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Influence of activation of microsphere and latex base addition on mechanical properties of concrete

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Abstract. In a modern civil engineering, it is important to erection construction in extremely complicated and difficult environmental conditions. Additives and admixes to concrete enable to achieved higher mechanical properties of concrete mixtures. This operation causes, the constructions accomplish durability in various environmental conditions. In the article, authors described scientific research made on concrete with additives: latex based polymer and microspheres. The tested additives were used in to different proportion each and they were combined with each other. The aim of research was to determine influence this two additives on compressive strength after 28 days, after 90 days, a tensile splitting strength, a sorptivity, a freeze-thaw resistance and a compressive strength on the specimens after freeze-thaw resistance test. Received results clearly show decrease in compressive strength of the modified concrete mixtures. The specimens prepared without additives achieved the highest compressive strength results.The researchers observed also increasing liquidity of concrete mixtures and decreasing sorptivity of hardener concrete under the influence of latex based polymer. The knowledge of basic properties of microspheres from co-combustion of coal is fundamental to its effect usage of building industry.

Keywords: concrete, compressive strength tests, fly ash microsphere, latex base polymer.

Introduction

Concrete is the basic material used in construction industry which must satisfy appropriate mechanical properties describe in PN-EN 206 + A1:2016-12 (Polski Komitet Normalizacyjny, 2003). Durability of concrete means maintaining mechanical properties in a definite time and in a specific environmental conditions. The introduction of new building technology and a growing demands of building materials with better and better technical properties enforce necessity of modifying the properties of concrete mixtures. The modification of properties of concrete mixtures is possible by using admixtures and additives. Effective usage of admixtures and additives is not an easy task. Many kinds of admixtures and additives are available on the market. The highest efficiency of admixtures and additives is only possible to achieve when the expected effect is comprehensively considered and analyzed at the stages: proportion of components, material characteristic of those components and on the conditions and method of conducting the technological processes during construction. The effect should be considered in both technical and ecological aspects. These aspects should be analyzed in relation to the designing, building and service life of constructions (Vičan, Śpiewak, Odrobinak, & Ulewicz, 2017; Tsapko, 2018).

Admixtures of concrete are components, which are added during making concrete mixtures in the amount not exceeding 5% in relation to the cement mass. Admixtures could modify properties of both, concrete mixtures and hardened concrete. Plasticizing admixture was used in research described in the article. The result of adding the admixtures is increasing the mixture liquid (Yaphary, Lam, & Lau, 2017; Dondelewski, 2008).

Additives of concrete are fine-grained, inorganic ingredients of concrete used to increase some properties or to obtain special properties of concrete. They are usually added to the concrete in amount above 5% in relation to the cement mass. Additives could significantly modify properties of both, concrete mixtures and hardened concrete. To prepare the specimens described in the article authors used microspheres and latex based polymer. Microspheres are fraction of emerging ashes as a result of burning of hard coal. Level of fineness is much smaller than ordinary fly ash (Yaphary et al., 2017; Dondelewski, 2008).

Striving for minimizing the negative impact of furnace wastes on the environment is the main in scientific consideration. Coal by-products produced in the energy sector are widely used in many areas, for example: construction industry, agricultural industry, mining industry. The coal by-products, mainly fly ash, are widely used in the building material industry (Kosior-Kazberuk, 2013; Hefni, Zaher, & Wahab, 2018; Jones, McCarthy, & Booth, 2006). According to research, the main chemical components of the microspheres in the oxide form is silicon, aluminium and iron, which comprise about 89% of their mass. They mineral ingredients are manly quartz and mullite (Chen, Ng, Li, & Kwan, 2017; Ebrahimi, Daiezadeh, Zakertabrizi, Zahmatkesh, & Korayem, 2018; Wajda & Kozioł, 2015).

Many studies have shown that ordinary fly ash tends to decrease early strength of concrete and increase significantly from 28 to 90 days. Many researchers reported, that compressive strengths of microspheres – modified concrete was very close to plain cement concrete and increased significantly from 28 to 90 days. It has been determined that concrete containing ultrafine fly ash can achieved higher long – term durability because of smaller size of fraction (Q. Wang, D. Wang, & Chen, 2017; Chindaprasirt, 2005; Haque & Kayali, 1998; Shaikh & Supit, 2005; Hefni et al., 2018). Researchers were made also investigation on cement concrete containing latex addition. Many research have shown that, in terms of compressive strengths of concrete containing latex base polymer showed better performance than ordinary concrete (Moodi, Kashi, Ramezanianpour, & Pourebrahimi, 2018; Ohama, 1987). In the science literature is not many research, in which this both components was combined. The aim of the research presented in this article is to determine the effect of adding microspheres and latex based polymer on the selected properties of concrete such as: compressive strength after 28 days since concreting, compressive strength after 90 days since concreting, freeze/thaw resistance test, compressive strength on the specimens after freeze/thaw resistance test, sorptivity and water absorption.

