

# Adhesion Strength and Other Mechanical Properties of SBR Modified Concrete

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**Abstract:** Polymer-cement composites are known repair materials. The aim of this work is to investigate the influence of various amount of dispersion of carboxylated styrene-butadiene copolymer on the selected mechanical properties of polymer-cement concrete (PCC) and on its adhesion to ordinary concrete. The compressive, flexural and tensile strengths as well as frost resistance and fracture resistance of the composites are tested. Adhesion strength of PCC to ordinary concrete, as one of most important performance of good repair material is evaluated and analyzed using three test methods. The results obtained in standard pull-off test are compared with the two other tests. The first one, which is an adaptation of WST (wedge splitting test) characterizes crack propagation in the plane of bond created during repair. In the second test the resistance to shear is a measure of adhesion strength.

**Keywords:** concrete, polymer modification, fracture, strength, adhesion, repairs.

## 1. Introduction

In the space of last decades traditional building materials overcame an evolution to a large degree due to development of chemistry. Especially, the application of polymers or monomers has multidirectional nature. Resin binders are used for production of resin concretes which characterize a high strength, chemical resistance and tightness.<sup>1</sup> Polymers are used for concrete impregnation. Development of superplasticizers makes manufacturing e.g. high performance concrete or self-compacting concrete possible. They influence mainly working properties such as flow, curing temperature range, and setting time. Polymers are also used for modification of cement binder, to create polymer-cement composites.<sup>2-4</sup> The aim is an improvement of performance of hardened materials with cement matrix, their final physical and chemical properties. Polymer-cement composites are used as adhesives, repair materials, industrial floors and top layers. It is assumed that polymer-cement composites starts when amount of polymer exceed 5% of cement mass. Different types of polymers are used. The most popular types of polymers include dispersions of synthetic rubbers as SBR or other copolymers and epoxy resins. Investigations are carried out on effectiveness of the polymer water solutions<sup>5</sup> and redispersible powders.<sup>6,7</sup> Compositions usually contain many others organic and inorganic compounds as spraying aids and other stabilizers. Final properties of polymer-cement composites can differ from each other. However according to investigations the polymer modifiers improve many properties as flexural strength,

tightness, chemical and abrasion resistance, adhesion strength to concrete substrate.

Adhesion is a complex phenomenon,<sup>8</sup> which strongly influences durability of bonds in multilayer repair systems. No less important is the way the adhesion strength is measured and results interpreted. Many laboratory tests were developed but comparison of the data is difficult. On site, mainly pull-off test is used but recently also non destructive methods have been intensively developing.<sup>9-11</sup>

## 2. Scope of the experiment

The aim of this work is to investigate properties of polymer-cement concrete modified by dispersion of carboxylated SBR (47% of dry polymer in water). SBR dispersion is well known modifier of concrete. However, introduction the carboxyl groups to the new SBR type products, which are known as a base of a new generation superplasticizers can change chemical activity of the modifier and should be investigated.

The issue is considered in two main aspects. The first one includes characteristic of PCC and discussion on the influence of investigated modifier on material properties. The second aspect undertakes comparison between different methods of measuring adhesion strength (pull-off, shearing and wedge-splitting). The research program includes preparation and testing the following composites (Table 1):

- ordinary cement concrete C40/50 (OCC), with maximum grain size of 16 mm; used as a reference concrete and as a substrate for carrying out of repairs; mixture of the concrete was prepared with superplasticizer, assuming  $w/c = 0.45$  and consistency S3 in slump test (EN 12350-2),

- polymer-cement concretes with different content of dry polymer referred (in %) to the cement mass: PCC-5% PCC-10%,

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**Table 1** Properties of concrete mixtures.

Description	OCC	PCC 5%	PCC 10%	PCC 15%	PCC 20%
Polymer content (% c.m.)	0	5	10	15	20
Components:	Content of components of concrete mixtures (kg/m <sup>3</sup> )				
Cement CEM I 32,5	356				
SBR dispersion:	0	38	76	114	151
- dry substance	0	18	36	54	71
- water from dispersion	0	20	40	60	80
Water - added	160	132	89	52	19
Water - total	160	152	129	112	99
Aggregate: 0~2 mm	692				
2~4 mm	192				
4~8 mm	423				
8~16 mm	615				
Superplasticizer	2.35	0			
w/c	0.45	0.43	0.36	0.32	0.28
Slump test (mm)	135	125	130	140	120
Mixture density (kg/m <sup>3</sup> )	2,391	2,351	2,335	2,330	2,324
Mixture porosity (%)	2	3.1	4.2	4.6	5.4
Shrinkage (%) after 28 days	0.19		0.02		
	0.12		0.03		
	0.13		0.03		

PCC-15%, PCC-20%; PCC composites were made by adding to the concrete mixture different amount of the polymer dispersion with maintaining constant consistency (S3) in comparison to OCC; with regards to water in the polymer dispersion, different values were obtained for each calculated water-cement ratio.

