INFLUENCE OF POLYMERIC ADDITIVES ON THE PROPERTIES OF CONCRETE MANUFACTURED ON THE BASIS OF AGGREGATES PRODUCED FROM CRUSHED CONCRETE WASTE

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ABSTRACT

The research is devoted to the analysis of the influence of various polymeric additives on the properties of hardened concrete with aggregate made from concrete waste. The following materials were used during the research: coarse aggregate - crushed concrete waste, fine aggregate - natural sand with 0.1/0.5 mm fraction and crushed concrete waste with particles' size of 0.125–4 mm, composite Portland limestone cement, water and 4 polymeric additives. 9 compositions of concrete mixtures were produced: the reference mixture and 4 concrete mixtures prepared by adding 1 % and 2 % (of the cement mass) from each of the polymeric additives. During the calculation of concrete composition, the selected slumping class of the concrete mixture was S1, and compressive strength class of the hardened concrete – C25/30. The following parameters of concrete samples were determined during the research: density, compressive strength, bending strength, water absorption, structural properties. Forecasted performance frost resistance was calculated and frost resistance was determined, as well as the alkali corrosion of concrete samples was analysed.

Key words: concrete waste, recycled aggregate, vinyl acetate copolymer, frost resistance, alkali-reactivity

INTRODUCTION

Concrete is one of the oldest and widely employed materials, prepared from natural components, such as sand, breakstone, cement and water. Nearly all of these materials belong to the group of non-renewable natural resources. Therefore, in order to save natural resources, scientists look for the best methods to replace these resources with waste materials. Buildings' demolition waste can be utilized for the production of the concrete with low and average strength. Nowadays more and more old buildings are being rebuilt, repaired or demolished. Moreover, there are a lot of unfinished constructions throughout the world and frameworks of these constructions have to be demolished in the course of time. In many countries, demolition waste is transported to the landfills that occupy a lot of space. This type of waste does not decompose in landfills, does not emit gas, and is not used in the production cycle of energy resources. Therefore, scientists look for methods to decrease the amount of this waste and utilise it in the new products.

Nowadays, reinforced concrete constructions and concrete products are crushed at a building demolition site or in some special area, where the metal (used for reinforcement of reinforced concrete constructions) is separated and concrete is stored in separate stacks. In Lithuania, such concrete is used as a road pavement base, however it is not used for the manufacturing of any new products. Currently, in various areas of the country large amounts of crushed concrete are stored, and the demand for this concrete in road construction is lower than the amount of crushed concrete produced. The crushed concrete is stored at demolitions sites, some of which are located within the city boundaries (Figure 1). At some sites concrete is stored until the moment when higher growth of demand for this material is achieved. The storage period may even exceed one year.

Figure 1. Storage of crushed demolition waste in Vilnius city (where the building of the Lithuanian film production studio was earlier located)

Many researchers have analysed the influence of concrete waste on the properties of hardened cement concrete and came to the conclusion that the strength of such concrete decreases by approximately 30 % (Finoženok et al., 2011;

Richardson et al., 2010) while water absorption increases (Finoženok et al. 2010). During the previous analysis it was determined that in order to maintain concrete strength within the specified range, it is necessary to separate fine aggregate fractions, which size is smaller than 0.125 mm, from the crushed concrete and to add in addition 40 % fine sand with the particle size up to 1 mm (Finoženok et al, 2012).

Analysis developed by the scientists (Shehata et al., 2010) shows that reduction of the of the amount of fine aggregate, produced from concrete waste, should also result in the decrease of the expansion of concrete during vitriolic corrosion. The provided analysis shows that application of the finer fraction of the aggregate produced from concrete waste in concrete mixtures, results in larger expansions during the sample vitriolic corrosion.

There are practically no investigations of alkali corrosion of concretes made with the aggregate obtained from concrete waste. Therefore, this research is focused on investigation of the behavior of concrete produced by using concrete waste, in alkaline environment.

