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Wear resistance of polymer-impregnated mortars and concrete

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Abstract

The wear resistance of mortar and concrete samples untreated and impregnated with solutions of epoxide resin was tested. The compressive strength has a decisive influence on the abrasion of untreated mortar and concrete samples. The idealized diameter area of the maximal grain of the gravel in the sample has less influence on it. The wear resistance of impregnated samples with low compressive strength markedly increases. The hardener used influences the polymerization rate of the activated resin in the structure of samples, with time, and their abrasion is influenced also in this way.

Keywords: Compressive strength; Polymers; Abrasion

1. Introduction

The wear resistance of floor constructions from mortar and concrete with cement binders is very important for their service life, especially in industrial enterprises. The resistance mentioned may be increased by the impregnation of the surface of construction by solutions of synthetic resins hardening after penetration into the structure of mortar or concrete.

Impregnation is a very effective treatment when the mechanical parameters of construction after hardening or after a certain time of service are low. Moreover, the resistance against chemical corrosion increases, and the permeability (gases, solutions) of construction markedly decreases after impregnation.

The wear resistance of mortars and concretes, in general, depends on a number of variables [1]. The parameters of cement are not important, while the wear resistance of aggregate has substantial importance. The granularity of aggregate, mainly, the size of maximal grain, also has an important role. Only fractions over 3 mm^2 contribute to the wear resistance of specimens, according to Ref. [1]. The wear of wet concrete is higher than that of dry concrete under the same other conditions [1,2]. A certain relationship between the compressive strength and wear characteristics of concrete exists, according to Ref. [1]. The relationship mentioned was not found in Refs. [3,4].

The water content of a mix is very important. Partial segregation may occur when water content is higher. Water penetrates to the surface of concrete or mortar layer. A different zone of porosity is created, with maximal value at the surface, to minimal value at the bottom [5,6]. Therefore, the upper part of the samples may have markedly lower wear resistance than the lower part does.

The advantage of water dispersions of polymers is that they can be applied on the concrete surface having high moisture content. Dispersions of copolymers are more effective [7]. Dispersions seem to be unsuitable for impregnation because they create, owing to the "filtration effect", only a coating on the porous surface, without deep penetration. The best results were obtained with solutions of two component resins, mainly those based on epoxides or polyesters [8–11]. These contribute to the cohesion of particles, especially when the porosity of samples is relatively high.

2. Experimental part

2.1. Materials and methods

2.1.1. Cement

Industrial Portland slag cement was used for the preparation of specimens. The parameters were content of slag

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30%, density 3.051 g/cm^3, specific surface area–Blaine 0.3650 m^2/g.

2.1.2. Aggregate

Natural gravel Fractions 0 to 16 were used. Fractions 0 to 1 mm, 0 to 3 mm, 0 to 8 mm and 8 to 16 mm were prepared. The ratio of the fractions used for concrete specimen preparation was 0 to 8:8 to 16 mm= 60:40 b.w.

2.1.3. Water

Tap water was used for the mix preparation.

2.1.4. Resin and hardeners

Medium molecular epoxide resin in xylene–butanol solvent was used. The concentration of the resin for the surface treatment was 20% b.w. Five different hardeners (without dilution) were used for the experiments. The basic parameters of the resin and hardeners are in Table 1. The depth of penetration of a solution into the structure of the mortar or concrete specimen depends substantially on its capillary activity.

The significance of the parameters influencing the capillary activity of liquids can be derived using a number of relationships. The most illustrative for our purpose seems to be the formula of Lucass [1].

$$h^2 = \frac{2\gamma \cos v r}{8\eta} \cdot \tau \qquad (1)$$

where h=height of elevation (m); γ=surface tension (N/m); v=contact angel (−); r=radius of capillary (m); τ=time (s); η=dynamic viscosity (Pa s).

The determination of the contact angle between the solutions and the porous solid surfaces is complicated with low reproducibility. Therefore, attention was focused on the determination of the viscosity and surface tension of activated resin and diluted solutions. Those parameters have top importance for the movement of solution in the capillary network of cubes [see Eq. (1)] and, therefore, also for the final depth of penetration and effectiveness of treatment. Activated solutions of resin were prepared using tested hardeners. Their viscosity was determined by a Höppler viscometer in accordance with standard ČSN 67 30 14. Results are in Fig. 1.

