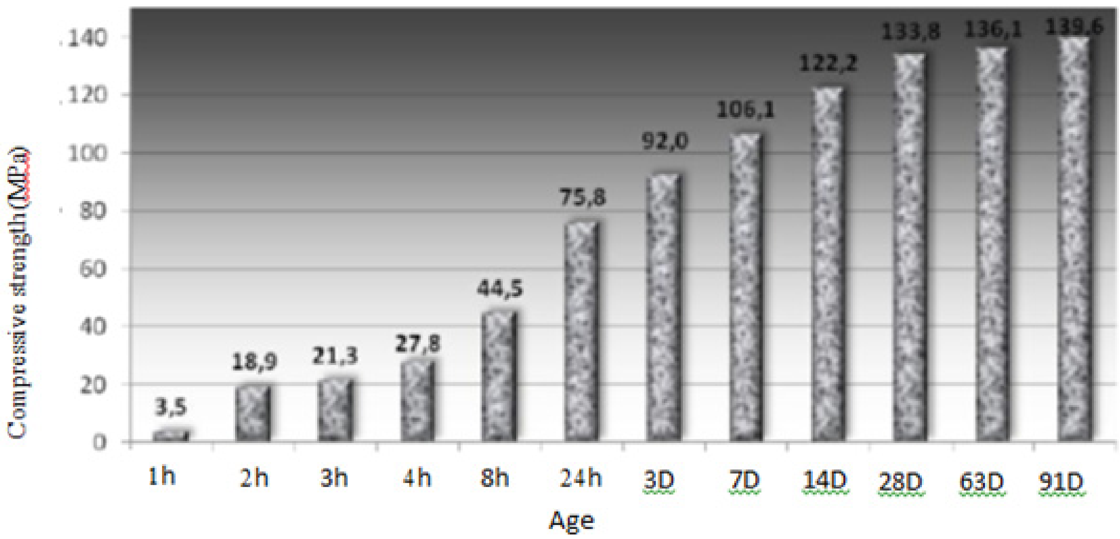
The results of these three characteristics showed the mortar is packed with a low content of incorporated air, which reduces the porosity in the microstructure of the mortar, a high value of density also results in smaller voids volume. All of these features lead to mortar with high density. The high density of concrete and mortar results in a material with low permeability, which is a key factor to achieve high mechanical strength. The density values found in the searched mortar can be compared with the density of a high performance concrete, but of course no additions coarse aggregate.

### 3.2 Characterization of the mortar in the hardened state

This item presents the mechanical behavior of self-compacting mortar with high initial and final strength.

The Figure 6 shows the results of the mean of four samples used to evaluate the compression strength in each age tested.

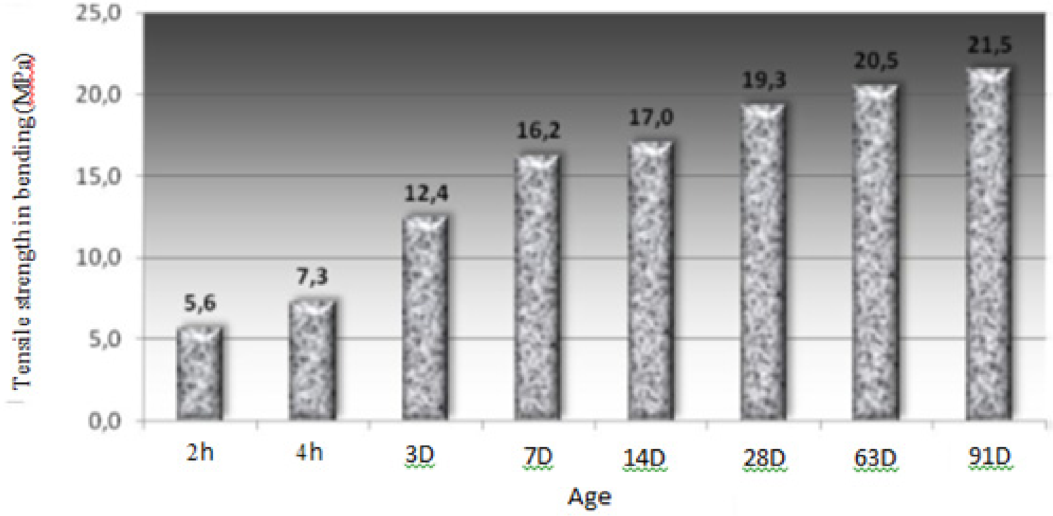
Figure 6 – Test results of compressive strength



