REHABILITATION OF REINFORCED CONCRETE BEAMS: MECHANICAL PERFORMANCE WITH ALKALI-ACTIVATED REPAIR MORTAR

REABILITAÇÃO DE VIGAS DE CONCRETO ARMADO: DESEMPENHO MECÂNICO COM ARGAMASSA DE REPARO ÁLCALI-ATIVADA

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ABSTRACT
The premature degradation of concrete structures is nowadays a common problem, and the use of repair materials to promote structural rehabilitation is usually necessary. The objective of this study was to evaluate the performance of cracked concrete structures repaired with alkali-activated mortar (AAM). A beam repaired with a polymer-modified mortar (PM) was used as a reference. Concrete beams of 120 mm wide x 250 mm high x 2.100 mm long were initially loaded in bending until failure. Thereafter, the beams were repaired with AAM or PM, and they were submitted to a new bending test, with some analysis: first crack load, maximum load, ultimate load, and crack formation. The results showed that the repair (AAM or PM) was efficient, although the repaired beams developed the first crack with a low load than reference beams. AAM showed to be as efficient as PM in recovering the concrete cracked beams.

KEY WORDS: *Concrete structures repair; Cracks; Alkali-activated mortar; Polymer modified mortar.*

RESUMO
A degradação prematura das estruturas de concreto é um problema comum atualmente. O uso de um material de reparo objetivando a reabilitação estrutural é usualmente necessário. O principal objetivo deste estudo foi avaliar o desempenho de estruturas de concreto fissuradas reparadas com argamassa álcali-ativada (AAM). Uma viga reparada com argamassa comercial modificada com polímero (PM) foi usada como referência. Vigas de concreto de 120 mm de espessura x 250 mm de altura x 2.100 mm de comprimento foram inicialmente carregadas com carga de flexão até a ruptura. Posteriormente, as vigas foram reparadas com AAM ou PM e elas foram submetidas a um novo ensaio de flexão com algumas análises: carga de primeira de primeira fissura, carga máxima, carga de ruptura e formação de fissuras. Os resultados mostraram que o reparo (AAM ou PM) foi eficiente, embora as vigas reparadas tenham desenvolvido a primeira fissura com uma carga menor que as vigas de referência. AAM se mostrou tão eficiente quanto a PM na recuperação das vigas fissuradas.

PALAVRAS CHAVE: *Reparo de estruturas de concreto; Fissuras; Argamassa álcali-ativada; Argamassa modificada com polímero.*

1. INTRODUCTION

Concrete is one of the most important materials in civil construction because it is cheap, durable, strong, and easily molded into different shapes (SHASH, 2005). However, different situations can compromise the durability of the concrete structures, such as the exposure to aggressive environments or the use of inappropriate materials (QIAN *et al.*, 2014; MIRMOGHTADAEI *et al.*, 2015).

Reinforced concrete is less likely to strain compared to other materials, presenting low ductility, originating cracks even with low load levels (RASHID, 2005). Ductility is a property associated with the material plastic deformation until the fracture. This deformation of materials is considered inelastic and did not return to the initial deformation (PARK, 2005). The concrete reinforcement consumes the energy applied in this phase, presenting an inelastic and irreversible displacement after yielding in stages II and III of a moment-curvature diagram (FAYYAD and LEES, 2017). In this stage, the cracks appear and spread. The cracks reduce the structural stiffness and modify the distribution of internal stresses, and the concrete does not show a linear behavior anymore (BAANT and OH, 1983; BAANT and OH, 1984).

Concrete cracking is a common phenomenon associated with materials decomposition and damage (ACI, 1998; ISSA *et al.*, 2007). The cracks in concrete may occur in plastic or hardened states due to internal stresses caused by excessive load or environmental conditions (RASMUSSEN *et at.*, 2017). In the plastic state, the cracks are formed by rapid water evaporation (e.g., plastic shrinkage cracking) (ISSA *et al.*, 2007). In the hardened state, the cracks are originated from design errors (e.g., the misconception of the service load, lack of reinforcement detailing, and errors in designing calculation) or construction defects (e.g., incorrect placement of steel, inadequate concrete cover, incorrectly made construction joints, insufficient compaction, segregation, poor curing conditions, and high water to cement ratio) (JUMAAT *et al.*, 2006). Different factors influence the crack pattern, such as the properties of steel and concrete, and size of the beam (FAYYAD and LESS, 2017; PIRES *et al.*, 2018).