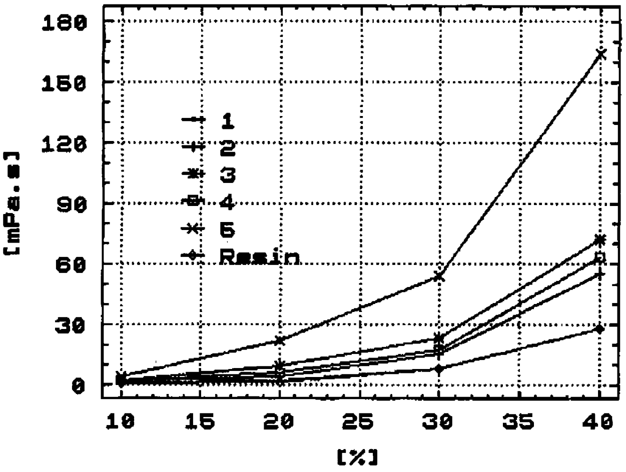

Fig. 1. Viscosity of resin and activated solutions of resin+Hardener Nos. 1 to 5 versus the initial concentration of resin.

Surface tension was determined by the Du Noüy method. Results are in Table 2.

2.1.5. Mortar and concrete specimens

The preparation, storing and testing (volume weight, compressive strength) of mortar and concrete cubes, with 70.7-mm edges, were in accordance with standards ČSN EN 1239-4, ČSN EN 1239-1 and ČSN 722440. The basic

Table 1
Basic properties of epoxide-resin and the hardeners used

Product	Description of basic characteristics	Parameters	Unit	Value	Resin:hardener b.w.
Epoxide resin	Medium molar epoxide resin in xylene–butanol solvent. Concentration 60% b.w.	Viscosity (+20 °C)	Pa s	0.6	100:0
		Consistency (+20°)	s	85	
		Dry (2 h/170 °C)	%	60. 2	
		Epoxy equivalent (100 g)	Mol%	0.19	
		Chlorine content in dry	%	0.5	
Hardener 1	Polyaminic hardeners with reaction products of medium and high molar polyvinylic compounds	Amine number viscosity	mg KOH	700	100:9
			Pa s	0,25	
Hardener 2		Amine number	mg KOH	200	100:39
		Viscosity	Pa s	1	
Hardener 3	Product of condensation of fat acids in trietanolamine	Amine number	mg KOH	480	100:12
		Viscosity (25 °C)	Pa s	3	
Hardener 4	Low molecular amine resin in xylene–butanol solvent	Amine number	mg KOH	230	100:50
		Fractions soluble in water	%	2.1	
Hardener 5	Product of condensation of fat acids in trietanolamine	Amine number	mg KOH	228	100:84
		Free diethylene triamin	%	1.8	

Table 2
Surface tension of solutions tested

Solution	Concentration (%)	Surface tension (10^{-5} N/m)
Slovent–xylene+butanol 4:1	–	28.54
Resin without hardener	60	32.56
	30	29.58
	20	29.00
Resin+Hardener No. 1	60	31.02
	20	29.20
Resin+Hardener No. 2	60	30.92
	20	29.61
Resin+Hardener No. 3	60	32.50
	20	29.08
Resin+Hardener No. 4	60	31.02
	20	29.12
Resin+Hardener No. 5	60	32.00
	20	29.06

parameters of the mortar and concrete specimens are in Table 3.

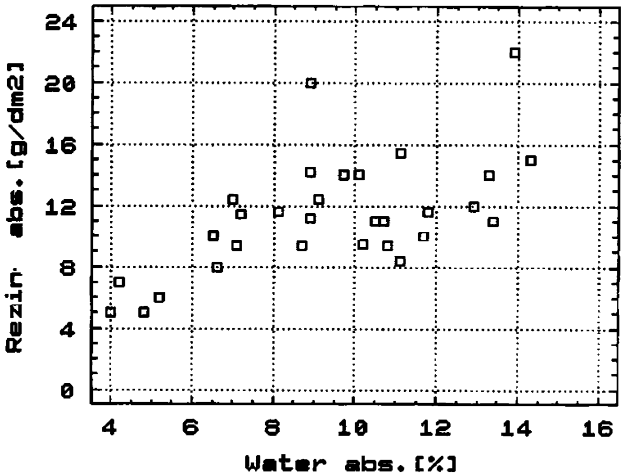

Fig. 2. Absorption of activated resin (20% concentration+Hardener No. 4) versus absorption of water (mass %) by mortar and concrete specimens (Table 3).