The results showed high values for a repair mortar, it is observed than was possible to do tests in one hour time, and the mortar already submitted to mechanical testing. The values were gradually increasing with age of the mortar. At early ages displayed high strength, and at 7 days the mortar showed strength greater than 100 MPa, still gain resistance up to 91 days.

As you can see in Figure 7, the compression strength and tensile strength are closely related in the same way that the values of compression strength gradually increased so did this analysis, achieving high initial and final tensile strength in bending. For this property the mortar got a great performance, reaching close to 20 MPa at 28 days.

Figure 7 – Test results of tensile strength in bending




The Table 5 presents the results of pullout resistance where it is analyzed surface adherence of the mortar. In this analysis was verified that the mortar has excellent bond strength. In CP6 the rupture occurred in standard substrate and not in the adhesion area with the mortar, so the value of CP6 was disregarded in the final average. For a structural repair mortar this property is important, because it is the bond between old concrete and repair.

Table 5 – Pullout test

| Sample | MPa |
|---|---|
| CP1 | 5.6 |
| CP2 | 4.6 |
| CP3 | 5.4 |
| CP4 | 4.9 |
| CP5 | 5.0 |
| CP6 | 3.3 |
| Avarege | 5.1 |

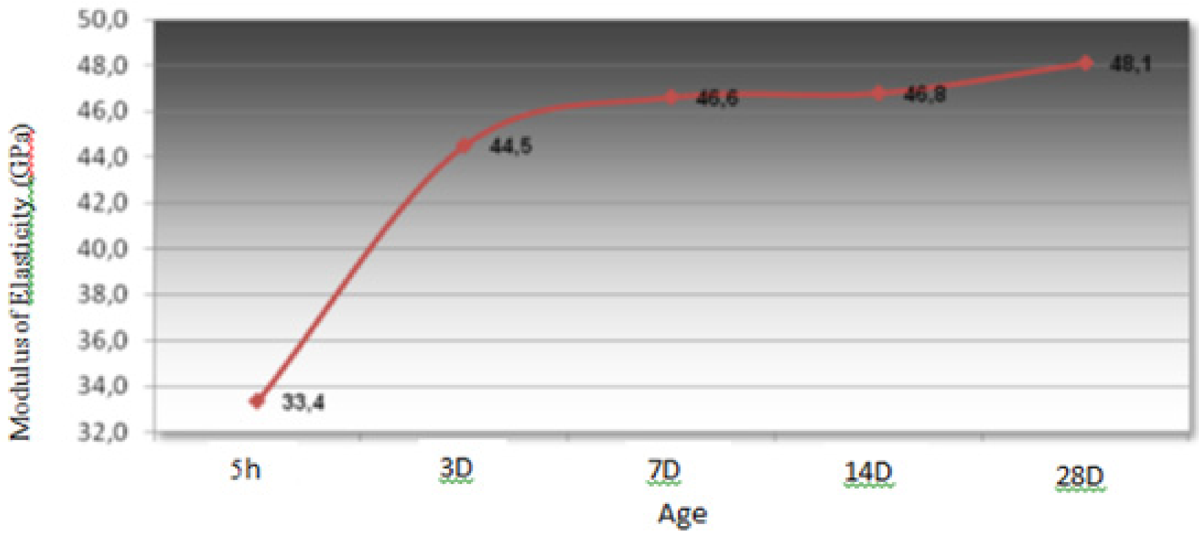
Table 6 contains the values obtained from a shear strength test carried out by axial compression. In order to simulate the recovery of concrete structure, it was a test to verify the performed to shear strength by axial compression in the connection point between the concrete and mortar repair. Through this test it was observed that the structure subjected to this kind of situation can support a compressive load of up to 44.5 MPa, without there being any change in the point of adhesion of the mortar over old concrete repair.