The cracks affect the appearance (aesthetics) or indicate significant structural distress and decrease the concrete lifetime because they are pathways for ingress of deleterious agents (SHASH, 2005; BEUSHAUSEN and ARITO2018). The correct repair of the cracks depends not only on understanding its causes but also on selecting a suitable repair technique (AHMAD *et al.*, 2012).

Checking the first crack originated due to the load x displacement behavior of the reinforced concrete beams is a way to verify the repair efficiency. New repair materials can influence mechanical properties of the beams and, consequently, the structural behavior and useful life of the elements. The first crack load, maximum load and ultimate load were designed at beams considering the 3 different stages of a structural element when subjected to the flexural strength (Figure 1).

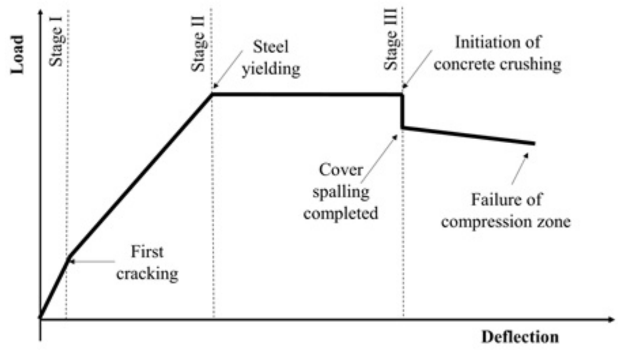


Figure 1. Different stages in moment-curvature diagram and the analyses points (adapted). Source: RASHID *et al.* (2005); PIRES *et al.* (2018).

Some materials are usually used to repair the cracked concrete, such as cement grout, epoxy injection, ferrocement layer, carbon fiber reinforced polymers sheets, section enlargement, and polymer-modified mortar (PM) (AHMAD *et al.*, 2012; THANOON *et al.*, 2005). An alternative to these commercial repair materials is the alkali-activated mortar (AAM) (GERALDO *et al.*, 2018; FAHIM HUSEIEN *et al.*, 2017).

AAM is an eco-friendly alternative to Portland cement (PC) produced by a chemical reaction of aluminosilicate sources with alkaline solutions (ZANOTTI *et al.*, 2017). The replacement of PC by AAM in some situations is an option to achieve a more sustainable civil construction material (COPPOLA *et al.*, 2018). The use of AAM as a material to repair deteriorated concrete structures has been investigated by different authors that confirmed the feasibility of this application (GERALDO *et al.*, 2018; PHOO-NGERNKHAM *et al.*, 2015; KRAMAR *et al.*, 2016; TEIXEIRA *et al.*, 2019; ROBAYO-SALAZAR *et al.*, 2019; HUSEIEN *et al.*, 2020; FRANÇA *et al.*, 2018; PHOO-NGERNKHAM *et al.*, 2020)

Phoo-ngernkham *et al.* (2015) proposed a repair AAM made from high calcium fly ash activated by sodium silicate and sodium hydroxide (NaOH). The authors reported the use of PC as an additive, and the increase in NaOH concentration improved AAM performance to concrete repair application.

Kramar *et al.* (2016) used different precursors (ground granulated blast furnace slag, fly ash, and metakaolin) activated by sodium silicate and NaOH to obtain an AAM to concrete repair, and the results were proper to be used as structural and non-structural repair mortars. In some cases, problems such as high capillary absorption and efflorescence were stated.

Geraldo *et al.* (2018) used AAM made with silica fume, metakaolin, and NaOH as concrete beam repair. The results showed good bonding adherence to the substrate and reduced the crack distribution in the beam.

Teixeira *et al.* (2019) showed that the AAM made with rice husk ash, metakaolin, and NaOH developed mechanical performance to repair damaged reinforced concrete specimens. The repaired beams reached a flexural strength similar to those made without repair.

Robayo-Salazar *et al.* (2019) evaluated a repair AAM made with natural volcanic pozzolan, and granulated blast furnace slag activated by a blend of sodium silicate and NaOH. The results showed high mechanical properties (compressive, flexural, and bond strengths).

Huseien and Shah (2020) proposed to use an AAM made by the activation of fly ash and ground blast furnace slag by a mixture of sodium silicate and NaOH as a concrete surface repair material. AAM had a compressive strength higher than 78 MPa and bond strength from 3,9 to 4,8 MPa at 28 days. AAM also had good compatibility with the concrete substrate, showing a high performance to repair deteriorated concrete.

França *et al.* (2018) reported that an AAM made with metakaolin, sodium silicate, potassium hydroxide, and PC (as a calcium source) had a better performance in concrete repair than a commercial mortar. AAM presented high adherence to the substrate, and the beams recovered with AAM had more ductility.

