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# EFFECT OF REDISPERSIBLE RESINS ON THE MECHANICAL STRENGHT AND CAPILLARY RISING OF HARDENED CEMENT MORTARSWPŁYW ŻYWIC REDYSPERGOWALNYCH

## WPŁYW ŻYWIC REDYSPERGOWALNYCH NA WYTRZYMAŁOŚĆ MECHANICZNĄ I PODCIĄGANIE KAPILARNE STWARDNIAŁYCH ZAPRAW CEMENTOWYCH

Abstract

This paper shows the results of impact that polymer additives with different chemical composition have on physical and mechanical properties of solidified mortar. During the research, modern polymer redispersed admixtures were used. An analysis of the changes was carried out using statistical methods and linear regression. It was found that the analyzed polymer admixtures affect the analyzed parameters with varying degrees of intensity.

*Keywords: redispersible polymers, the strength of the cement-based mortars on compression, bending strength, capillary rising*

Streszczenie

W pracy przedstawiono wyniki badań wpływu domieszek polimerówych o zróżnicowanym składzie chemicznym na właściwości fizyczne i mechaniczne utwardzonych zapraw cementowych. W badaniach wykorzystano nowoczesne domieszki polimerów redyspergowalnych w postaci: kopolimeru octan winylu/wersenian winylu, kopolimeru octan winylu, wersenian winylu, etylen i akrylan butylu oraz kopolimer ester kwasu akrylowego/styren. Analizę zachodzących zmian przeprowadzono z wykorzystaniem metod statystycznych, posiłkując się regresją liniową. Stwierdzono, że analizowane domieszki polimerowe z różnym natężeniem oddziałują na analizowane parametry.

*Słowa kluczowe: polimery redyspergowalne, wytrzymałość zapraw cementowych na ściskanie, wytrzymałość zapraw na zginanie, podciąganie kapilarne*

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**Designation**

$Rc$  –  compressive strength [MPa]
$R_G$  –  tensile strength in bending $R_G$ [MPa]
$w/c$  –  water-to-cement ratio
$H$  –  capillary rising [mm]
$R$  –  correlation coefficients
$p$  –  computer level of significance
$F$  –  the value of statistics $F$ Fisher-Snedecor

# 1. Introduction

The addition of polymer resins creates new possibilities for modifying the properties of mortars. Factors affecting them positively include: increase flexibility, increase in hydrophobicity, and improving adhesion and mechanical strength. Resin binders bind during mortar hardening in which they are distributed by means of coalescence. As a result of the evaporation of water, "rolls" of polymer chains get close to each other, binding irreversibly. In the bound form, the polymer creates thin layers of high flexibility (so called "polymer film") which are covering the grain mixes. The tightness of such coating, the continuity of the "film" in the volume of hardened material, the viscosity, and the formed microstructure, all depend on the type and quantity of the polymer present in the mortar.

In construction mortars, the addition of polymer resins does not exceed 2% of all the constituents of the recipe. Higher amounts of polymer can adversely affect the workability of the mortar. The most commonly used polymer resins contain polyvinyl acetate vinyl or acrylic acid esters. Research of the influence of these polymers on the properties of hardened mortar have been well documented in the literature. It was found that, while the addition of these polymers improves the physical properties of the mortar (absorption, adhesion, flexibility, etc.), the mechanical properties – especially compressive strength – are lowered. New, innovative redispersible resins are usually copolymers containing within their main chain – in addition to the previously mentioned – other compounds and this way one can better influence the change of mechanical properties of hardened mortars.

This paper presents *the results of research of the dependence of mortar cement's compressive strength $R_C$* [MPa], tensile strength in bending $R_G$ [MPa], and capillary rising $H$ [mm] based on the share of polymers of diverse chemical structure, forming the modern technological solutions in the production of redispersed polymer resins. In the interpretation of the results, statistical methods based on linear regression model were used.

