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PERFORMANCE ANALYSIS OF REINFORCED POLYMER CEMENT MORTARS "RPCMS" USED FOR REPAIRING CONCRETE STRUCTURES

ANALIZA PORÓWNAWCZA ZAPRAW CEMENTOWO-POLIMEROWYCH STOSOWANYCH DO NAPRAWY BETONU

Abstract

Concrete structures operating under different environmental conditions are subject to the action of aggressive gaseous and liquid media, which leads to their degradation. Even well-designed buildings, after time, can have problems to fulfil appropriate requirements concerning their further service life. Fiber reinforced mortars based on cement modified with different types of polymers are commonly used materials for renovating concrete structures. They should fulfil requirements concerning their high adhesion to concrete, minimum tensile strength, compatibility with repaired concrete and low shrinkage. The aim of the work was to compare the performance of three reinforced PCMs based on various polymers. The following features were tested: adherence to concrete, shrinkage and flexural strength.

Keywords: concrete structures; polymer modified mortar, concrete degradation

Streszczenie

Konstrukcje betonowe eksploatowane w różnych warunkach środowiskowych narażone są na działanie agresywnych mediów gazowych i ciekłych, co prowadzi do ich stopniowej degradacji. Nawet dobrze zaprojektowane budowle mają z czasem problemy ze spełnieniem odpowiednich wymagań dotyczących ich bezpiecznej eksploatacji. Powszechnie stosowanymi materiałami naprawczymi są zaprawy cementowe z dodatkiem włókien i polimerów. Muszą one spełniać odpowiednie wymagania dotyczące ich odpowiedniej adhezji do podłoża betonowego, minimalnej wartości wytrzymałości na zginanie, kompatybilności z naprawianym betonem oraz małego skurczu. Celem pracy było porównanie trzech materiałów naprawczych zawierających różne polimery. Badano następujące cechy: przyczepność do betonu, skurcz oraz wytrzymałość na rozciąganie.

Słowa kluczowe: konstrukcje betonowe, zaprawy modyfikowane polimerem, degradacja betonu

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1. Introduction

Concrete is the most frequently structural material because of the following features:
- ease of concrete placement,
- good durability,
- high mechanical strength,
- relatively low cost [1].

It has been used for many years to build a great number of structures such as houses, large buildings and bridges. A period of dynamic growth in concrete use came during the 1960s as a result of an application of superplasticizers, ready-mix concrete and boarding. The common outlook that concrete is a durable, maintenance-free construction material has changed in recent years. Some examples can be given to show that concrete has not fulfilled assumed requirements [2]. Although a lot of concrete structures are successfully constructed worldwide each year, there are a great numbers of structures that deteriorate or become unsafe due to the following factors: incorrect design, poor workmanship and maintenance, overloading, chemical attacks, corrosion of rebar, foundation settlement, abrasion, fatigue effect, atmospheric contamination, floods etc. These factors affect the durability of concrete structures. In recent years, the growing need to repair structures has led to a significant increase in the expenditure for restoration in comparison with costs of new structures. It has been estimated that, currently in Europe (particularly in Italy), the cost of maintenance and repair works of old structures is around 50% of the total expenditure on construction [3]. Repair and rehabilitation of deteriorated concrete structures are crucial for their service life. An appropriate repair method improves the performance of the structure (prolongs serviceability), increases its strength and stiffness, enhances the appearance of the concrete surface, provides water tightness and prevents from attacks of aggressive media on reinforcement [4]. Currently, Reinforced Polymer Cement Mortars “RPCMs” are commonly used to renovate old concrete. The materials consist of cement and addition of polymer, oligomer or monomer to mortar mix. The chemical modifier may polymerize both after mixing (post-mix), i.e. the polymerization takes place during the hydration of Portland cement or polymerize before mixing (pre-mix). In latter case, chemically inactive polymers are introduced into concrete mix and their action is predominantly physical-chemical. Repair materials should be characterized by the following properties: high tensile strength and adhesive strength to steel and/or old concrete, good corrosion and chemical resistance, low shrinkage etc. The increase of these properties, in comparison with ordinary concrete, is achieved by an addition of some polymers such as sulfonated melamine-formaldehyde resin, styrene-butadiene rubber, polyvinyl alcohol and methylcelullose [5, 6].