It is obvious that properly selected chemical additives can increase concrete strength, its frost resistance and improve rheological properties of concrete mixture. There are no special additives developed for the mixtures from crushed concrete waste. Each chemical additive in the cement system fulfils one or another task: modifies mixture viscosity, increases mixture diffusiveness and fluidity, prevents mixture lamination segregation, increases adhesion to the base material, etc. There are chemical element products that increase the adhesion of cement systems to the base material - polymeric additives in the base material: vinyl acetate copolymers. In accordance with the manufacturer's recommendations, these additives increase the adhesion of repaired concrete and reinforced concrete products to the repaired cement mixture, decrease humidity with saline CO2 penetration through the hardened layers, as well as increase frost resistance. Therefore, vinyl acetate copolymers have been chosen for concrete mixtures with filler made from crushed concrete waste. It was assumed the additives should increase the adhesion of concrete pieces with cement paste and, possibly, change rheological properties of concrete mixtures.

This research was carried out with the aim to investigate the possibility of improving the properties of hardened concrete by using the selected polymeric additives when the concrete is produced by using crushed concrete waste.

MATERIALS AND METHODS

Research materials

Cement, coarse aggregate - crushed concrete waste, fine aggregate - sand and crushed concrete waste, and polymeric additives were used for the tests.

Cement: composite Portland limestone cement CEM II/A-L 42.5 N, satisfying the requirements of standard LST EN 197-1 "Cement. Part 1. Composition, technical requirements and conformity criteria of regular cements". Other properties of this cement are described in the article (Finoženok et al., 2011).

Coarse aggregate: 4/16 mm crushed concrete waste. Crushed concrete waste is obtained from crushing the internal partitions of multistorey large-panel buildings built in 1977-1990s. Coarse fractions were used as the coarse aggregate, and fine fractions were refined and used for the production of fine aggregate. Concrete compressive strength before crushing - 25 MPa. Water absorption of coarse aggregate produced from concrete waste reached 10.5 % after 3 minutes of soaking in water, and – 13 % after 48 hours of soaking. These properties were considered during selection of the composition of concrete mixture.

Fine aggregate: 0.1/0.5 mm natural sand and crushed concrete waste with 0.125/4 mm fractions. The crushed concrete waste was obtained by sieving the remaining particles after the coarse fractions were sorted out. The finest particles smaller than 0.125 mm were not used, because, these considerably decrease concrete strength (Finoženok et al., 2011). 60 % of sand (of the weight of fine aggregate) was added. This amount was selected proceeding from the earlier conducted research, which proved that such amount of sand with 1 mm particles makes it possible to prepare concrete with the intended properties from crushed concrete waste.

The main characteristics of coarse and fine aggregates are presented in Table 1.

Table 1

Characteristics of coarse and fine aggregates

Aggregate	Title and value of the parameter		
	Bulk density, g/cm^3	Particles density, g/cm^3	Hollow ness, %
4/16 mm crushed concrete waste	1.09	2.04	47
0.125/4 mm crushed concrete waste	1.21	2.56	53
0.1/0.5 mm sand	1.4	2.38	41

The granulometric composition of coarse aggregate, produced from crushed concrete waste, is shown in Figure 2, and the granulometric composition of fine aggregate from concrete waste used in the research - in Figure 3

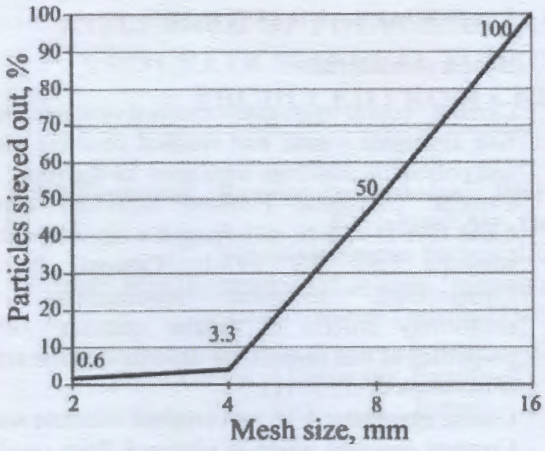

Figure 2. Granulometric composition curve of coarse aggregate from crushed concrete waste

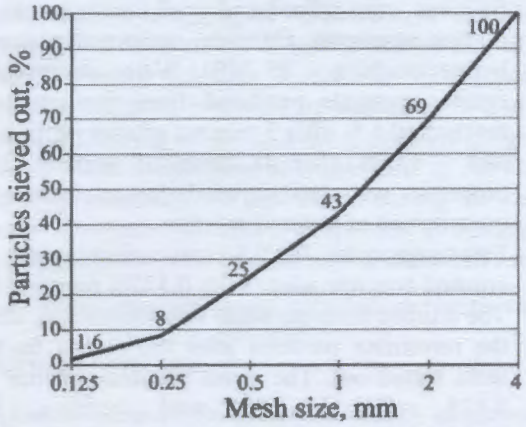

Figure 3. Granulometric composition curve of fine aggregate from crushed concrete waste