Phoo-ngernkham *et al.* (2020) showed the possibility of using an AAM made with high calcium fly ash, sodium silicate, NaOH, and calcium carbide residue as a technically and cost-effective repair material to damaged concrete. The bond strength between AAM and concrete was improved with the calcium carbide residue incorporation.

This paper investigates AAM as a repair material to structural rehabilitation of cracked reinforced concrete beams. The beams were loaded in bending until failure and restored with the repair mortar. A PM repair was used as a reference. Data about the performance (first crack load, maximum load, ultimate load, and crack formation) of these beams repaired with both mortars were collected and analyzed.

2. MATERIALS AND METHODS

2.1 Materials

A Brazilian high early strength PC (CPV-ARI), similar to ASTM type III, was used to make the concrete. The cement had a surface area of 3.880 m^2/kg (Blaine method) and specific gravity of 3,13 g/cm^3. The SO_3, CaO content, and loss on ignition (LOI) were 3,18%, 63,33%, and 4,50%, respectively.

According to Brazilian standards, steel bars used are named CA 50 and CA 60 (CA is the reinforced concrete, and 50 and 60 are the minimum yield stresses. Table 1 shows the actual tensile strength of the steel bars per the NBR 7480/2007 (ABNT, 2007). The only change is the production process of the steel. The CA50 is made by hot forming and has a characteristic strength of 500 MPa while the CA 60 is made by cold forming and strength of 600 MPa.

TABLE 1. Tensile strength of steel bars. Source: Authors.

Category	Diameter (mm)	Yield stress (MPa)	Failure stress (MPa)
CA 50	8,0	678 ± 30	794 ± 25
CA 60	4,2	1.064 ± 26	1.108 ± 5

Quartz river sand was used as fine aggregate and crushed basalt was used as coarse aggregate. The sand was also used to make AAM. Table 2 and Figure 2 show the properties of the aggregates.

NaOH in flakes (purity = 98%) was used as the alkali activator, and commercially available MK and RHA were used as aluminosilicate sources for the AAM production (Table 3).

TABLE 2. Physical properties of the aggregates. Source: Authors.

Physical property	Aggregates		Reference
	Fine	Coarse	
Maximum grain size (mm)	2,40	19,00	NBR NM 248
Fineness modulus	2,35	2,72	NBR NM 248
Specific gravity (g/cm³)	2,64	2,72	NBR NM 45
Bulk density (g/cm³)	1,89	1,43	NBR NM 45

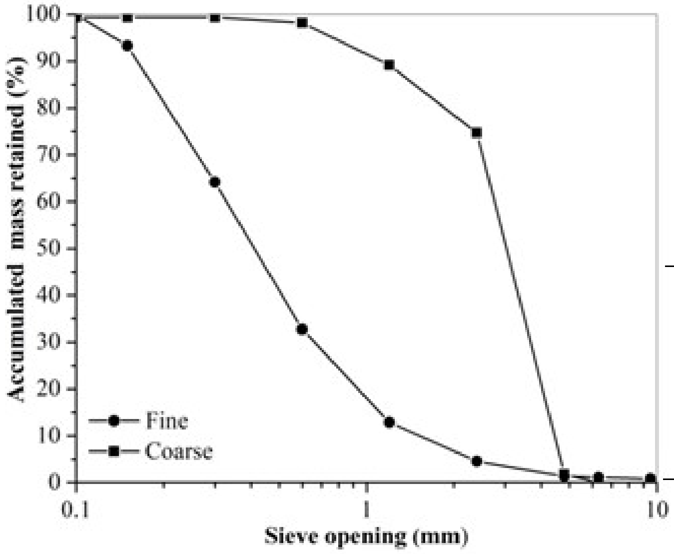


Figure 2. Aggregates sieve analysis. Source: Authors

Water used was from the municipal supply. Chemical composition was obtained by X-ray fluorescence (Shimadzu XRF, 1800). Particle size distribution was obtained using laser equipment (Malvern Mastersizer, 2000). Surface area was calculated by BET method (Quantachrome NOVA 4200).

TABLE 3. MK and RHA chemical composition and physical properties. Source: Authors. Source: Authors.