2.1.6. Water absorption

Cubes were dried out at +110 °C, and their weight was determined. Afterwards, they were placed into a vessel. The flow of water into the vessel was regulated so that the specimens were immersed up to 2 h. The specimens were stored 24 h in water, and their weight was determined after 1 h of storing in laboratory conditions. Water sorption (mass %) was calculated. Results were used for the preparation of the relationship in Fig. 2.

Table 3
Composition and basic properties of the samples tested

	Water (kg m^{-3})	Cement (kg m^{-3})	Gravel (mm)	Compressive Strength (MPa)	Böhme (cm^3 50 cm^{-2})	Böhme treated (cm^3 50 cm^{-2})	Consumption of resin (g dm^{-2})
1	336	285	0 to 1	5.9	70.0	29.0	12.0
2	228	400		18.7	33.0	13.3	14.0
3	312	400		13.5	43.0	23.0	11.6
4	167	540		27.9	24.3	13.3	15.4
5	371	530		18.3	32.6	13.1	12.0
6	425	500		13.9	51.5	24.2	11.0
7	252	720		32.3	16.6	12.0	14.0
8	427	700		23.9	28.0	20.0	14.0
9	476	700		21.1	34.6	19.0	15.0
10	152	200	0 to 3	5.9	60.0	12.1	32.0
11	228	300		14.2	45.2	17.2	11.2
12	342	300		7.3	71	27.0	8.4
13	204	400		22.7	30.2	13.9	11.6
14	320	400		16.3	41.0	24.8	9.4
15	200	500		30.4	18.0	12.0	14.2
16	310	500		20.5	28.3	19.8	11.0
17	375	500		18.1	38.8	20.4	10.0
18	178	200	0 to 8	8.9	40.3	13.5	20.0
19	187	300		19.1	23.2	18.9	9.4
20	273	300		11.9	32.8	21.0	9.4
21	204	400		30.8	18.4	16.2	12.4
22	300	400		20.8	31.1	18.6	12.4
23	220	500		39.5	17.5	14.6	11.4
24	305	500		17.0	33.0	16.7	9.5
25	345	500		14.8	35.1	15.5	11.0
26	140	200	0 to 16	10.3	24.0	16.5	10.0
27	150	300		30.0	16.8	16.3	8.0
28	160	400		38.2	16.5	16.0	7.0
29	170	500		49.0	16.4	15.9	6.0
30	200	760		55.0	16.9	15.8	5.0
Cement	330	1600	0	78.0	41.2	31.9	6.0

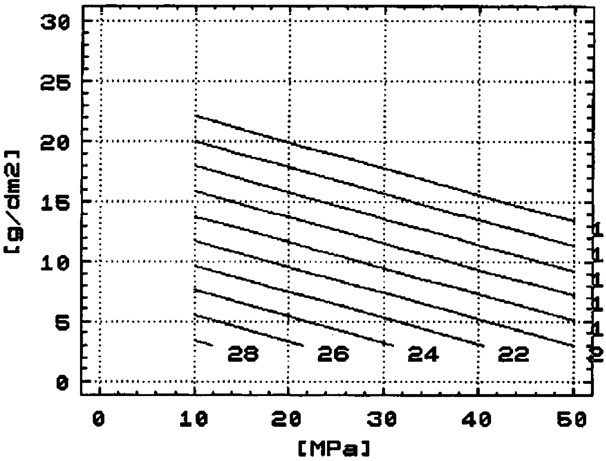

Fig. 3. Relationship between abrasion (cm^3/50 cm^2—numbers at lines), compressive strength and consumption of 20% solution of resin+Hardener No. 4 used for surface treatment.