# 2. The experimental part

## 2.1. Materials used

The research was conducted on cuboidal samples made in laboratory-scale from the formulas containing: cement CEM I 42.5 R (140 kg/t), cellulose texture agent (1 kg/t), a super

white lime (50 kg/t) and silica sand with a particle size of 0.00–0.5 mm. Three series of samples were prepared, where during the individual tests conducted within each of the series, one of the tested resins was added in the amounts of $C_{PR}$ = 0.0, 5.0, 10.0, 15.0, 20.0 kg/t ($C_{PR}$ – polymer share). Three redispersible powders were chosen for the purpose of research: 1 – copolymer vinyl acetate/vinyl versatate; 2 – copolymer vinyl acetate, vinyl versatate, ethylene and butyl acrylate, 3 – acrylic acid ester-styrene. Each change in weight, resulting from varying amounts of the individual components, was replenished up to 100% with quartz sand. The study was conducted at constant ratio w/c ratio of 2.5.

## 2.2. Preparation of samples

First, dry ingredients weighed on a laboratory scales to the nearest 0.01 g had been mixed. A prepared dry mix was mixed with water in a standardized stirrer according to the standard: PN-EN 196-1: 2006 [7]. Then rectangular forms with dimensions of 40 mm × 40 mm × 160 mm were filled with the mortar, in two equal layers; each of the layers was compacted by 25 rammer impacts. Prepared samples had been seasoned for 7 days in a polyethylene bag, and later on, after stripping, for another 21 days in relative humidity conditions of 65% +/–5%.

The strength test was performed on the Tecnotest testing machine. First tensile strength test was carried out by applying the load with the steady increase in the force until the destruction of the sample caused by a break.

One half of each of the broken bars was allocated to the compressive strength test and the second one to the capillary rising test. The result of each of these tests was a value destroying the sample. The samples intended for capillary rising study were weighed and placed in the dryer in a temperature of 60°C until a constant mass was achieved.

Dry samples were coated with wax mass on the surface, perpendicular to the mirror of water, in which they were submerged during the test.

After 24 hours the samples were weighed, and then cut along the longer axis thus specifying the height of the capillary rising and the weight absorbability

One result was an average measurement of three tests.

## 2.3. The study of the mechanical properties

Table 1 presents the results of compressive strength research $R_C$ [MPa], and tensile strength in bending $R_G$ [MPa] of the hardened mortar samples, containing polymeric additives which are: 1 – copolymer of vinyl acetate/vinyl versatate, 2 – redispersible binder based on a copolymer of vinyl acetate, vinyl versatate, 3 – copolymer of acrylic acid ester/styrene. The amount of dopants in the individual samples were varied and were, respectively at a level of: $C_{PR}$ = 0, 5, 10, 15 and 20 kg/t. For each quantity of a particular polymer admixtures three samples were made.

The visual evaluation of the scatter plot (Fig. 1–2) shows that the relationship is linear and for all of the tested polymer additives, along with increasing participation of polymer additives, compressive strength and tensile strenght of hardened mortars is increased.

Correlation coefficients ($R$) in each case are high and are, respectively for $R_{C1}$: 0.9122 for $R_{C2}$: 0.87 and $R_{C3}$: 0.948, so in each case, there is a strong dependence of compressive strength on the quantity of polymer additives. Because $F$ is high and $p < 0.0000$ – linearity is important.