Materials

The test were carried on for concrete with Portland cement (CEM I 42.5 R), gravel fraction 2–16 mm, water from the municipal water supply network, 0–2 mm sand, latex based polymer, microspheres and HRWR.

To test the influence of microspheres and latex base polymer on mechanical and durability properties of concrete, nine different mix proportion of mentioned above components were prepared (in article mark as C1 to C9). The first series, marked as C1, is a reference for comparison of mechanical and durability properties of concrete. The series C1 was prepared without adding microspheres and latex based polymer. In the other eight series, one or both tested additives in different proportion were used. Concrete compositions are presented in Table 1.

Table 1. The amount of ingredients on 1 m^3 concrete

	Cement (kg)	Water (kg)	Sand 0–2 mm (kg)	Gravel 2–16 mm (kg)	Latex based polymer (kg)	Microspheres (kg)	HRWR (kg)
C1	300	150	356	1633	–	–	3
C2	300	136.5	352	1614	22.5	–	3
C3	300	123	348	1595	45	–	3
C4	300	150	337	1544	–	30	3
C5	300	150	318	1456	–	60	3
C6	300	136.5	333	1526	22.5	30	3
C7	300	123	314	1438	22.5	60	3
C8	300	123	329	1507	45	30	3
C9	300	150	310	1419	45	60	3

Preparation of specimens

The specimens were made and cured in line with PN-EN 12390-2 (*PN-EN 12390-2 Making and curing specimens for strength test, in Polish Stand.*, 2001). To prepare tested concrete, all components from Table 1 were weighed and mixed in a concrete mixer. Then, the concrete was put in the cube forms of a 10×10×10 cm. Specimens were thickened in two layers. The day after concreting, specimens were took out of cubes and put in water for 28 days. After 28 days, the article authors started a strength tests.

Methods

Consistency test

A consistency test was carried out as a flow table test according to PN-EN 12350-5 (*PN-EN 12350-5 Testing fresh concrete. Part 5: Flow table test, in Polish Stand.*, 2011). The vertical and horizontal diameters were measured after removing a conical mould. The result was given as an average value.

Compressive strenght test after 28 days, after 90 days and after freeze/thaw resistance test

A compressive strength test after 28 days, after 90 days and after freeze/thaw resistance were determined by using a testing machine ToniTechnik ToniPACT II. The rate of loading was maintained at 0.5 MPa/s. Five specimens from each series were used to take the test. The half of them was tested after 28 days since concreting and the other half after 90 days. The test was conducted on 10×10×10 cm concrete cubes and expressed by the formula (1):

$$F_c = \frac{10 \cdot F}{A_c}, \quad (1)$$

where: F_c – compressive strength of specimens [MPa]; F – maximum load [kN]; A_c – cross-sectional area of specimens [cm^2].

Tensile splitting strength test

A tensile splitting test was made in line with PN-EN 12390–6 (*PN-EN 12390-6 Testing hardened concrete - Part 6: Tensile splitting strength of test specimens, In Polish Stand.*, 2011). A tensile splitting strength test was determined using a testing machine ToniTechnik ToniPACT II. The rate of loading was maintained at 0,05 MPa/s. Five specimens from each series were used to take the test. The test was conducted on 10×10×10 cm concrete cubes and expressed by the formula (2):

$$F_c = \frac{2 \cdot F}{\pi \cdot L \cdot d}, \quad (2)$$

where: F_c – tensile splitting strength test [MPa]; F – maximum load [N]; L, d – the dimension of the cross – section [mm].

Sorptivity test and water abrorption test

A sorptivity test was conducted on halves of a cube specimens with an edge of 10 cm obtained from the tensile strength test. The specimens were placed in the distilled water at about 3 mm depth. The test consisted of weighing the samples after 15 minutes, 30 minutes and 1 hours since the immersing in the destilled water. The test lasted six hours. Sorptivity was defined as a slope of the linear function expressing the dependence of the mass of absorbed water on the time (3):

$$\frac{\Delta m}{A_s} = S \cdot t^{0.5}, \quad (3)$$

where: Δm – mass of absorbed water [g]; A_s – area of the water ingress [cm^2]; S – sorptivity [g/(cm^2·h$^{0.5}$)]; t – time [h].

A water absorption test was taken in line with PN-88/B-06250 (*PN-EN 88/B-06250 'Plain concrete', in Polish Stand.*, 1988) on halves of 10 cm-edged cubic specimens. The test was taken after 28 days of curing specimens in water. The water absorption were determined as (3):

$$N_w = \frac{(G_2 - G_1)}{G_1} \cdot 100\%, \quad (3)$$

where: N_w – water absorption [%]; G_1 – average mass of dry specimens [g]; G_2 – average mass of wet specimens [g].