Table 6 – Shear axial compression

| Sample | MPa |
|---|---|
| CP1 | 22.2 |
| CP2 | 21.9 |
| CP3 | 22.1 |
| CP4 | 22.9 |
| Avarege | 22.3 |

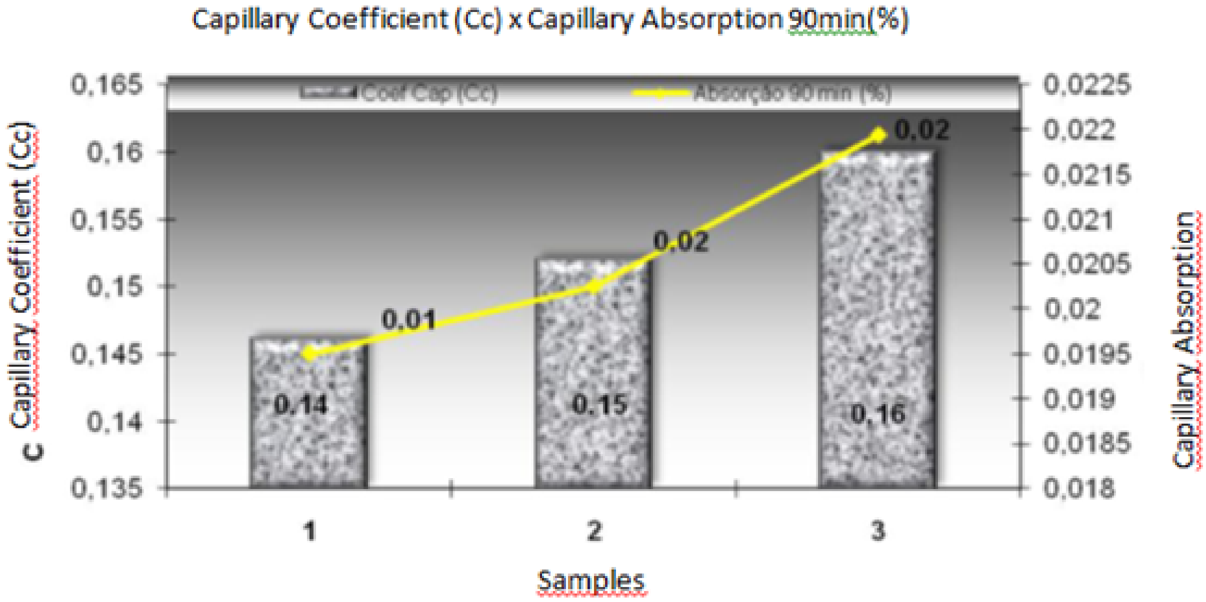
The values obtained for the modulus of elasticity of the concrete are shown in Figure 8. This analysis was possible to verify the high modulus of elasticity of the mortar, it is known that the higher the resistance of the mortar, the greater the value of its modulus of elasticity. The experimental results have confirmed that increased the modulus of elasticity in a manner similar to the compressive strength to a value greater than 40GPa at 7 days. Note also that the modulus of elasticity grew rapidly in the early age, and then the curve is stable.