The following properties were tested: mixture density (EN 12350-6) and porosity (EN 12350-7), shrinkage, compressive strength ( $f_c$ ) (EN 12390-3), flexural strength ( $f_f$ ) (EN 12390-5), superficial tensile strength ( $f_t$ ) (EN 1766, EN 1542), fracture intensity factor ( $K_{IC}$ ), fracture energy ( $G_F$ ).

Adhesion strength was measured between substrate made of OCC and selected repair materials (OCC, PCC-10%, PCC-20%). Besides the type of material other factors influencing adhesion such as moisture of substrate's surface and direction of concreting in relation to the substrate's surface were observed.

Repair materials were placed on dry (acc. EN 12636) or moist (without film of water) sandblasted concrete substrates. For the pull-off test (Fig. 1) 50 mm thick overlays were poured on 100 mm thick plates. To measure the adhesion strength in direct shearing the cubic samples (150 × 150 × 150 mm) were prepared. One half of such sample was made of OCC (substrate) and the second half was placed using the investigated material. The WST was the third method used. Hardened concrete substrate and repair material were bonded with a notch placed in the plane of the bond. In the case of the two last methods, the following conditions were tested: concreting in the direction vertical to the dry substrate's

surface or concreting in the direction parallel to the moist substrate's surface.

### 3. Properties of concrete mixture

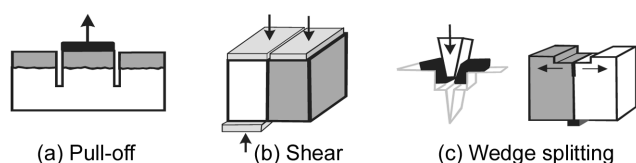
Four PCC concrete mixtures of the same consistency and with increasing amount of polymer were prepared (Table 1). Because of plasticizing effect of polymer, the increase of polymer amount in the concrete mixture results in decrease of w/c ratio. For 20% of the polymer added to the mixture the water-cement ratio decreases to 0.28; simultaneously the decrease of the mixture density and the increase of porosity were observed. Moreover, the delaying of hardening process was observed in the case of the highest amount of polymer. Curing conditions were kept according to EN-1542.

### 4. Properties of polymer cement concrete

Compressive strength measurements indicate that the addition of 5% of polymer results in the decrease in the concrete strength about 16% (Fig. 2). Then, with further increase in the polymer amount, the decrease of the concrete strength is falling, and for 20% of the polymer is close to 3%. Such changes can be attributed to the increase of the mixture porosity (Table 1, Fig. 3) when adding the polymer, what can be partially compensated by decreasing of the w/c. Flexural and superficial tensile strength of concrete significantly increase with growing amount of the polymer (Fig. 3).

During the freeze-thaw resistance test, the OCC indicated low resistance and after 80 cycles a dense network of cracks appeared and samples lost 25% of their previous strength (Table 2). 5% of polymer did not improve the properties of concrete. However, samples of PCC-5%, unlike OCC, even after 150 cycles were tight, without visible cracks. The addition of 10% and 20% of the polymer more significantly improved concrete resistance.

Fracture parameters were determined through WST test. Sam-

**Fig. 1** Schemes of adhesion strength tests.

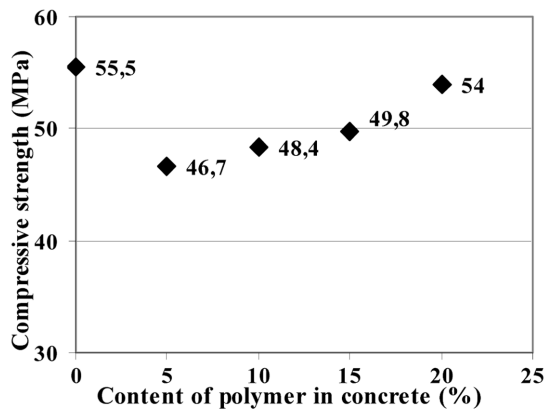


Fig. 2 Relation between the content of polymer in concrete and compressive strength.