2. Materials and test methods

The selected RPCMs for these studies were one-component mortars commonly used as repair materials. They consisted of cement, fibers and different types of polymer. RPCM-A contained two polymers: melment F10, which was a product based on melamine and methylcellulose as well as set retarding admixtures. The properties of the melamine-based polymer are as follows: an increase in concrete strength, waterproof and resistance to chemicals. As far as methylcellulose is concerned, it is characterized by high water retention for proper curing and improved mortar workability. A polymer addition in RPCM-B was methylcellulose while, in the case of RPCM-C, it was a melamine based polymer together with polyvinyl alcohol (PVA). PVA polymer is added to mortars, since it allows obtaining a high adhesion as well as a high tensile strength and flexibility of mortar. The mixtures of the three mortars were prepared according to EN 1015-2 [7] and requirements given in the technical sheets of the used materials (mixing time, water-mortar ratio). The samples, before demoulding, were kept under polyethylene foil for 24 hours at 20±2 C and 95% RH and then, after demoulding, were kept for 2 days at 20±2 C and 95 RH under the foil. Afterwards, they were put into a climatic chamber at a temperature of 21±2°C and 65±5% RH for the following 25 days. Unmodified mortar was prepared according to PN-EN 196-1:1996 [8]. Flexural strength of the RPCMs was determined according to EN 1015-11 [9]. Three-point bending tests were done by the means of the Zwick/Roell Z100 universal machine using 40 × 40 × 160 mm samples with a curing period of 7 and 28 days. Pull-off tests were performed according to EN 1542 [10]. For measuring the pull-off forces, a concrete slab (C30/37) of dimensions 1300 × 1300 × 150 mm was prepared according to EN 1766 [11] and then, after an appropriate curing, thickness of the mortars of 10 mm were applied. Then, the mortar thickness was covered using a polyethylene sheet and left to cure for 7 days at around 20°C. The sheet was then removed and the concrete slab was kept in air at around 20°C and 65% relative humidity for the remaining 21 days. After 28 days, pull-off tests were done using the Proceq Z15 dynamometer. Pull-off tests consisted in the measuring of the adhesive strength of the repaired material to the old concrete. The material was loaded at a constant rate and the maximum strength was recorded. The tests were performed after 1 day after installing the steel dollies (disks) on the repair materials. The load was applied at a continuous and even rate until failure. Shrinkage tests and sample preparation were done according to OENORM B 3329:2009 [12]. The test allows analysing the deformations that may occur in a mortar after its application. RPCMs were inserted within U-shaped profiles, previously covered with neoprene sheet. One sample for each RPCM was obtained by filling a U-shaped stainless steel profile with length of 1000 mm and cross section of 60 × 38 mm. Three displacement sensors were connected to the sliding anchors of the moulds. The mortars inside U-shaped profiles were free to shrink or expand, because the container was made of a fixed anchor and a sliding anchor movable on three wheels at both sides. The motion of this anchor was registered by a high sensitive "linear variable differential transformer" (LVDT) probe. A digital probe was used as displacement sensor, which was connected to the probe interface electronics that has converted the analogue signals into a digital format. Shrinkage tests were performed on the three samples for 45 days. Observations of an interfacial transition zone between the old concrete and a bonding slurry as well as between the bonding slurry and a repair material were done using the Zeiss EVO MA 10 microscope.

3. Test results

3.1. Bending results

The obtained flexural strengths of the three RPCMs (A, B and C) after curing periods of 7 and 28 days are presented in Fig 1.