Figure 8 – Modulus of elasticity of the concrete



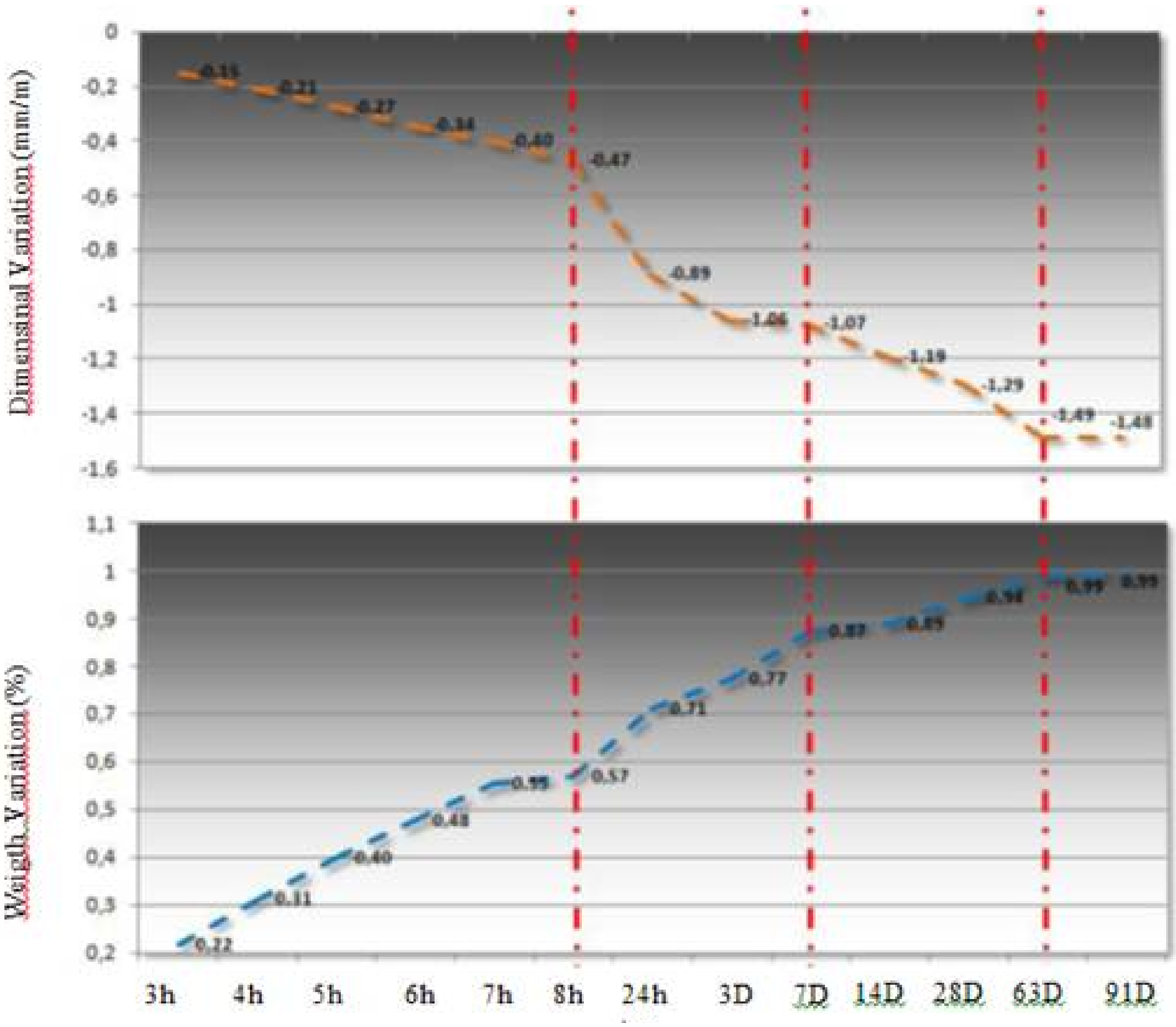

The Figure 9 shows the results of absorption by capillary action performed according NBR 15.259. In this test it was verified that this material exhibits a very low permeability, due its water absorption through the capillary gaps have a maximum of 0.02%. This property is of great importance to achieve high mechanical and chemical resistance, because no voids within the material resistance to penetration by aggressive liquids or gases is large, increasing the structural durability and extending the fields of application of mortar.