**The results of the summary statistics for compressive strength and bending strength**

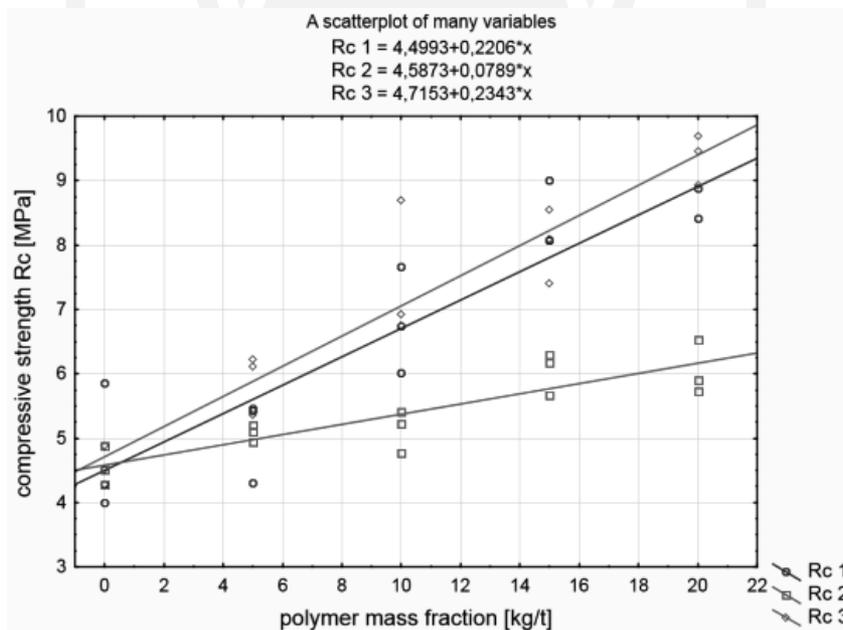| Statistics | Summary statistics, the dependent variable | | | | | |
|---|---|---|---|---|---|---|
| | $R_{C1}$ | $R_{C2}$ | $R_{C3}$ | $R_{G1}$ | $R_{G2}$ | $R_{G3}$ |
| $R$ | 0.9122 | 0.87 | 0.9482 | 0.99197 | 0.97144 | 0.98017 |
| $R^2$ | 0.8321 | 0.758 | 0.8992 | 0.98399 | 0.94370 | 0.96073 |
| $R2$ | 0.8192 | 0.739 | 0.8914 | 0.97866 | 0.92494 | 0.94765 |
| $F(1,3)$ | 64.46 | 40.78 | 115.98 | 184.471 | 50.289 | 73.413 |
| $p$ | < 0.0000 | < 0.0000 | < 0.0000 | < 0.0008 | < 0.0057 | < 0.0033 |
| Standard error of estimation | 0.75 | 0.34 | 0.59 | 1.15 | 2.16 | 1.80 |



Fig. 1. Scatterplot, along with a selection of linear regression function at compression strength and at tensile strength. Markings on the chart correspond to the 1 – copolymer of vinyl acetate, vinyl versatate, 2 – redispersible binder based on a copolymer of vinyl acetate, vinyl versatate, ethylene and butyl acrylate,
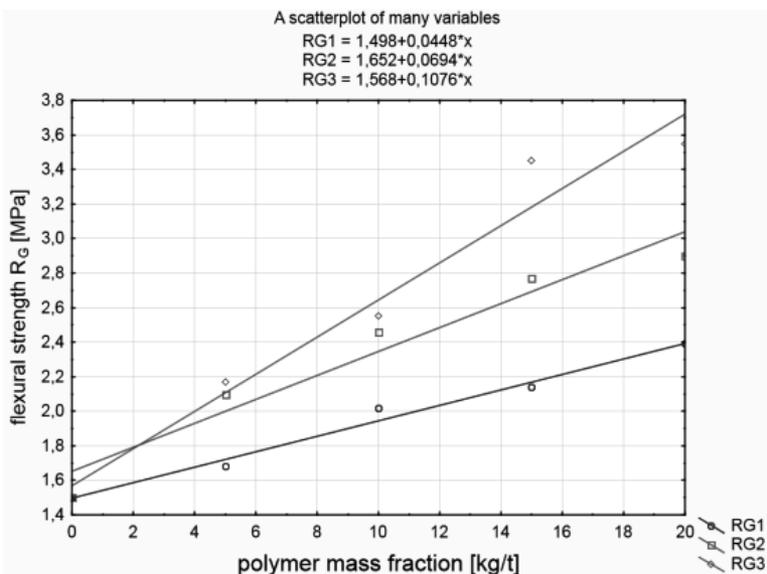3 – copolymer of ester acrylic acid – styrene

Fig. 2. Scatterplot, along with a selection of linear regression function at
compression at tensile strength. Markings on the chart correspond to the
1 – copolymer of vinyl acetate, vinyl versatate, 2 – redispersible binder based
on a copolymer of vinyl acetate, vinyl versatate, ethylene and butyl acrylate,
3 – copolymer of ester acrylic acid – styrene

The dependence of compressive strength on the quantity of the analyzed polymer additives
can be described with the following equations:

$$R_{C1} = 4.4993 + 0.2206 \cdot C_{PR1} \pm 0.75 \tag{1}$$

$$R_{C2} = 4.5873 + 0.0789 \cdot C_{PR2} \pm 0.34 \tag{2}$$

$$R_{C3} = 4.715 + 0.2343 \cdot C_{PR3} \pm 0.59 \tag{3}$$

where:

$R_C$ – compressive strength on the quantity of the analyzed polymer additives,
$C_{PR}$ – polymer share of the analyzed polymer additives.