Freeze/thaw resistance test

In each series, five similar specimens were used to make a freeze/thaw resistance test. The test consists of frosting specimens for 4 hours at the temperature – 18 °C then, defrosting at the temperature +18 °C for 2 hours. The research consists of 150 freeze/thaw cycles. The evaluation of freeze/thaw resistance was based on:

- Visual checking condition of the specimens (the advent of cracks, destructions).
- Total mass of concert defects had not exceed 5% of the mass of specimens before the test.
- The result of compressive strength taken on specimens after the freeze/thaw resistance test cannot differ from the compressive strength test taken on specimens after 28 days more than 20%. An average loss of compressive strength were determined as (4):

$$\Delta R = \frac{(R_1 - R_2)}{R_1} \cdot 100\%, \quad (4)$$

where: ΔR – loss of average compressive strength [MPa]; R_1 – average compressive strength after 28 days [MPa]; R_2 – average compressive strength of specimens subjected to freeze/thaw cycles [MPa].

Results and discussion

Results of consistency test

The results are presented in Table 2.

Table 2. The results of consistency test

	Vertical dimeter (mm)	Horizontal dimeter (mm)	On average (mm)	Concrete class
C1	380.0	435.0	407.5	F2
C2	485.0	465.0	475.0	F3
C3	540.0	520.0	530.0	F4
C4	375.0	510.0	443.0	F3
C5	350.0	360.0	355.0	F2
C6	470.0	420.0	445.0	F3
C7	400.0	410.0	405.0	F2
C8	565.0	550.0	557.5	F5
C9	460.0	460.0	460.0	F3

The consistency is a measure of the liquidity of concrete mixture. The highest liquidity was characteristic for specimens from series C8. Latex base polymer in amount 15% in relation to cement mass and microspheres in amount 10% in relation to cement mass were used to prepare specimens from series C8. The lowest results were achieved by specimens from series C5, which were prepared with microspheres in amount 20% in relation to cement mass. Concrete consistency class was determined in line with PN-EN 12350-5:2011 (*PN-EN 12350-5 Testing fresh concrete. Part 5: Flow table test, in Polish Stand.*, 2011).

Results of compressive strength test after 28 days, after 90 days and on specimens after freeze/thaw resistance test

Table 3 presents results of the compressive strength test after 28 days, after 90 days since concreting, and on specimens after the freeze/thaw resistance test. The results given in the table are the average value of five specimens from each series.

Table 3. The results of compressive strength tests

	Average compressive strength test after 28 days (MPa)	Average compressive strength test after 90 days (MPa)	Average compressive strength test on specimens after freeze/thaw resistance test (MPa)
C1	53.51	60.45	49.24
C2	47.42	51.51	41.75
C3	44.53	49.33	18.85
C4	52.93	57.82	24.49
C5	47.96	53.46	25.15
C6	43.72	50.23	37.36
C7	40.87	44.64	39.36
C8	40.56	44.27	32.22
C9	43.66	49.16	34.99

The highest average compressive strength after 28 days was achieved by specimens from series C1 – 53.51 MPa. The second highest result was achieved by series C4 – 52.93 MPa. Specimens C1 were prepared without additives. Specimens C4 were prepared with microspheres in amount 10% in relation to cement mass. The lowest average compressive strength test after 28 days was achieved by specimens from series C8 – 40.56 MPa and C7 – 40.87 MPa. Both microspheres and latex based polymer were used to prepare specimens from series C8 and C7. Microspheres in amount 10% in relation to cement mass were used along with latex base polymer in amount 15% in relation to cement mass in series C8. Microspheres in amount 20% in relation to cement mass and latex base polymer in amount 7.5% in relation to cement mass were added together in series C7.

The highest average compressive strength after 90 day since concreting was achieved also by specimens without admixtures – 60.45 MPa. The average compressive strength after 90 days was achieved by specimens C1, accordingly 4.35% and 11.56% higher than the average compressive strength for series C4 and C5. The lowest results were observed also for specimens from series C8.

The highest result of compressive strength test on specimens after the freeze/thaw resistance test was achieved for specimens from series C1. The second highest result was achieved by specimens from series C2. Specimens form series C3 were marked with the lowest average compressive strength. Latex based polymer in amount 15% in relation to cement mass was used to prepare specimens from series C3.

Scientific research have shown, that concrete containing finer fly ash or latex base polymer achieved better performance than ordinary concrete (Wang et al., 2017; Moodi et al., 2018). The research made by authors clearly shown that, connection this two additions get worse the compressive strengths of specimens in each age. Non – modified concrete achieved the highest results. Especially surprising is fall in compressive strength of concrete containing fly ash microspheres.

Result of tensile splitting strength test

Table 4 presents results of tensile splitting strength test. The results given in the table are average of five specimens from each series.