Figure 9 – Absorption capilary



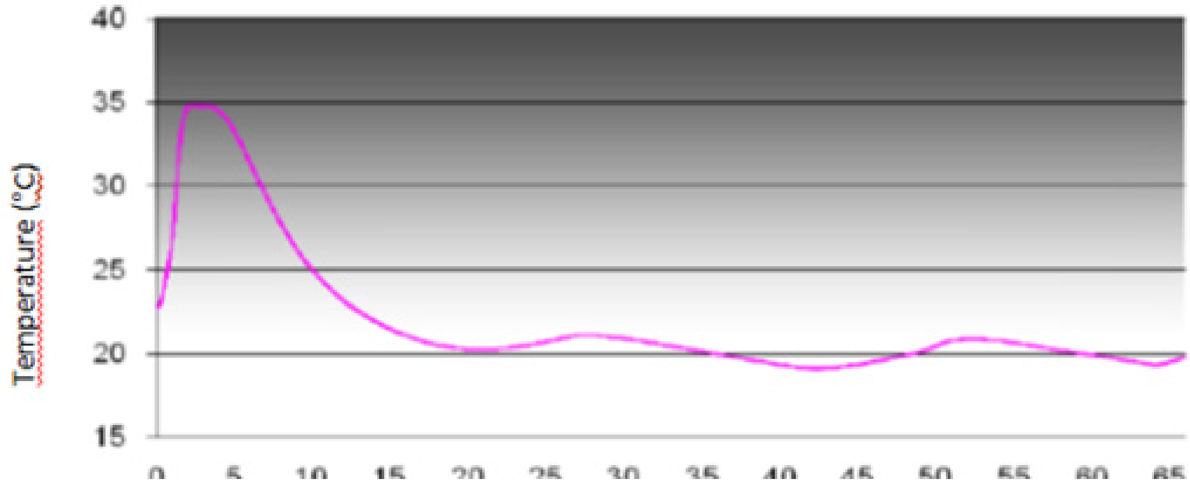

The Figure 10 shows the values for the dimensional variation of shrinkage and weight variation over time. It can see that the mortar shrank over time of hydration, a factor that contributes to this was the high consumption of cement used in the mixture and also the addition of different products in the same composition. The mass variation is illustrated in percentages, but knowing that the mass shrank, there was a mass loss of less than about 4.2 grams to 91 days, which is represented around 0.99% of mass variation according to the chart above.

Figure 10 – Dimensional variation and weight variation




The release curve of the heat of hydration of the cement is shown in Figure 11. Through the above figure is possible to observe the rapid exothermic process this mortar where cement hydration stages occurring within the first hour and 30 minutes after the mortar contact with water can already be considered as the end of the handle and the paste starts to hardening and it have initial strength one hour after mixing. Therefore, their heat of hydration is high in the early age, but stabilizes the temperature over time.

Figure 11 - Curve of the heat of hydration of the cement




## 4 Conclusions

This work aimed to study the development of a self-compacting mortar with high initial and final strength to grouting.

The behavior of self-compacting mortar in the fresh state showed the same characteristics of a self-compacting concrete: the ability to move in a certain area by action of its own weight, ie, without application of external forces for its compaction, ability to flow without segregate or exude, viscosity suitable for the components of the mortar to flow at the same speed, keeping the particles in suspension until setting. The time of workability of the mortar was limited to 15 minutes for the handling and application, how this is a product of rapid demoulding and also high initial strength, it was not possible to have a longer workability.

Considering the results of tests in the hardened state of the mortar, it can conclude that the mortar displayed high mechanical properties, reaching close to 140 MPa compressive strength, 22 MPa in tensile strength in bending and modulus of elasticity about 48 GPa. It was observed that these values could be even higher if a packaging method performed particles, using a medium sand of natural origin which has a higher mechanical strength than sand used, cement content also could have been smaller, if it was used the addition of quartz powder, as would be further increasing the compactness of the microstructure of the material may result the same resistance values achieved.

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