This means that the largest increase in compressive strength is associated with an increase
in the participation of copolymer No. 1 (polymer increase by 1 kg, increases $R_{C1}$ by 0.22 MPa),
and copolymer No. 3 (increase of the polymer by 1 kg increases $R_{C3}$ 0.2343 MPa). In this
case, the addition of admixtures of these polymers to the mortar recipe in an amount of
20 kg/t has increased the compressive strength approx. by 5 MPa compared to the samples that
did not contain polymer admixtures. For copolymer No. 2, lower increases in compressive
strength – $R_{C2}$ were observed (polymer increase by 1 kg increases $R_{C2}$ by 0.0789 MPa). The
polymer additive in an amount of 20 kg/t caused a rise of $R_C$ approx. by 1 MPa.

The results of the measurement of tensile strength in bending of the samples were given a similar statistical analysis. The parameters $R$, $R^2$, $R2$, $F(1.3)$, p, have been assessed as in the previous case. Also, in this case, a strong dependence of bending strength on the quantity of polymer additives was observed.

The dependence of tensile strength in bending on the amount of polymer additives can be described with the following equations:

$$R_{G1} = 1.498 + 0.0448 \cdot C_{PR1} \pm 1.15 \tag{4}$$

$$R_{G2} = 1.652 + 0.0694 \cdot C_{PR2} \pm 2.16 \tag{5}$$

$$R_{G3} = 1.568 + 0.1076 \cdot C_{PR3} \pm 1.80 \tag{6}$$

where:

$R_G$  –  tensile strength in bending on the quantity of the analyzed polymer additives,
$C_{PR}$  –  polymer share of the analyzed polymer additives.

This means that the largest increase in tensile strength in bending is associated with an increase in the participation of copolymer No. 3 (increase by 1 kg increases $R_{G3}$ by 0.1076 MPa). In this case, the addition of polymer admixture to the mortar recipe in an amount of 20 kg/t has increased the compressive strength approx. by 3 MPa compared to the samples that did not contain polymer admixtures. Then in case of copolymer No. 2 (polymer increase by 1 kg increases $R_{G2}$ by 0.069 MPa), the addition of polymer admixture in an amount of 20 kg/t has increased $R_{G2}$ approx. by 1.5 MPa. For copolymer No. 1 lower increase in the $R_{G1}$ strength was observed (polymer increase by 1 kg increases $R_{G1}$ by 0.0448 MPa), the addition of polymer admixture in an amount of 20 kg/t has increased $R_{G1}$ approx. by 1.0 MPa

Table 2

**Results of summary statistics for the capillary rise test**

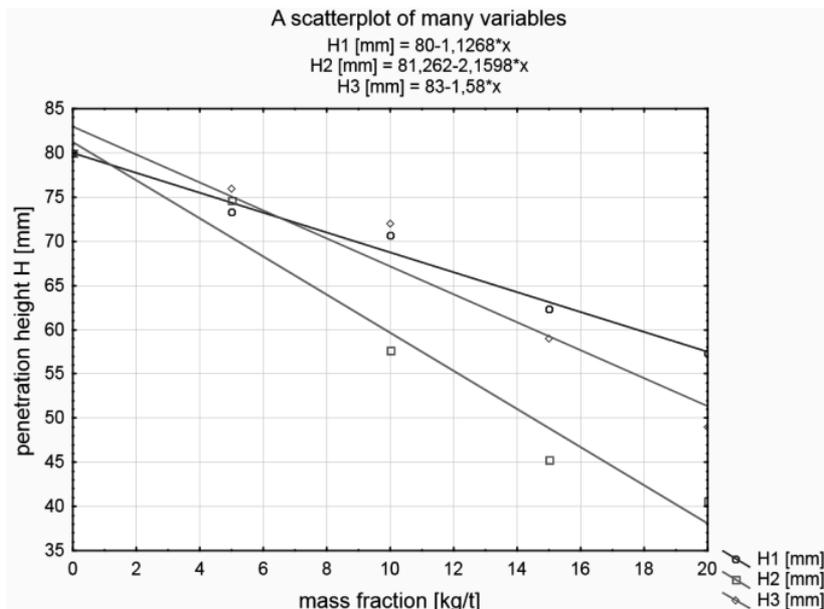| Statistics | Summary statistics, the dependent variable | | |
|:---:|:---:|:---:|:---:|
| | $H1$ | $H2$ | $H3$ |
| $R$ | 0.99154 | 0.98226 | 0.97036 |
| $R^2$ | 0.98315 | 0.96483 | 0.94161 |
| $R2$ | 0.97754 | 0.95311 | 0.92214 |
| $F(1, 3)$ | 175.146 | 82.317 | 48.379 |
| $P$ | $< 0.0009$ | $< 0.0028$ | $< 0.0060$ |
| Standard error of estimation | 1.18 | 1.71 | 2.20 |