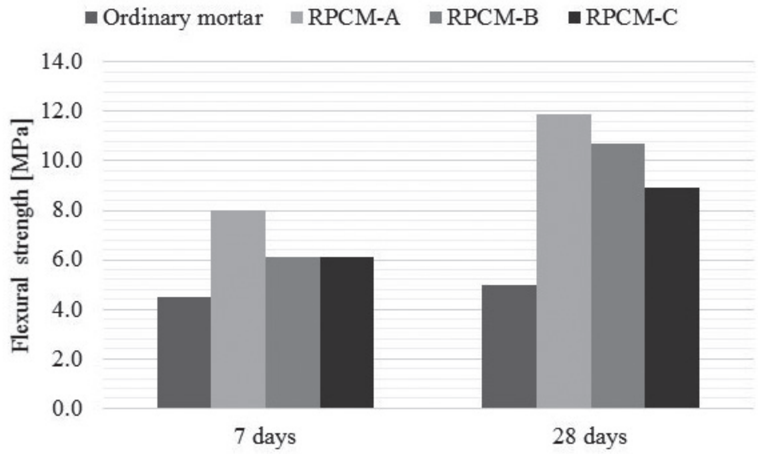

Fig. 1. Bending tests results of the RPCMs and comparison with ordinary mortar

Test results show that the repair materials tested exhibit much higher values of flexural strength than that of ordinary mortar used as a reference sample. The difference is particularly clear in case of the samples cured for 28 days. The flexural strengths of the repair mortars were also higher than values provided in the technical sheets of the companies and are within the range of test results obtained by other authors with reference to similar proprietary repair materials [13].

3.2. Pull-off adhesion tests

The obtained bond strengths of the three RPCMs, using a dynamometer, are presented in Table 1. As a reference, an unmodified mortar, M was also tested using Proceq Z15 dynamometer.

Table 1

Pull-off test results of the RPCMs

	RPCMs	Bond strength MPa	Mean value MPa	Mode of failure
Proceq Z15 dynamometer	A	3.7–4.3	4.0	in concrete
	B	3.8–4.5	4.1	in mortar/in concrete
	C	3.1–3.5	3.4	in mortar/in concrete
	M	1.3–1.6	1.5	in mortar

RPCMs showed very good adhesion to the concrete support and test results were much higher than that of ordinary mortar. In case of polymer mortars, failures occurred in the substrate or in the repair material and in case of unmodified mortar, it took place in mortar.

In all cases, cohesive mode of failure was observed. Bond strengths were homogeneous keeping in mind the tested feature. All values were much higher than 2.0 MPa, which was the minimum recommended value according to EN 1504-3 [14].

3.3. Scanning Electron Microscopy

SEM photograph of one of the repair material systems shows that the repair system was well placed on the old concrete to ensure high adhesion and the pull-off tests confirmed it, Fig. 2. One can see three zones: the layer of the repair material at the bottom, the bonding slurry in the middle, while the old concrete is at the top.