2.1.7. Impregnation

The specimens were dried at +105 °C after 90 days of storing in laboratory conditions. The activated solution of resin (resin 20%+Hardener No. 4) was applied with the brush on their surface. The treatment was repeated in intervals of 30 min until the saturation of the surface was reached. The consumptions of activated resin sufficient for the saturation of the surface layers of the specimens are in Table 3. The specimens treated were stored 7 days in laboratory conditions and, afterwards, dried out at +70 °C. Results are in Fig. 3.

The kinetics of hardening of a resin in the pores of specimen may have an influence on its abrasion.

The cubes (Composition No. 6, see Table 3) were chosen for the experiments to obtain time dependence of abrasion valuable for a different hardener. The cubes were treated with the same amount of activated solution (11 g/dm^2). The samples were stored in laboratory conditions up to 28 days, and abrasion was determined after a different time of storing. Results are in Fig. 4.

2.1.8. Abrasion

Abrasion was tested using appliance type Böhme (producer: Tonindustry, Germany) in accordance with the standards DIN 52 108, ČSN 744506. The appliance simulates the sliding abrasion.

2.1.9. Regression analysis

Regression analysis was carried out using the computer program Statgraphics 2. The following limits were used for judgment of R^2 (coefficient of multiple determination) significance: R^2<30%—any or very bad correlation, 30%<R^2<60%—medium good correlation, R^2>60%—very good correlation between the tested variables exists.

3. Evaluation of results

The results in Fig. 1 show that viscosity exponentially decreases with a decrease of resin concentration. The increase of viscosity is minimal up to 20%.

The courses of relationships show that all hardeners (at prescribed mixing ratio with the solution of resin) cause an increase of viscosity. The optimal parameters of the final solution for impregnation can be chosen from the results in Figs. 1 and 4. The abrasion of specimens treated by solution with Hardener No. 5 is the lowest in all terms, as is evident from Fig. 4. But the viscosity of 20% solution with this hardener is the greatest, according Fig. 1. Results indicate that Hardener No. 4 seems to be optimal because its influence on viscosity of activated 20% resin is minimal. In addition, the abrasion of speci-

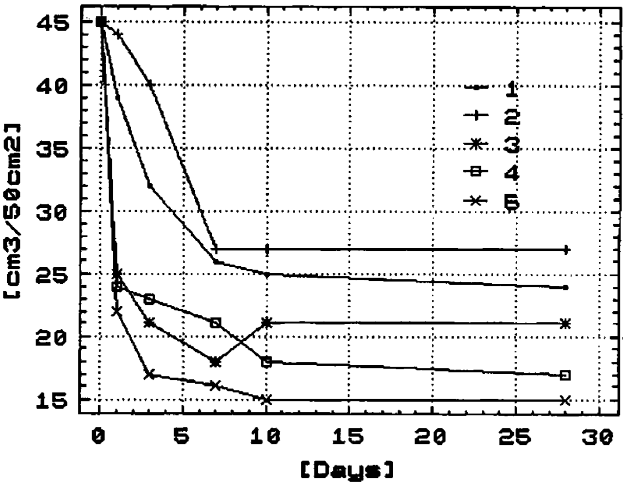

Fig. 4. Abrasion of the same specimens (Set No. 6, Table 3) treated by 20% solution of resin and Hardener Nos. 1 to 5 (11 g/dm^2) versus time of storing in laboratory conditions.

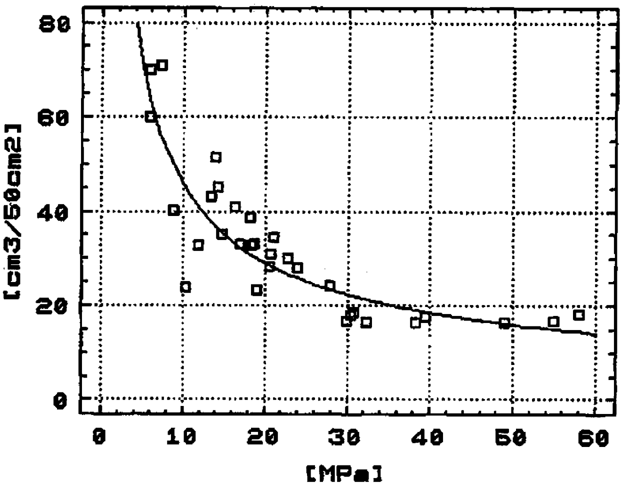

Fig. 5. Abrasion of untreated specimens versus their compressive strength (see Table 3).