Chemical composition	Metakaolin (wt.%)	Rice husk ash (wt.%)
SiO_2	55,77	89,51
Al_2O_3	32,48	0,13
K_2O	2,70	1,68
Fe_2O_3	1,88	0,05
TiO_2	1,42	-
MgO	0,76	0,30
Others	0,23	1,38
LOI	4,76	6,95
Physical properties		
Bulk density (g/cm³)	0,496	0,473
Specific gravity (g/cm³)	2,57	2,14
Surface area – BET (m²/g)	22,3	6,5
Average diameter (µm)	20,4	20,4

2.1.1. PM and AAM: production and properties

The PM, AAM, and concrete beams production followed the flowchart in Figure 3. These steps are described with details throughout this topic, as follows.

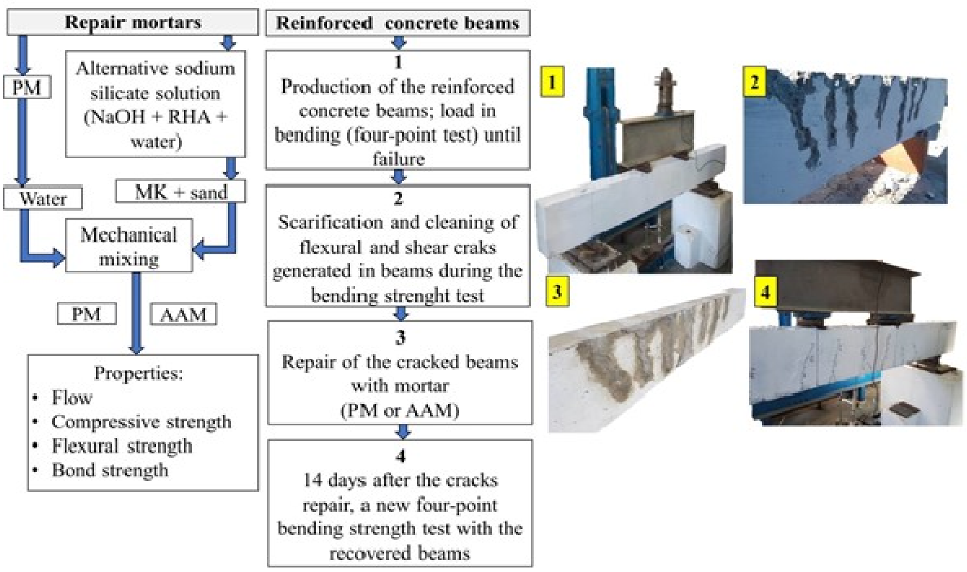


Figure 3. Aggregates sieve analysis. Source: Authors

2.1.1.1. Mortar production

The PM was prepared with a water-solid ratio of 1/7,14 (in mass, indicating that each 1 kg of water was mixed with 7,14 kg of dry mortar) such as indicated by the producer.

The mixing process was made with a mechanical mixer (20 L capacity) until complete homogenization (5 min). The PM spread diameter (173 mm) was determined by the flow table in three perpendicular directions, according to NBR 13276/2016 (ABNT, 2016).

For the AAM production, an alternative sodium silicate solution was mixed with MK and sand. The alternative solution was made with RHA to a NaOH solution. This mixture was put in a magnetic stirrer with heating (90 °C ± 5 °C) for 30 min, and after was stored in a sealed container for 48 h before using.

The AAM mix design was comprised of NaOH content of 81 g, water = 230 g, RHA = 104 g, MK = 355 g, and sand = 1.065 g. The MK: the sand ratio was 1:3, in mass. The mixing procedure was made as follows: alternative sodium silicate solution and MK were mixed until obtaining homogenization (4 min) in a mechanical mixer equipped with a long stainless-steel stirrer. After that, the sand was added, and a new mixing process was made until obtaining a homogeneous slurry (4,5 min). The AAM spread diameter (182,5 mm) was determined by the flow table in three perpendicular directions.

2.1.1.2 Mortar properties

The mortar properties evaluated were flexural and compressive strengths (1, 7, and 28 days) and bond strength (3, 7, and 28 days).

Flexural and compressive strengths were obtained in prismatic samples (40 mm x 40 mm x 160 mm). According to NBR 13279/2005 (ABNT, 2005), it was made the three point flexural strength, and the compressive strength was made with both parts resulted from the flexural strength test. The bond strength was made using the "Triplet test" method. Three prismatic concrete samples (40 mm x 40 mm x 160 mm) were bonded by mortar layers with 10 mm thickness, such as detailed by Teixeira *et al.* (2019). The mechanical tests were made in a Versa Tester testing machine (maximum load of 150 kN).

AAM compressive strength results at 28 days was 40 MPa and flexural strength was 8,7 MPa which means, respectively, 2,1 and 2,8 times higher than the strengths presented by PM at the same age. The bond strength at 28 days of AAM (3,2 MPa) was also higher than that achieved by PM (1,4 MPa). This result is significant because the bond between the mortar with the substrate is an essential parameter to guarantee an efficient and durable repair. Figure 4 shows AAM and PM mechanical properties.