Additives: the following selection of polymeric additives were used: vinyl acetate copolymer (E), copolymer from vinyl acetate and ethylene with mineral additives and protective colloid (V5), copolymer from vinyl acetate and ethylene with higher vinylesters with mineral additives and protective colloid (V7), synthetic copolymer with a large molecular mass (R). All additives were in powder form, except for the last one, which was in a liquid state. The characteristics of the additives are presented in Table 2.

Table 2

Characteristics of polymeric additives

Marking of the additive	Title and value of the parameter		
	Bulk density, g/cm³	Density, g/cm³	pH
E	0.35–0.55	–	4–6
V5	0.38–0.48	–	7
V7	0.40–0.55	–	8
R	–	1.0	5–8

Liquid additive is used to modify the viscosity of concrete mixtures according to the manufacturer's recommendations. The mixture becomes less sensitive to water amount variations, and the recommended amount is 0.1–1.5 % with relation to the amount of fine particles (<0.125 mm) in the mixture.

Composition of the mixtures analysed

9 compositions of concrete mixtures were prepared: reference mixture K (containing no additives), and concrete mixtures prepared by adding 1 % and 2 % (by weight of cement mass) of one of the above listed additives. In mixture E (E1 and E2), 1 % and 2 % (by weight of cement mass) vinyl acetate copolymer was used; V5 (V51 and V52) – copolymer from vinyl acetate and ethylene with mineral additives and protective colloid; V7 (V71 and V72) – copolymer from vinyl acetate and ethylene with higher vinylesters with mineral additives and protective colloid; R (R1 and R2) – synthetic copolymer with a large molecular mass. For calculation of concrete composition, the selected slumping class of the concrete mixture was S1 according to LST EN 206-1 „Concrete - Part 1: Specification, performance, production and conformity", and the compressive strength class of the hardened concrete – C25/30. The concrete composition was selected depending on the characteristics of raw materials, by implementing computational - experimental methodology and by using tables, diagrams and nomograms. The composition of concrete mixture is presented in Table 3.

Initially, the dry concrete components, such as cement, fine aggregates and coarse aggregate as well as powder additives, were mixed in dry conditions. After the mixing of dry components, water was poured and the concrete mixture was remixed until an even consistency was obtained. After mixing, the concrete mixture was left for 5 minutes, and remixed afterwards. This procedure was completed in compliance with the recommendations of the manufacturers of polymeric additives. The liquid polymeric additive initially was mixed in water, and later water was added to the dry components.

After the preparation of the mixture the slumping factor of the concrete mixture was verified according to LST EN 12350-2 "Testing of fresh concrete. Part 2. Slump test". Concrete was classified as belonging to slumping class S1. Although the used additives change the amount of water required for preparation of the cement paste of normal consistency, these additives did not change the concrete mixture consistency in concrete mixtures. Most likely, high water absorption of the aggregates used has the greatest influence during the initial stage.

The prepared concrete mixture of the required consistency was poured into the moulds. Samples were vibrated on a laboratory vibrating platform for approximately 1 min. Samples were cured in accordance with LST EN 12390-2 "Testing of hardened concrete. Part 2. Making and curing specimens for strength tests".

Table 3

Compositions of concrete mixtures

Concrete marking	Cement, kg/m³	Coarse aggregate, kg/m³	Fine aggregate, kg/m³		Additive, kg/m³	Water, l/m³	W/C
		Crushed concrete waste, 4/16mm	Fine sand, 0.1/0.5 mm	Crushed concrete waste, 0.125/4mm			
K	450	560	631	421	–	328	0.73
E1, V51, V71, R1	450	560	631	421	4.5	328	0.73
E2, V52, V72, R2	450	560	631	421	9	328	0.73

After 7 and 28 days of hardening, mechanical properties were determined. Other concrete samples after 28 days of hardening were dried out in a laboratory dryer, after that the physical as well as mechanical properties of the samples were determined.