Regression summary is presented in Fig. 3:

Fig. 3. Scatterplot, along with a selection of linear regression function. Markings on the chart correspond to the 1 – copolymer of vinyl acetate, vinyl versatate, 2 – redispersible binder based on a copolymer of vinyl acetate, vinyl versatate, ethylene and butyl acrylate, 3 – copolymer of ester acrylic acid – styrene

The relationship of capillary rising water on the amount of polymer additives in the recipe of mortar can be described by the following equations:

$$H1 = 80 - 1.1268 \cdot C_{PR1} \pm 1.18 \tag{7}$$

$$H2 = 81.262 - 2.1598 \cdot C_{PR2} \pm 1.71 \tag{8}$$

$$H3 = 83 - 1.58 \cdot C_{PR3} \pm 2.20 \tag{9}$$

where:

$H$ – capillary rising water [mm],

$C_{PR}$ – polymer share of the analyzed polymer additives.

The visual evaluation of the scatter plot (Fig. 3) shows that the relationship is linear, and for all studied polymer additives, together with the increase in participation of polymer additives, the height of capillary rise was getting smaller. The lowest values of capillary rising were determined for samples containing polymer No. 2 (redispersible binder based on a copolymer of vinyl acetate, vinyl versatate, ethylene and butyl acrylate). the addition of polymer admixture in an amount of 20 kg/t to all the components of dry mortar mix reduces the height of capillary rising by 40 mm.

## 3. Conclusions

The aim of this study was to investigate the effect of polymer additives on mechanical and physical properties of hardened mortars. These additives have a positive impact on studied properties in the mortar's recipes. It may be noted, however, that despite the great innovation that has been made in terms of redispersible resins production, there is none that would improve all mechanical and physical properties of mortars. Vinyl acetate/vinyl versatate copolymer shows reinforcing properties in terms of compressive strength, the additive: copolymer of vinyl acetate, vinyl versatate ethylene and butyl acrylate significantly increases the bending strength and capillary rising of the hardened mortars, copolymer of acrylic acid ester-styrene, significantly improves the mechanical properties of the mortar, while it affects the capillarity rise of the sample to a lesser extent. Despite the above mentioned issues it can be concluded that this is the best additive, considering its effect on mechanical and physical properties of the mortars.

## R e f e r e n c e s

[1] JennI A., Holzer L., ZurbrIggen R., Herwegh M., *Influence of polymers on microstructure and adhesive strength of cementitious tile adhesive mortars*, Cem Concr Res, 35, 2004, 35-50.

[2] Ohama Y., *Principlesof latex modification and some typical properties of latex modified mortars and concretes*, ACI Mater, J 1987, 511-518.

[3] Ru Wang, Pei-Ming Wang, Xin-Gui Li., *Physical and mechanical properties of styrene – butadiene rubber emulsion modified cement mortars*, Cement and Concrete Research 35, 2005, 900-906.

[4] Silva D.A., Roman H.R., Gleize P.J.P., *Evidences of chemical interaction between EVA and hydrating Portland cement*, Cement and Concrete Research 32, 2002, 1383-1390.

[5] Stanisz A., *Przystępny kurs statystyki z zastosowaniem Statistica na przykładach z medycyny*, StatSoft Polska Sp. z o.o., Kraków 2007.

[6] Fox J., *Applied Regression Analysis, Linear Models and Related Methods*, Sage Thousand Oaks, 1997.

[7] PN-EN 196-1: 2006: Methods of testing cement. Determination of strength.