PM presented a decrease in all mechanical properties evaluated at 28 days. It is suggested that unfortunately something happened with the specimens tested at this age (maybe during molding or testing).

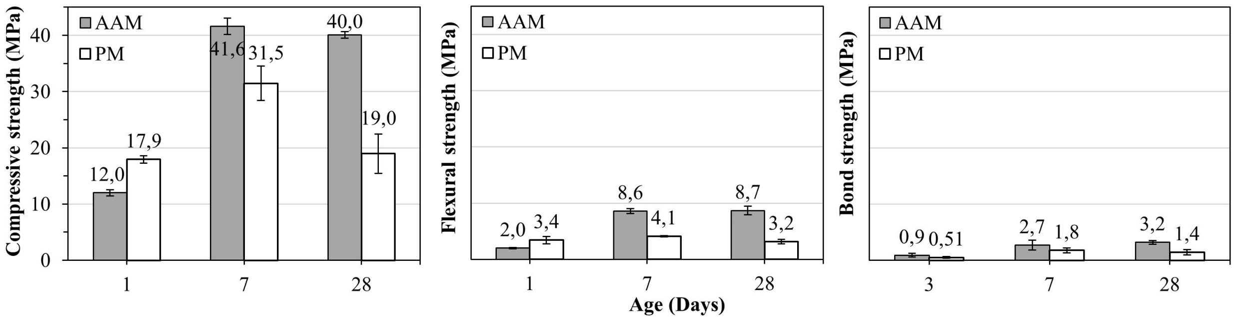


Figure 4. Compressive, flexural, and bond strength of repair mortars. Source: Authors

2.1.2 Concrete

The concrete used in the beams production was designed to reach a minimum compressive strength of 40 MPa at 28 days. The concrete mix design was 1: 1,43: 2,14: 0,45 (Portland cement: fine aggregate: coarse aggregate: water-cement ratio, in mass).

The concrete was prepared with a mechanical concrete-mixer (inclined shaft), and the slump test result was 80 mm ± 10 mm, according to NBR NM 67/1998 (ABNT, 1998).

To characterize the concrete of the beams, cylindrical specimens (100 mm diameter by 200 mm high) were cast to make axial compressive and indirect tensile strength by diametral compression (split test) (Brazilian Test) at the age of 28 days, following NBR 5739/2018 (ABNT, 2018) and NBR 7222/2011 (ABNT, 2011). The concrete specimen was compacted using a vibrating table for 1min30s to eliminate the entrapped air (the vibrating time was established according to the water content used, and represented the time when the concrete revealed to have homogeneity). The specimens were demolded 24 h after casting and cured in laboratory conditions (average temperature of 25 °C and relative humidity of 60%). Until testing age (28 days). The tests were made in a machine (maximum load of 1.200 kN).

The American Society for Testing of Materials (ASTM) states that the tensile strength by the split test, in general is higher than the pure tensile strength (BALBO, 2013).

The concrete achieved at 28 days compressive and diametral tensile strengths of 45 MPa and 4 MPa.

2.1.3. Reinforced concrete beams

The reinforced concrete beams had a rectangular cross-sectional area (width of 120 mm and height of 300 mm) and length of 2.100 mm. Figure 5 shows the beams geometry and reinforcement details.

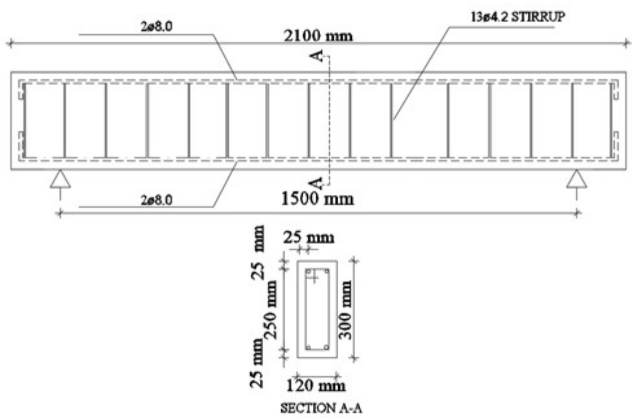


Figure 5. Concrete beams geometry and reinforcement details. Source: Authors

Four longitudinal reinforcing bars of 8 mm were employed: two in the tension zone and two in the compression zone. The stirrups were arranged with 4,2 mm diameter reinforcing bars at 150 mm spacing on center.