ples measuring  $200 \times 200 \times 100$  mm (high  $\times$  width  $\times$  thickness) with notch 70 mm were split under COD control at a rate 0.1 mm/min. Relationship between horizontal component of splitting force ( $P_h$ ) and CMOD were found (Fig. 4). Fracture energy was calculated as a ratio of work of fracture (surface area under the  $P_h$ –CMOD curve) and ligament area. The calculations indicate (Fig. 5) that 5% of the polymer in the concrete causes decrease both in the fracture intensity factor ( $K_{IC} = 0.85$ ) MPam<sup>0.5</sup> and in the fracture energy ( $G_F = 104.1$  N/m) in comparison to the ordinary concrete ( $K_{IC} = 1.01$  MPam<sup>0.5</sup>,  $G_F = 124.0$  N/m). However, higher amount of the polymer, it means 10, 15 and 20% causes increase in:

- fracture intensity factor about 24%, 27% and 43% respectively,
- fracture energy about 21 %, 27 % and 41% respectively.

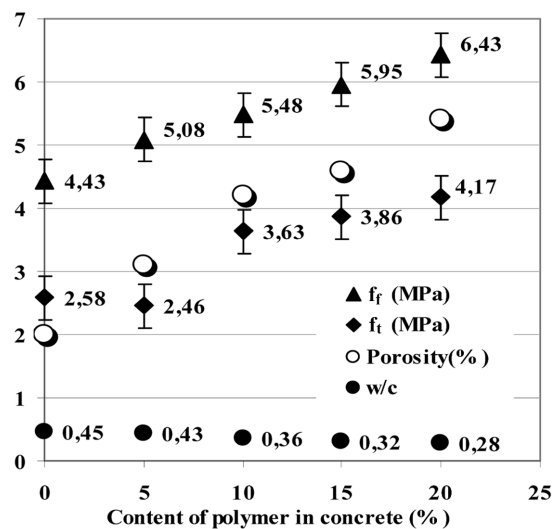


Fig. 3 Relation between the content of polymer in concrete and: mixture porosity, water-cement ratio, flexural strength ( $f_r$ ) and superficial tensile strength ( $f_t$ ); standard errors are marked for points.

## 5. Adhesion strength

### 5.1 Pull-off test

Adhesion strength of ordinary concrete to the same type of concrete substrate, prepared by sandblasting and wetting, was equal  $f_h = 2.90$  MPa (Fig. 6). The cohesion failure in the substrate was observed. The same picture of the failure was observed for PCC, however only when the substrate's surface was dry before placing the material. After surface wetting a significant decrease in adhesion was observed and damage occurred at the interface in 100%.

Table 2 Results of freeze-thaw test of ordinary cement concrete (OCC) and polymer-cement concretes (PCC).

Polymer content ( % )	Number * of cycles	Average compressive strength (MPa)		Decrease in strength ( % )
		Samples after cycles	Reference samples	
0	80	41.0	55.3	25.9
5	100	25.8	46.2	44.2
	150	26.5	50.7	52.3
	200	28.0	50.0	44.0
10	100	45.1	45.5	0.9
	150	38.7	45.1	14.2
	200	42.7	45.3	5.7
15	100	43.1	46.8	7.9
	150	49.9	50.9	1.9
	200	45.0	48.3	6.8
20	100	52.2	55.9	6.6
	150	51.9	54.0	3.9
	200	52.9	56.3	6.0
OCC – after 80 cycles		PCC-5% after 100 cycles		PCC-5% after 150 cycles

\* Cycle: freezing for 4h in temperature  $T = -18^\circ\text{C}$ , thawing for 4h in water  $T = +18^\circ\text{C}$



Fig. 4 Relationship between horizontal component of splitting force ( $P_h$ ) and CMOD for ordinary concrete (C40/50) and polymer cement concretes with 20% of polymer (PCC-20%). Photography illustrates a test set-up.