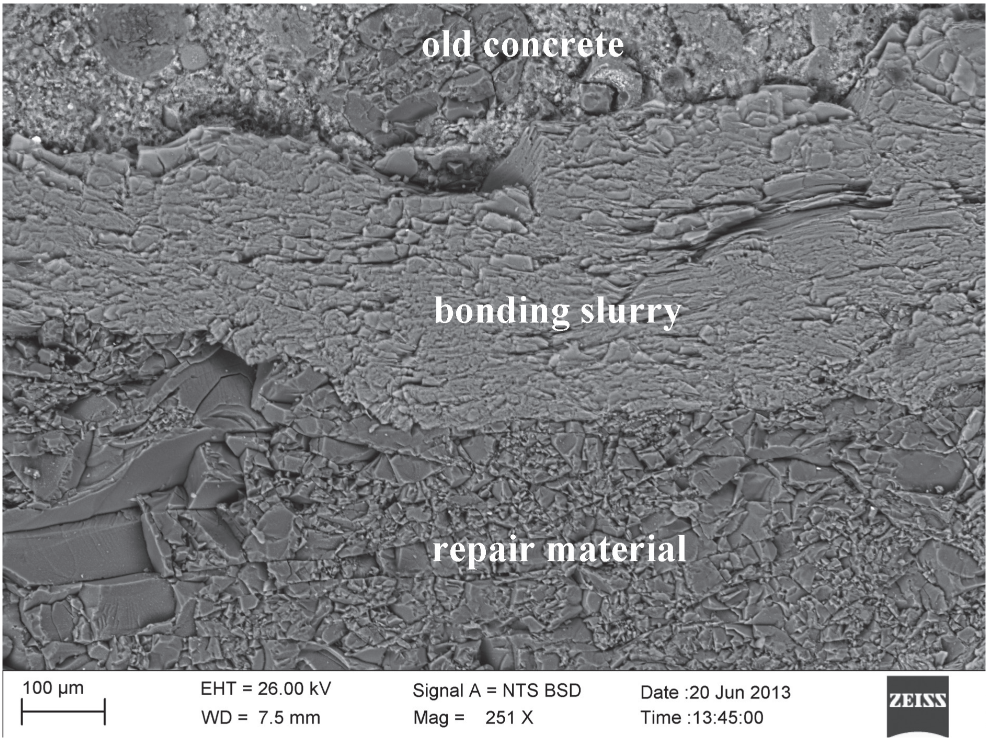

Fig. 2. SEM of one repair material system

3.4. Shrinkage results

Fig. 3 presents samples during shrinkage tests. RPCM-B and RPCM-C showed some expansion in the early stage of setting. RPCM-B showed the expansion within 24 hours after moulding and the maximum value was 0.1 mm/m. In case of RPCM-C, expansion period lasted up to 7 days, reaching the maximum value of 0.26 mm/m after around 48 hours after moulding. Then, progressive contraction of these materials was observed and, after 28 days, the maximum contraction values were 0.52 mm/m and 0.34 mm/m, respectively.

RPCM-A also showed very good volumetric stability. The difference in deformation was only 0.39 mm/m after 28 days and lack of expansion was observed. Micro-cracks did not emerge in any RPCMs samples during the test period.

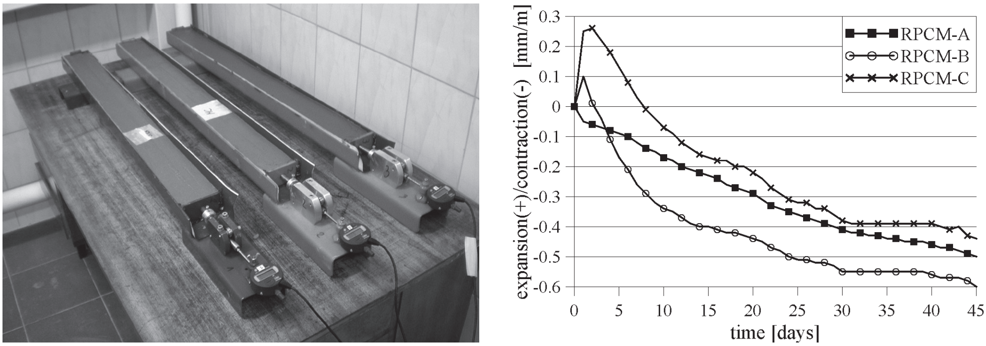

Fig. 3. RPCMs samples during shrinkage tests (a) and the course of shrinkage during 45 days (b)

4. Discussion

4.1. Effective repair related to the presence of micro-fibers

The behavior of the repair system with fibers, up to cracking, is mainly governed by the performance of the cement matrix. RPCM flexural strength increases until 28 days. The porosity can play a major role, since the volume fraction of pores is not the same in the materials after 7 and 28 days. It is known that cement hydration strengthens the cement-based materials by filling the capillary pores with hydrates, especially during the first month of setting [15]. Cement hydration is responsible for the increase in bending strength. During shrinkage tests, micro-fibers present in hardened RPCMs prevent micro-cracks, induced by plastic shrinkage, from developing into macro-cracks. These fibers bridge material and therefore hold together the existing macro-cracks, thus reinforcing the mortar against failure. Good performance of RPCMs can be largely attributed to the crack bridging ability provided by the micro-fibers, which limit crack opening and distribute the stresses to the nearby matrix, thus suppressing strain occurrence. Moreover, the application of polymers in concrete also helps to bridge micro-cracks [16].

