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Influence of EVA and acrylate polymers on some mechanical properties of cementitious repair mortars

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ABSTRACT

In repair works of reinforced concrete, patch repairs tend to crack in the interfacial zone between the mortar and the old concrete. This occurs basically due to the high degree of restriction that acts on a patch repair. For this reason, the technology of patch repair needs to be the subject of a discussion involving professionals who work with projects, construction maintenance and mix proportioning of repair mortars. In the present work, a study is presented on the benefits that the ethylene vinyl acetate copolymer (EVA) and acrylate polymers can provide in the mix proportioning of a repair mortar with respect to compressive, tensile and direct-shear bond strength. The results indicated that the increase in bond strength and the reduction in the influence of the deficiency in curing conditioning are the main contributions offered by the polymers studied here.

1. Introduction

Reinforced concrete is a composite material. Its success depends on the concrete performance and its ability to protect the steel reinforcement from corrosion. On the other hand, the future performance of a patch repair intervention depends not only on the repair phase, but also on the non-repaired concrete around it. Very often the strategy must not only aim to provide repair protection but also to protect the remaining concrete from the harmful conditions that made the repair necessary [1–3].

Among the materials used in the composition of repair mortars, polymers form a category of great importance to the technology of patch repair for reinforced concrete structures. Polymers certainly are a type of material that is, in general, part of the composition of industrialized repair mortars.

In general, repair mortars are constituted by Portland cement, fine aggregate, plasticizers, mineral admixtures (such as limestone or silica fume) and polymers (such as styrene–butadiene – SBR, acrylic and ethylene vinyl acetate – EVA), among others. A polymer-based addition consists of a polymeric compound that is the main effective ingredient to modify or improve the properties, such as strength, deformability, adhesion, waterproofness and durability, of cement mortar and concrete [4].

The kind of interaction developed between cementitious and polymeric phases in the same aqueous solution is not clear, and some controversies exist among researchers [5]. A group of researchers believes that only physical interactions occur between the systems and, in most cases, a polymeric film is formed inside the composite, which is responsible for the improvement in the hardened-state properties of mortars and concretes [6,7]. Other researchers believe that physical and chemical interactions occur between polymers and Portland cement [8–12]. Chemical interaction could result in the formation of complex structures and in changes in the morphology, composition and quality of hydrated cement phases, especially of calcium hydroxide [9].

Among the repair mortars available in the Brazilian market and recommended for the same purpose (repair of reinforced concrete structures), there are products with very different characteristics [13]. Therefore, their characterization should be analyzed together with that of the concrete of the structure to be repaired. Only with this information, can the designer choose the most adequate specification of the product for a given intervention case [14,15].

The mechanical properties of repair mortars are essential for the performance of a repair system. Its adequacy to usage depends, among other factors, on the compressive, tensile and bond strength to the substrate to be repaired. The development of research with

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the objective to study new materials and adequate mix proportions of the distinct components of a repair mortar is very important for the advance of the rehabilitation technology of reinforced concrete structures. One of the main problems to be solved is cracking in the interface between the repair material and the old concrete. This occurrence is directly related with the tensile bond strength and the modulus of elasticity. Many other special properties in the fresh and hardened state of the mortar can also be important for a satisfactory performance, and they should be chosen according to concrete structure and rehabilitation technology requirements, as discussed in the literature and standards.

The purpose of this study is to evaluate the effects of an ethylene vinyl acetate copolymer (EVA) and an acrylate copolymer on some mechanical properties of repair mortars like flexural, compressive and direct-shear bond strength. Moreover, the influence of the curing conditions and cement type were also investigated. Unfortunately, the modulus of elasticity could not be measured for these mortars, but properties related to repair cracking during shrinkage were analyzed in [14], along with others that are not detailed here.

2. Materials

Moreno Jr. [16] developed a previous selection of materials and mix design of the mortars studied here. He adopted workability and bond strength tests as the main efficacy criteria among many other properties, including modulus of elasticity. Concerning bond performance, direct pull-out and flexural bond strength of repair mortars were evaluated for three levels of concrete strength. In that work, EVA and acrylic copolymers were the additions initially compared. Because in [16] the acrylic copolymer showed problems of mixing and bond failure for three mix proportions in the three concrete substrates, its manufacturer proposed the use of an alternative acrylate copolymer in the comparison with EVA in this study, because only the second had good mixing and bond performance.