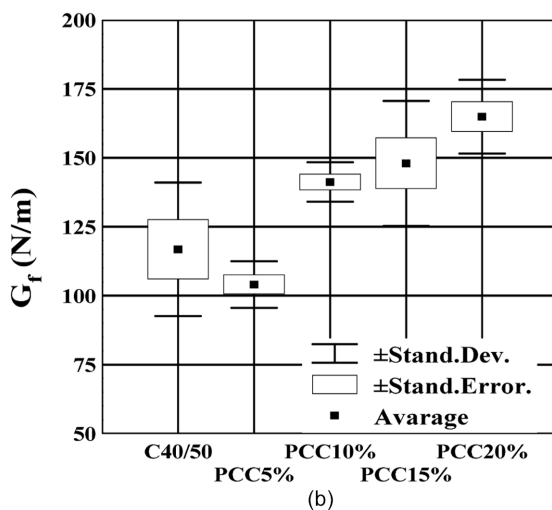
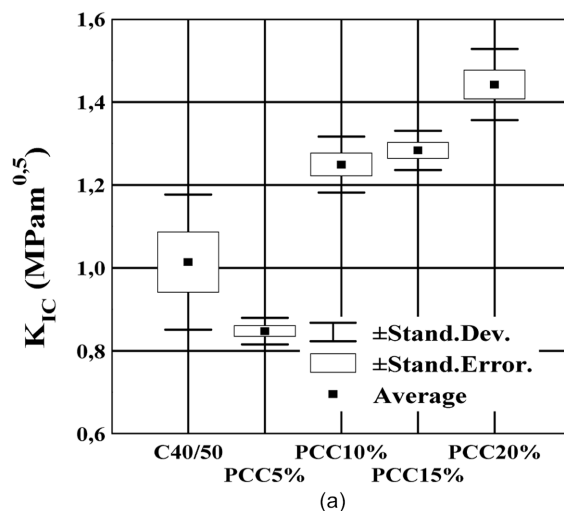


Fig. 5 Average values and standard deviations of (a) fracture intensity factor ( $K_{IC}$ ) and (b) fracture energy ( $G_F$ ) of ordinary concrete C40/50 and polymer-cement concretes with 5% (PCC-5%), 10% (PCC-10%), 15% (PCC-15%) and 20% (PCC-20%) of polymer.

## 5.2 Shear test

Failure stress for each bond was calculated as a simply proportion between a failure load and a bond's area. Significant differences in the adhesion were found in that test. PCC-10% was the most efficient when was placed in vertical direction to the dry sub-

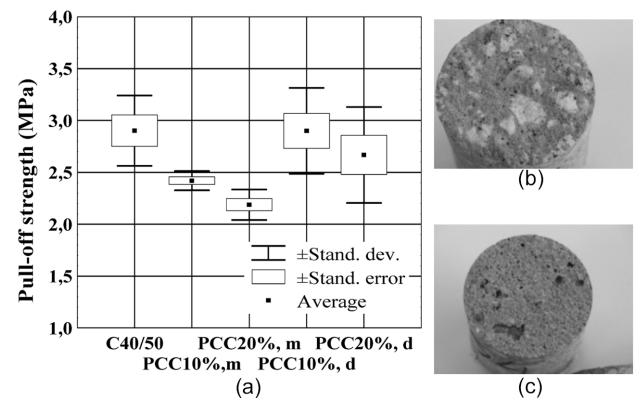


Fig. 6 (a) Adhesion between the repair material (C40/50, PCC-10%, PCC-20%) and the concrete substrate (C40/50); influence of the substrate conditions (m-moist, d-dry). Pictures illustrate: (b) the cohesion failure in the substrate, (c) the adhesion failure between the materials.