Table 4. Results of tensile splitting strength test

	Average tensile splitting strength test (MPa)
C1	3.79
C2	3.54
C3	3.30
C4	3.75
C5	3.51
C6	3.42
C7	3.42
C8	3.32
C9	3.47

The highest tensile splitting strength was characteristic for specimens form series C1 (3.79 MPa) which were prepared without additives. Similar result was achieved by specimens from series C4 – 3.75 MPa. The lowest result was achieved by specimens from series C3 – 3.30 MPa. Latex based polymer in amount 15% relation to cement mass was used to prepared specimens from series C3.

Results of sorptivity and water absorption test

Table 5 presents results of sorptivity and water absorption test.

Table 5. Results of sorptivity and water absorption test

Series	Sorptivity [$g/(cm^2 \cdot h^{0.5})$]	Water absorption		
		Average mass of dried specimens (g)	Average mass of soaked specimens (g)	Water absorption (%)
C1	0.0994	1075.65	1124.12	4.51
C2	0.0801	1090.77	1143.35	4.82
C3	0.0645	1084.80	1139.00	5.00
C4	0.0898	1118.45	1169.60	4.67
C5	0.0866	1088.45	1142.78	5.00
C6	0.0702	1088.38	1135.25	4.79
C7	0.0558	1046.83	1098.75	4.96
C8	0.0490	1059.87	1110.38	4.77
C9	0.0429	1072.53	1124.47	4.85

The highest sorptivity, which was 0.994 $g/(cm^2 \cdot h^{0.5})$ was obtained for specimens from series C1, which were prepared without additives. The lowest sorptivity, which was 0.0429 $g/(cm^2 \cdot h^{0.5})$, obtained for series C9. Both latex base polymer and microspheres was used to prepare specimens from series C9. Sorptivity of C9 was 57% lower than ordinary concrete – C1.

The highest water absorption were characteristic the specimens from series C3 – 5% and C5 – 5%. Latex base polymer in amount 15% of cement mass was used to prepare specimens from series C3. Microspheres in amount 30% of cement mass was used to prepare specimens from series C5. The lowest water absorption was achieved by specimens from series C1 – 4.51%.

Results of freeze/thaw resistance test

In the Table 6, relative decrease of compressive strength results after 150 freeze/thaw cycles were presented. The loss of compressive strength on specimens after the freeze/thaw resistance test should not be higher than 20% in relation to the compressive strength test after 28 days. The loss of compressive strength of specimens after the freeze/thaw resistance test was not higher than 20% for five series: C1, C2, C6, C7 and C9. Figure 1 presents specimens before and after freeze/thaw resistance test. The specimens did not show any defects.

Table 6. Results of freeze/thaw resistance test – relative decrease of compressive strength

	Average compressive strength test after 28 days (MPa)	Average compressive strength test on specimens after freeze/thaw resistance (MPa)	Decrease of compressive strength (related to the day 28) (%)
C1	53.51	49.24	7.98
C2	47.42	41.75	1.96
C3	44.53	18.85	5.73
C4	52.93	24.49	53.73
C5	47.96	25.15	47.56
C6	43.72	37.36	14.55
C7	40.87	39.36	3.69
C8	40.56	32.22	20.56
C9	43.66	34.99	19.86

Figure 1. Specimens before and after 150 freeze/thaw cycles

Conclusions

Authors of the article carry out scientific research because of necessity of modification concrete mixtures and hardened concrete. The aim of scientific research is to design quantitative composition of concrete mixtures to improve the mechanical properties of hardened concrete. In this article there are research of selected properties of concrete made by using additives: microspheres and latex based polymer. The authors performed compressive strength test after 28 days, 90 days since concreting and on specimens after freeze/thaw resistance test. Base on the obtained test results the following conclusions could be formulated:

- The tested additives used in proposed quantity on the weight of the cement decrease compressive strength of all of modified series of concrete. Latex base polymer has significantly decreased compressive strength test performed on specimens after freeze/thaw resistance test. The lowest medium result was achieved by the specimens was 18.85 MPa and it was 57.67% less than specimens without additives. The highest medium result was achieved by specimens without additives in all three compressive strength tests and it amounted to 53.51 MPa.
- The results of consistency test show, that additive of latex based polymer contributed to increasing liquidity of concrete mixtures. The highest liquidity was characteristic for specimens from series C8, which was prepared with latex based polymer in amount 15% in relation to cement mass.
- The results show that using latex based polymer reduce concrete sorptivity and porosity and make concrete more watertight. Specimens with additive of latex based polymer (series C8 and C9) were characteristic the lowest sorptivity. The sorptivity achived by series C8 and C9 was about 49% less than specimens from series C1.

The knowledge of basic properties of microspheres from co-combustion of coal is fundamental to its effect usage of building industry.

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