Plastic shrinkage occurs up to the moment when concrete is set. It depends on the amount of water lost on the concrete's surface, which in turn is influenced by the temperature, relative humidity and wind speed. Plastic shrinkage is higher, if cement content is higher in the concrete mix and the water to cement ratio is lower [17]. The mortar cracking due to shrinkage depends on three parameters: shrinkage deformation (ε), Young's modulus (E) and tensile strength (f_{Rt}). During plastic shrinkage, low tensile stresses (σ_t) are induced for the very low Young's modulus and it is therefore sufficient, by the addition of micro-fibers, to raise slightly f_{Rt} the cementitious composite until it becomes greater than σ_t induced by the shrinkage. In case of the drying shrinkage, an addition of micro-fibers is not sufficient to reach levels above σ_t, where Young's modulus is higher.

4.2. Effective repair related to the presence of polymer adhesives

The modification of concrete using polymers allows improving some of its properties, such as tensile and flexural strength, adhesion to different substrates and tightness [1]. The polymers may be added in the form of dispersion, often called latexes [6]. Latex adhesives exist as water emulsions and are added to the Portland cement mixtures of the RPCMs. The water reacts with cement and hydration takes place. The latex particles improve the stability of the mortars. Latexes increase tensile and bending strengths and primary adhesive properties on concrete surfaces. Moreover, latex addition allows reducing the formation of voids and cracks during the curing stage [18]. Other forms of additions include emulsions, redispersible powders, water solutions of polymers as well as liquid synthetic resins [5].

4.3. Effective repair related to volumetric stability and adhesion

Shrinkage tests have shown that three mortars exhibited volumetric stability for 45 days. RPCM-B and RPCM-C have had expansion within first days. The expansive binders compensate the shrinkage and prevent the separation of mortar-concrete interface or cracks formation in the mortar due to the shrinkage. The consequence would be a mortar detachment caused by its movement in relation with the old concrete. The situation, that frequently occurs, is when the mortar tends to shrink, but it cannot move because of friction presence: a stress (σ) is established, which leads to cracking of mortar. Because of the expansive binders reaction with water and other products present in the fresh mixture, mortar increases in volume while setting and curing. Currently calcium oxide and magnesium oxides are added to mortars as expansive agents (EXP) together with shrinkage reducing admixtures (SRA) like propyleneglycol ether in order to ensure stable and durable mortars [19]. While drying, shrinkage causes the reduction or decrease in compressive stresses accumulated during the initial expansion. The adhesion of the repair layer is effective if it enables the load transfer (from substrate) and ensures even distribution of stresses. In fact, stress concentration, induced by shrinkage during setting, is mainly located at the mortar-concrete interface.

In this investigation, based on the obtained results, the following parameters were calculated: concrete tensile strength f_{Ct} equal to 2.9 MPa (it was obtained from the formula $f_{ctm} = 0.30 f_{ck}^{\frac{2}{3}}$, according to Eurocode 2 [16] for C ≤ 50/60 classes); repair material tensile strength f_{Rt} equal to 7.6 MPa (it was obtained by $f_{ctm} = \dfrac{f_{ctm,fl}}{\left(1.6 - \dfrac{h}{1000}\right)}$, according to Eurocode 2 [20]); repair material adhesion strength f_{Ra} equal to 3.9 MPa. Comparing the above values, it is possible to correlate the following relation:

$$\sigma_t < f_{Ct} < f_{Ra} < f_{Rt}$$

which allows to state that RPCM requirements are higher than those of standard cement concrete ones according to the current standards.

5. Conclusions

Based on the test results and literature data, the following conclusions can be drawn:
- Currently used RPCMs may be successfully applied for repairing deteriorated concrete covers of structures due to their very good mechanical properties.
- The addition of micro-fibers and polymers prevents micro-cracks and helps to resist the induced shrinkage stresses.
- The presence of polymers in repair materials can significantly improve their properties such as the flexural strength and bond strength.

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