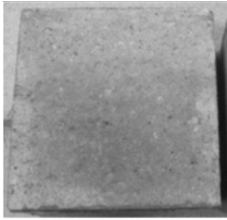
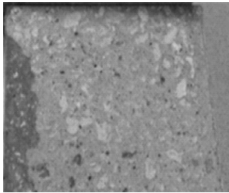
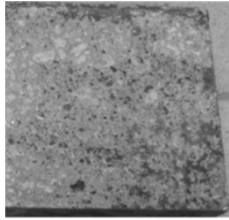
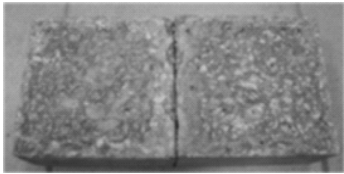
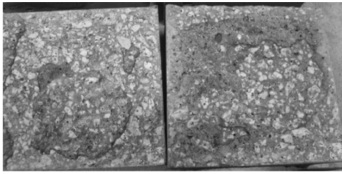
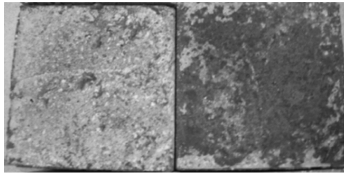
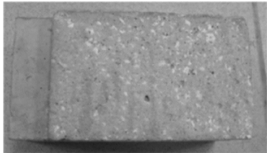
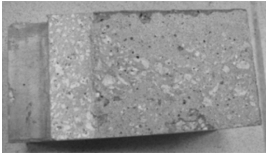
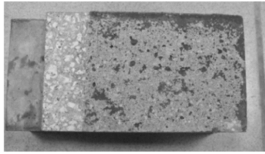
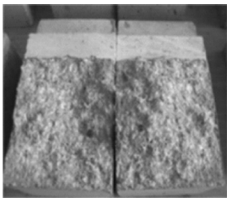

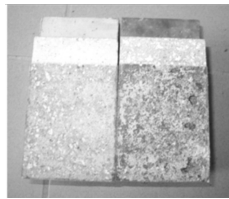
strate's surface (OCC). Damage of the bond (mixed mode type) occurred at 4 MPa (variability 6.5%) (Table 3, Fig. 7). In the case of PCC-20% the average adhesion strength was lower (3,14 MPa) and variability much higher (30%). Especially that high value of variability coefficient indicates a low resistance (quality) of the investigated joint on circumstances (technology, loading) represented by test. The weakest was the bond between OCC and OCC. This bond was also the weakest, when fresh concrete was placed parallel to the substrate's surface. Even after wetting the substrate's surface the adhesion was very low (0.7 MPa) in comparison to PCC. Also the coefficient of variation (16.5%) was higher than for PCC (5÷7%).

## 5.3 Wedge splitting test

When concreting was carried out parallel to the moist concrete's surface the results of WST test reflect the shear test (Table 3, Fig. 7). The best bond was formed between PCC-10% and ordinary concrete, lower adhesion was reached by PCC-20%. The samples made by using only ordinary concrete, as a substrate and repair material, destroyed during demoulding (only one was tested).

When the direction of concreting was vertical to the dry substrate's surface the same tendency of decrease in adhesion with the increase in the polymer content was observed. But in that case the adhesion of OCC was high ( $K_{IC} = 0.88 \text{ MPam}^{0.5}$ ), what contra-

**Table 3** Results of shear and WST tests; samples destroyed during the tests - mainly the halves made of repair materials are shown

C40/50	PCC 10%	PCC 20%
Shear test – average strength (MPa)		
Concreting parallel to the moist concrete C40/50 substrate's surface		
<b>0.71 MPa</b> -the adhesion failure	<b>3.55 MPa</b> - mixed failure mode; very thin layer of cement paste is seen on PCC surface as well as aggregate, which was pull-out from the substrate.	<b>2.48 MPa</b> - the adhesion failure; very thin layer of cement paste is seen on the PCC material (dark)
		
Concreting vertically to the dry concrete C40/50 (on the left) substrate's surface		
<b>2.9 MPa</b> - the cohesion failure in repair concrete or substrate	<b>4.0 MPa</b> - mixed failure mode; PCC (dark grey) and aggregate (white) from substrate	<b>3.14 MPa</b> - the adhesion failure; PCC (dark grey)
		
WST test - $K_{IC}$ (MPam <sup>0.5</sup> )		
Concreting parallel to the moist concrete C40/50 substrate's surface		
<b>0.28 MPam<sup>0.5</sup></b> – the adhesion failure	<b>0.87 MPam<sup>0.5</sup></b> -mixed failure mode; very thin layer of cement paste is seen on PCC (dark) as well as aggregate (white) pull-out from substrate	<b>0.44 MPam<sup>0.5</sup></b> – the adhesion failure; PCC is a darker one
		
Concreting vertically to the dry concrete C40/50 (on the left) substrate's surface		
<b>0.88 MPam<sup>0.5</sup></b> ; the cohesion failure in repair concrete or substrate	<b>0.68 MPam<sup>0.5</sup></b> 90% adhesion failure	<b>0.52 MPam<sup>0.5</sup></b> the adhesion failure
		

dicts to the shear test.