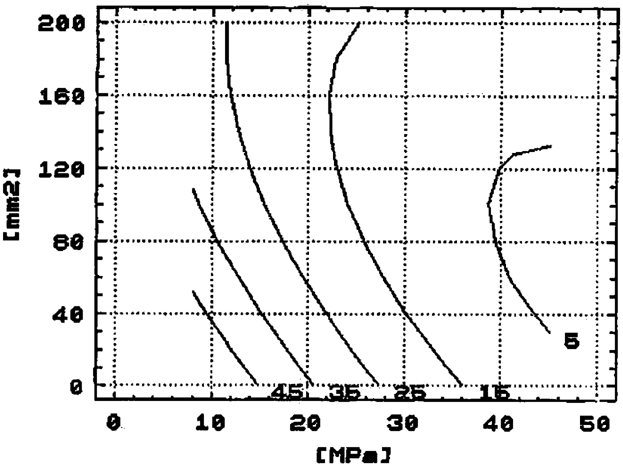

Fig. 6. Relationship between abrasion (cm^3/50 cm^2—numbers at lines), compressive strength of mortar and concrete specimens (see Table 3) and diameter area of the maximal grain of gravel used for specimens preparation.

mens is close to those impregnated using Hardener No. 5. The optimal parameters of the solutions for impregnation, in practice, can be determined by the above-described method.

Surface tension of resin is only slightly influenced by the hardeners and concentration changes, as is evident from Table 2. Therefore, the viscosity seems to be the most important parameter for the depth of penetration of activated solution.

The results in Fig. 2 indicate that a certain relationship between the absorption of water and that of activated resin exists. The results in Fig. 5 show that the abrasion of specimens extremely increases when compressive strength is under 10 MPa. Abrasion decreases rapidly in the range 8–20 MPa. A slight decrease can be observed in the range 20–30 MPa. A further increase of compressive strength up to about 50 MPa has minimal influence on abrasion. The compressive strength of specimens over 50 MPa is reached by increasing the dose of cement to a maximal value, 78 MPa, of the specimen without any aggregate. The abrasion of specimens has a tendency to increase with the proportional decrease of aggregate content to the upper limit 41.2 cm^3/50 cm^2 (only hydrated cement; see Table 3).

The dispersion of points in Fig. 5 and the obtained value R^2=78% indicate that other variables not included influence the abrasion of the specimens tested. Further analyses showed that correlation characteristic increases to R^2=89% when the diameter area of the maximal grain of aggregate used is included into the number of independent variables. The relationship obtained in contour presentation is in Fig. 6. The courses of lines indicate that the abrasion of specimens decreases with the increase of the maximal grain of aggregate and the compressive strength of specimens.

Impregnation contributes to the decrease of abrasion of the tested samples, as can be derived from Table 3. Regression analysis of the following variables was carried out to obtain more illustrative results: Y=abrasion of impregnated specimens, X_1=compressive strength of specimens, X_2=diameter area of maximal grain in specimens, X_3=absorbed amount of activated resin after surface treatment. The regression coefficients, t value and significance level of the variables showed that the influence of X_2 on Y changes is markedly lower than in the case of untreated specimens. The abrasion of impregnated specimens depends predominantly on the compressive strength and on the amount of absorbed activated resin after surface treatment, as is evident from Fig. 3.

4. Conclusions

1. The surface tension of the activated solution of resin is only slightly influenced by the hardeners and concentration changes of resin. But they have significant influence on the viscosity changes.
2. A relationship between the compressive strength of the untreated samples, the diameter area of the maximal grain of aggregate used and abrasion was found. The results of the regression analyses indicate that the compressive strength of specimens has a dominant influence on abrasion changes.
3. The influence of maximal grain diameter area on the abrasion of impregnated specimens is minimal. Their abrasion depends predominantly on the absorption of activated resin and also on the compressive strength.
4. The abrasion of specimens impregnated by the same amount of activated 20% solution of resin is influenced markedly by the time of hardening and the hardener used. Abrasion decreases up to 7 days of hardening in laboratory conditions. Later changes are minimal.

Acknowledgements

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