Two concrete beams were tested until failure, and then they were repaired with AAM (REF1) or PM (REF2) (Table 4).

TABLE 4. Compositions and identifications of the reinforced concrete beams. Source: Authors

Identification	Beam	Type of repair mortar
REF1	Reference	None
REF2	Reference	None
RP.AAM	(REF1 repaired)	AAM
RP.PM	(REF2 repaired)	PM

2.2. Methods

2.2.1 Beams bending strength

The reinforced concrete beams were submitted to the four-point bending strength test until failure. Thereafter, the load was applied in increments until failure bending, and shear cracks of about 2 mm width were developed due to the charge application. The crack perimeter was chipped to a depth of about 15 mm, washed with water, and the repair mortar was applied on the wet surface. The beams were repaired with AAM and PM, and so a new test was conducted.

The reference beams were submitted to the first bending strength test 30 days after molding, and they were repaired (AAM or PM) eight days after this first test (beam age during repair application = 38 days). When the beams were 52 and 14 days of the repairs, it was made a second bending strength test of the repaired beams.

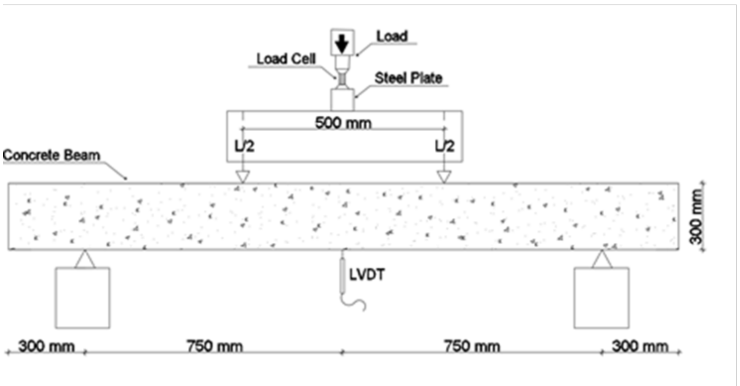
All the beams were tested on a 210 kN hydraulic actuator equipped with a load cell and tested under. The distance between the two lower supports was 1.500 mm, and the load was carried out by a single load distributed in two application points with a distance of 500 mm (Figure 6). The mid-span deflections of the concrete beams were measured with a Linear Variable Differential Transformer (LVDT) installed at the bottom side of the beam. The beams deflected as the load increased, causing flexure cracks along the span.

Reference beams were tested until ductile failure, which occurred when the LVDT captured a displacement of approximately 3,5 mm without significant load increase.

The maximum bending strength was calculated by Equation 1.

$$Fs = UL.\ell / B.h^2 \qquad \text{(1) Equation}$$

Where: Fs = Bending strength (MPa); UL = Maximum load (N); ℓ = distance between the supports (mm); B = beam cross-sectional width (mm); and h = beam cross-sectional height (mm).



a) Project of the beams bending test.

(b) Beam during the bending test.

Figure 6: Layout of the reinforced concrete beams test set-up with LVDT equipment Source: Authors

The maximum compressive strength was obtained by Equation 2:

$$\sigma = M.Y/I \qquad (2)\ \text{Equation}$$

Where: σ = maximum compressive strength (MPa); M = maximum moment (N.mm); Y = distance between the neutral axis and the tensioned edge (mm); and I = moment of inertia (mm^4).

2.2.2. Crack formation and failure mode

The crack formation and failure mode were determined by visual observation during the flexural strength test.

3. RESULTS AND DISCUSSIONS

3.1 Bending test

Table 5 lists the results of the first crack load, maximum load, ultimate load, ultimate deflection, and maximum compressive strength measured in the concrete members during the bending test. The ultimate load expresses the moment when the test was stopped (start of the concrete fracture in compressed concrete, Stage III) to preserve the LVDT placed under the beam.

The beam repaired with AAM had the first crack with a load 25% lower than reference one; however, the load value was 35% higher than that achieved by the beam repaired with PM. The first cracks are formed during Stage II (PIRES *et al.*, 2018). RP.AAM had a slight decrease in the ultimate deflection (10,6% lower) and maximum compressive strength (1,9% lower) when compared to the reference

TABLE 5: Results of the repaired beams tests. Source: Authors

Beam	First crack load (kN)	Max. load (kN)	Ultimate load (kN)	Ultimate deflection (mm)	Max. comp. strength (MPa)
REF1	24,50	48,02	42,43	7,02	9,60
REF2	25,27	46,63	45,22	7,12	9,33
RP.AAM	19,60	47,06	46,06	6,28	9,41
RP.PM	14,47	47,10	44,20	7,62	9,42

Repaired beams (RP.AAM and RP.PM) had a maximum load, differing only 1% of the reference beams. RP.AAM had a decrease of 10,54% and RP.PM presented an increase of 7,02% in ultimate deflection when compared with their respective reference beams. Both of the repaired mortars were efficient in recovering the beams load capacity and strength with good performance.