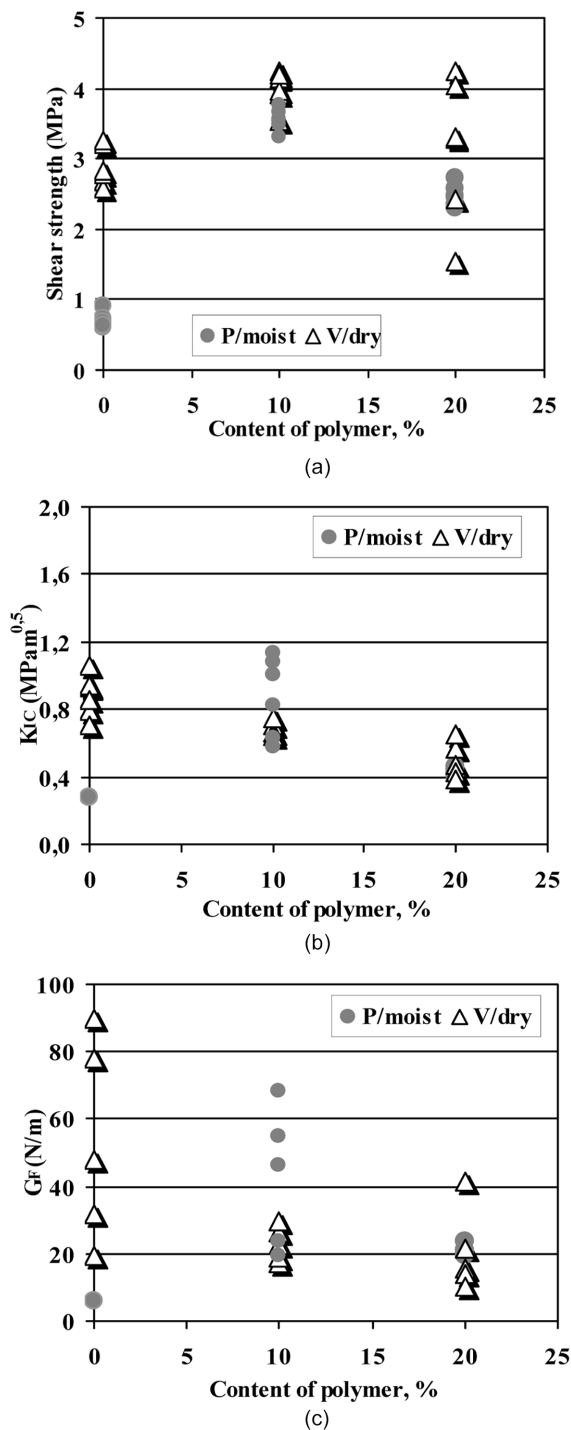
Analyzing the failure modes it can be observed that when  $K_{IC}$  is as high as 0.87 or 0.88 MPam<sup>0.5</sup> the damage runs in the concrete substrate. It is a similar level of fracture toughness to calculated for C40/50 concrete (0.85 MPam<sup>0.5</sup>). So in that case the resistance of the bond for fracture was higher than the resistance of concrete. Majority of investigated adhesion bonds indicate lower fracture toughness. Fracture energy shows similar relationship as  $K_{IC}$ . However, particularly high variability of the results is observed. It mirrored earlier author's observation, that when a peak load is reached the farther conditions of crack propagation at the bond plane of two different materials are complex and less reproducible.

It is a reason that the fracture energy is in that case a poor measure of the adhesion strength.

## 6. Conclusions

On the basis of the results the following conclusions can be drawn:

- Carboxylated SBR added to the concrete mixture causes: w/c reduction, increase of porosity, delaying setting (for high amount of polymer) and shrinkage reduction.
- Polymer modification of cement matrix can results in: decrease in compressive strength and increase in: flexural strength,



**Fig. 7** Bond strength between concrete C40/50 substrate and repair concrete in relation to the polymer content, measured in shear (a) and in WST (b, c) tests;  $K_{IC}$  - fracture intensity factor,  $G_F$ -fracture energy; P (parallel) and V (vertical) describe the direction of material placing in relation to the concrete substrate's surface; dry and moist relate to the substrate's surface conditions.

tensile strength, fracture toughness and frost resistance of concrete, PCC, in comparison to OCC, can create more reliable repair bond in different circumstances of repair works.

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