Research methodology

The following parameters of concrete samples were determined during the research: density, compressive strength, bending strength, water absorption, structural properties. Predicted performance frost resistance was calculated and frost resistance as well as resistance against vitriolic corrosion were determined.

Density of the concrete samples was determined according to LST EN 12390-7 "Testing of hardened concrete. Part 7. Density of hardened concrete". Absorption of the concrete samples was established by soaking for 24, 48 and 72 hours in 20±1°C temperature water.

Bending strength of concrete samples was estimated after 7 and 28 days of hardening by testing the produced 40x40x160 mm prism-shaped samples. Compressive strength of the concrete was determined in accordance with LST EN 12390-3 "Testing of hardened concrete. Part 3. Compressive strength of test specimens" after 7 and 28 days of hardening. Samples were compressed by using the press "AUTOMAX 3000" in compliance with the requirements of LST EN 12390-4 "Testing of hardened concrete. Part 4".

The structural properties of concrete samples, such as effective porosity of concrete body, total open porosity, reserve of porous volume, qualified thickness of the wall of capillaries, the capillary rate of mass flow in a vacuum in the direction of freezing, the capillary rate of mass flow in a vacuum in a perpendicular direction of freezing, degree of structural inhomogeneity, capillary rate of mass flow, set under normal conditions, were determined in accordance with the special methodology described in literature (Kičaitė et al., 2010; Mačiulaitis et al., 2007). These parameters were considered when the predicted performance frost resistance was calculated by the equations proposed in (Mačiulaitis et al., 2010).

Frost resistance of the samples was estimated in accordance with LST CEN/TS 12390-9:2006/P:2007 "Testing of hardened concrete - Part 9: Freeze-thaw resistance. Scaling". Testing was carried out in accordance with alternative CF/CDF test method considered in (Cepuritis et al., 2012) where the authors studied the testing methodology and temperature variation curves.

Alkali-reactivity of the hardened formation masses was determined according to RILEM TC 219-ACS (Alkali-Aggregate Reactions in Concrete Structures) as AAR-2. 40x40x160 mm prism-shaped samples were prepared from the concrete mixture and hardened for 28 days according to LST EN 12390-2. After 28 days of hardening each element was measured and the main reference point for the prism length estimation was inserted. Prism-shaped samples were stored in 80 °C±2 °C temperature water for 24 hours. Afterwards, their initial (zero) reference length was measured. After the measurements the prism-shaped samples were soaked into 1M NaOH solution with 80 °C±2 °C temperature. In these conditions the prism-shaped samples were stored for 14 days. Length of the specimens was measured periodically.

RESULTS AND DISCUSSION

Resulting density values of the samples are provided in Figure 4. Density of all the batches of concrete mixtures is similar, results vary from 1.89 g/cm³ to 1.95 g/cm³.

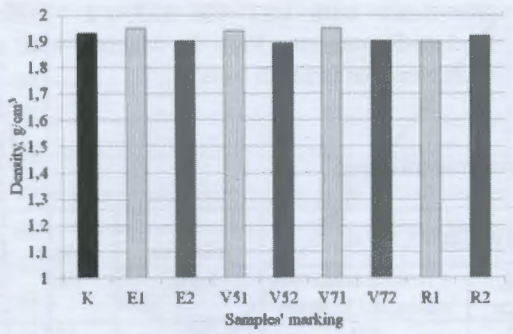

Figure 4. Density results of the samples

Compressive and bending strength of the concrete samples were determined after 7 and 28 days of hardening. The obtained results of compressive strength are shown in Figure 5, and the resulting values for bending strength - in Figure 6. It can be seen that that highest results for compressive and bending strength are reached in the reference samples. When the analysed chemical additives are added to the concrete mixtures, compressive and bending strengths do not reach these values.