2.1. Cements and superplasticizer

Two Portland cements were used in this work. The first one is named CPII F-32 in Brazil and is equivalent to cement type I according to ASTM C 595 [17,18] (filler-modified Portland cement). The second one is named CPV ARI, which is equivalent to cement type III according to ASTM C 150 [17,19] (Portland cement with high early strength). The chemical compositions and physical properties of the cements are listed in Table 1. Only the first cement was previously selected by [16], while the second was a practical comparison in this study, because of its higher mechanical properties.

In [16] a naphthalene sulfonate superplasticizer, which is in accordance with ASTM C494 [20] Type A–F and ASTM C1017 [21] Type I, was simultaneously selected with the type I cement due to the above mentioned properties. The same admixture was then used here.

2.2. Polymer-based additions

As previously justified in the introduction to this section, two water-redispersible powder additions were used. The first was based on an ethylene vinyl acetate copolymer (EVA) and the second was based on an acrylate copolymer. Their properties, as declared by the manufacturers, are given in Table 2.

Table 2
Characterization of polymers according to the manufacturer.

Characteristic	Test method	Polymeric addition	
		EVA	Acrylate
Solid content (%)	DIN 53 189	99.7	99.8
Apparent density (g/l)	DIN 53 466	458.2	461.3
Appearance	–	White powder	White powder
Particle size	DIN 53 734	Maximum of 4% above 400 μm	Maximum of 4% above 400 μm
Interval of particle size	–	1–7 μm	0.5–10 μm
Minimum film-forming temperature	DIN 53 787	0 °C	5 °C

2.3. Concrete substrate and repair mortars

The mix proportion of the reference concrete used in this study was 1.0 (Portland cement – CPII F): 2.24 (fine aggregate): 3.12 (coarse aggregate) and the water/cement ratio was equal to 0.60. This substrate had compressive strength of 32 MPa after it was cured in water for 28 days.

Coarse aggregate for the preparation of the reference concrete was a dense, crushed granitic stone (bulk density = 1424 kg/m^3 and specific gravity = 2742 kg/m^3). Fine aggregate was natural siliceous river sand (bulk density = 1480 kg/m^3 and specific gravity = 2600 kg/m^3). The granulometric analysis of aggregates used in this work is presented in Fig. 1.

The original experimental program [14] was formed by six repair mortars prepared in laboratory and seven industrialized cementitious repair mortars. The industrialized mortar group was used to gain an overview of the properties of the products available in the Brazilian market. Detailed results about Brazilian industrialized cementitious repair mortars have been presented in [14] and in another previous paper of the main authors [13].

The mortars prepared in laboratory are the focus of analysis here and they were made with two types of cement, a superplasticizer and two copolymer-based additions, resulting in the six repair mortars presented in Table 3. The fine aggregate was of the same kind as that used in the concrete. As initially explained, the materials and mix proportion were studied and previously defined in [16]. In this study, mortar flow was adjusted to be constant at 200 ± 10 mm, these values being typical of manual application.

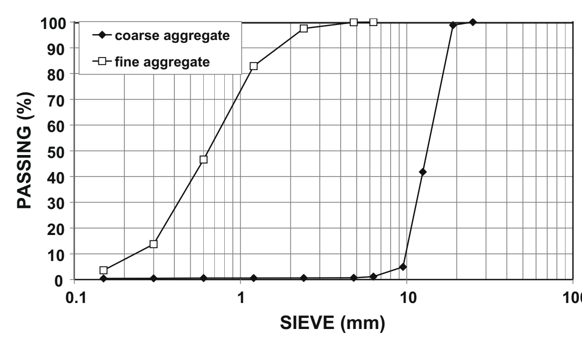

Fig. 1. Granulometric analysis of aggregates [14].

Table 1
Chemical compositions and physical properties of cements [14].

Cement	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Free lime	Total alkalis as Na_2O_e [a]	Insoluble residue	Loss in ignition
(a) Chemical compositions (%)												
CPV-ARI PLUS RS	21.80	5.63	3.58	58.08	2.76	2.75	0.12	0.65	1.81	0.55	0.44	3.59
CPII F 32	16.70	3.56	5.03	57.5	6.65	2.83	0.05	0.39	1.94	0.31	1.80	6.38

Cement	Specific gravity (23 °C)	Fineness		Setting time		Compressive strength of mortar (MPa)		
		Residue on sieve of 75 μm (%)	Blaine's specific surface area (m^2/kg)	Initial set (h:min)	Final set (h:min)	3 days	7 days	28 days
(b) Physical properties								
CPV-ARI PLUS RS	3.10	0.3	377	3:50	5:00	20.6	28.6	42.0
CPII F 32	3.03	1.6	379	3:25	5:15	12.8	29.0	37.2

[a] $Na_2O_e = Na_2O + 0.658K_2O$.