The deflection at the mid-span was measured and plotted against the load (Figure 7).

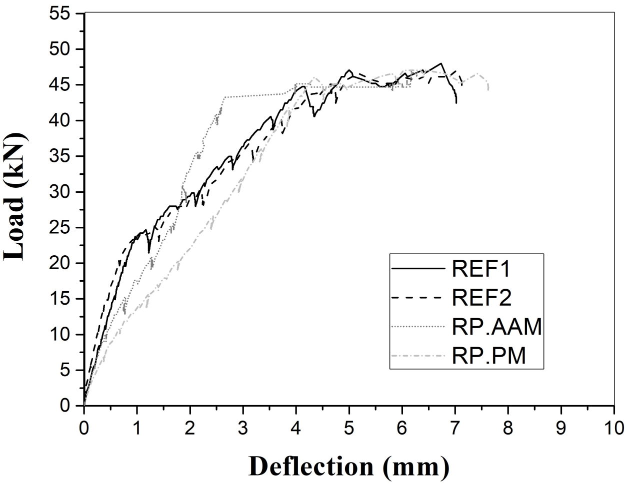


Figure 7. Curves of load and deflection of reference and repaired concrete beams. Source: Authors

Dividing the load-deflection graph in three stages (plastic, cracked-elastic, and elastic), as shown in Figure 1, it was verified that the beam repaired with PM had a more elastic behavior due to the low modulus of elasticity of the repair material, such as observed by Nounu and Chaudhary (NOUNU and CHAUDHARY, 1999). Figure 7 indicated that RP.AAM was more rigid than RP.PM, which may be related to the higher bond strength and mechanical strength of AAM (Figure 4).

Delatte (2009) considered that the bond strength of a repair mortar to structural load is 1,5 MPa. AAM presented a value twice higher, while PM did not achieve the minimum suggested by the author. AAM had higher strength and was a more rigid material, which influences the repair. As explained by Austin *et al.* (1999), the bond strength is a crucial issue to repair efficiency.

The use of AAM can delay the initial cracks in the beam. RP.AAM maintained 80% of the first crack load, while RB.PM preserved 57%. The results indicated AAM had 20% better performance than PM, which can be explained by the higher bond strength.

The relationship between the applied load and the corresponding deflection is approximately linear up to the first cracking load. After cracking, the performance was not linear with increasing in deflection up to the failure (AHMAD *et al.*, 2013).

The load-deflection curves showed that the initial stiffness of the repaired beams (RP.AAM and RP.PM) was lower than the reference ones (Figure 7). The beam repaired with AAM had similar behavior with the respective reference beam.

3.2 Crack formation and distribution

Figure 8 shows the crack pattern displayed in each specimen.

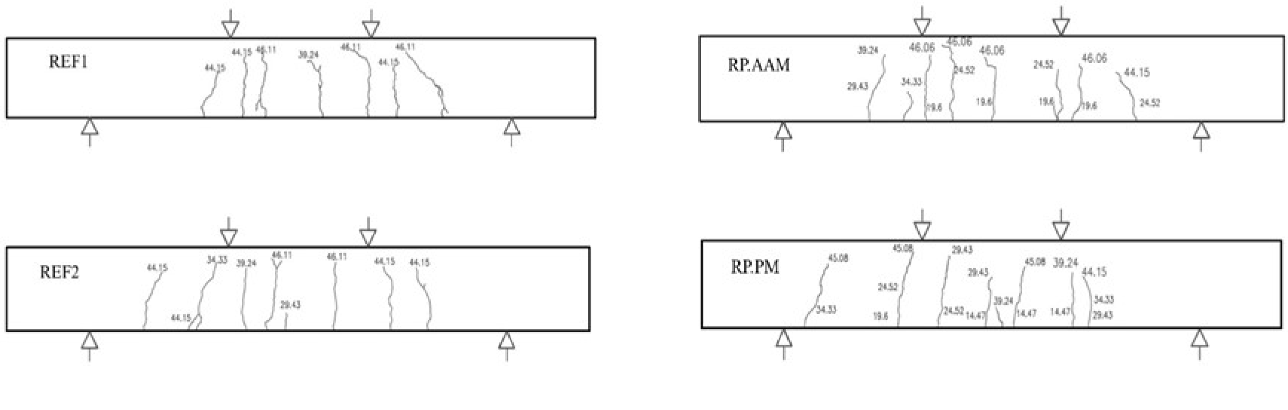


Figure 8: Crack patterns and failure mode of beams (units in kN). Source: Authors

All the specimens failed by bending. The first cracks that occurred in all the tested beams were bending cracks perpendicular to the load and positioned in the middle third of the beams (IGNJATOVIĆ *et al.*, 2017). As the load was increased, shear cracks also began to develop between the loading points (AHMAD *et al.*, 2013).

Small tensile cracks were formed at the bottom of the beam towards the centerline at loading between 14 kN and 30 kN. Then, in a load of approximately 46 kN, 45° shear cracks started to occur between the point loads and the supports, and at the end of the beams. The first cracks in the beams were formed in 8,67 cm (REF1), 13,03 cm (REF2), 1,41 cm (RP.AAM), 1,32 cm (RP.PM) counted from the centerline in the region of maximum bending strength. As reported by

Ahmad *et al*. (2013), this result implies that the steel reinforcement started yielding almost in the same region.

The main cracks were concentrated within the concrete in areas of high bending load, which appeared with lower loads in the repaired beams.

Table 6 shows the results of the number and types of cracks in the beams.

TABLE 6. Number and types of cracks originated in the beams. Source: Authors

Beam	Quantity of cracks		Failure mode
	Bending	Shear	
REF1	7	2	Bending
REF2	7	3	Bending
RP.AAM	7	2	Bending
RP.PM	7	1	Bending

The beams failed by bending strength, and presented the same number of bending cracks, independently of the type of the repair mortar. However, a decrease in the number of shear cracks was observed in the beam repaired with PM, which is related to the fact of AAM be a more elastic material and able to higher deformation, absorbing more loads before cracks appear.

Figure 9 shows the variation of cracks in beams faces related to the applied load.

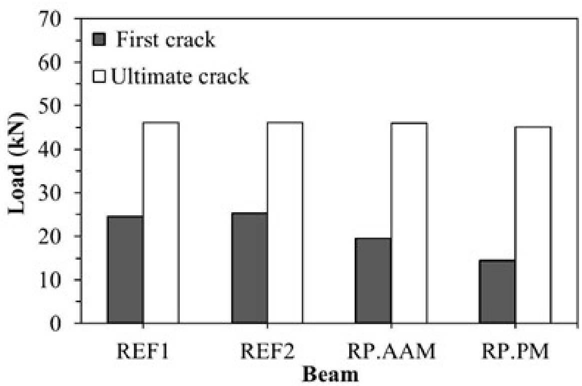


Figure 9. Variation of cracking load and ultimate load. Source: Authors

The load level of ultimate crack was similar in all the studied beams. The first crack load corresponds on average 50% of the ultimate cracks to the reference beam and 36% to the repaired beam.

RP.AAM met the requirements to work with service loads, since the beam was dimensioned by increasing the loads and reducing the strength. As shown in table 5, the load of the first crack was 20% lower than the reference beam; therefore, if the safety coefficients are disregarded, the beam meets the service limit state. However, the ultimate load of beam AAM is 8,55% higher than the reference beam.

4. CONCLUSIONS

This study described the mechanical properties of cracked reinforced concrete beams repaired with an alkali-activated mortar (AAM) and a polymer modified mortar (PM). Specimens were submitted to bending strength until failure and repaired with AAM or PM. Based on this study, the following conclusions can be drawn:

I. Beams repaired with AAM and PM developed the first crack at lower load levels than the references. The ultimate crack in repaired beams occurred at load levels similar to reference beams.

II. AAM provided the reinforced concrete beams rehabilitation, recovering 80% of the first crack load. With this level of load, structures can be placed in serviceable conditions, however, with limits on the use of accidental loads and deformations. The use of AAM can extend the durability of structures, prolonging their useful life and decreasing the repair cost throughout their life cycle.

III. Reference and repaired beams failed by bending strength, presented similar quantities of bending cracks, and a low difference in the number of shear cracks, indicating similar crack formation.

IV. The results indicate that AAM was efficient in rehabilitation of cracked concrete reinforced structures, with a performance similar to the commercial mortar (PM).

V. AAM developed suitable properties to be used as repair material in concrete structures.

Futures studies should ensure and validate AAM as a repair material, aiming to increase the bond strength, decrease the costs, and simplifying the productivity in the construction site.

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