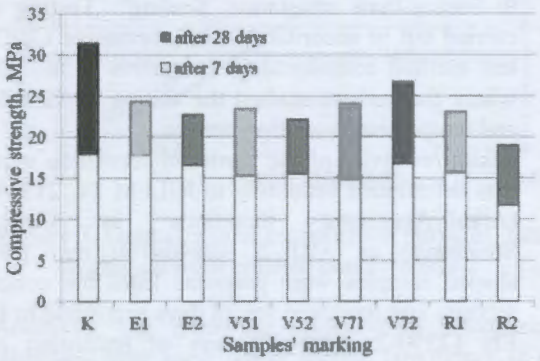

Figure 5. Results of estimation of sample compressive strength

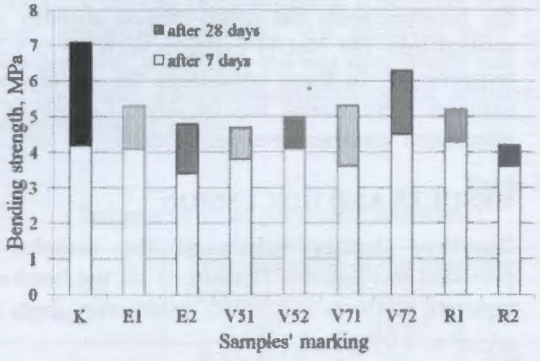

Figure 6. Results of estimation of sample bending strength

Results of the research show that after 7 days concrete with polymeric additives reached similar strength values as the reference concrete. However, after 7 days of hardening, the strength growth rate in the samples with the additives decelerated, which produced a large effect on the final results of compressive and bending strengths. No samples with the additives had as large an increase of the strength value after 8-28 days of hardening as it was observed in the reference samples. It can be assumed that polymeric additives slow down the strength increase processes at a later stage.

Water absorption was determined after 24, 48 and 72 hours of soaking in water. The results for water absorption are shown in Figure 7. It can be noticed that when 1 % (by weight of the cement) of additives of vinyl acetate copolymer is added to the formation mass, the absorption rate in the samples (E1, V51, V71) decreases. By adding 2 % (by weight of the cement) of these additives, absorption of the samples (E2, V52) becomes higher than that of the reference samples (K). After three days of soaking in water absorption of all samples, except for V72 samples, changed insignificantly. A larger amount of V72 additive determines the period of water absorption in the samples. It is possible that, if the samples are soaked further, absorption of these samples would increase, and absorption of other samples would remain unchanged because they reach the absorption saturation limit in normal conditions. It is worth noting that values for the absorption of R1 and R2 samples after 72 hours of soaking, are very similar to that of the reference sample. Therefore, synthetic copolymer with a large molecular mass added to the formation mass does not change absorption of the samples.

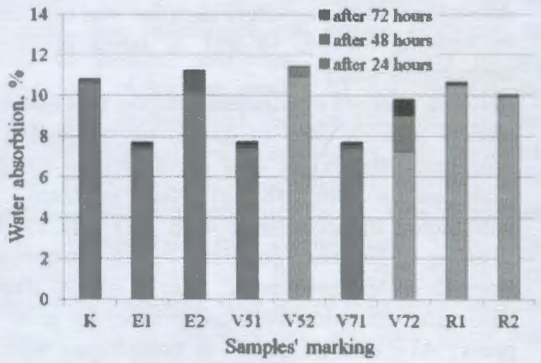

Figure 7. Results of estimation of sample absorption

The determined structural characteristics of the samples are shown in Table 4. Predicted performance frost resistance of the samples was calculated according to the structural characteristics presented in the table. According to the performed calculations E2 samples would have the highest frost resistance, R1, V72 and K samples - the lowest.

Table 4

Structural characteristics of the samples

Sample marking	W_e	W_r	R	D	N	g_1	G_1	G_2	*FRE*
K	20.8	22.0	6.50	4.30	3.55	0.25	0.35	0.82	13
E1	16.0	16.8	4.60	4.96	1.40	0.18	0.55	0.51	24
E2	21.2	23.2	8.35	3.32	3.40	0.40	0.44	1.08	32
V51	15.5	16.1	4.20	5.20	1.40	0.14	0.51	0.54	25
V52	22.0	24.3	9.45	3.11	6.50	0.38	0.42	0.96	19
V71	14.7	15.3	3.80	5.53	1.00	0.14	0.49	0.48	21
V72	18.1	19.8	8.90	4.04	2.70	0.18	0.34	0.81	14
R1	20.5	22.7	9.90	3.40	0.18	0.23	0.15	0.13	12
R2	19.4	21.5	10.0	3.65	0.18	0.27	0.18	0.27	20

Notes: W_e – effective porosity of concrete body, %; W_r – total open porosity, %; R – the reserve of porous volume, %; D – the qualified thickness of the wall of capillaries, units; G_1 – the capillary rate of mass flow in a vacuum in the direction of freezing, g/cm²; G_2 – the capillary rate of mass flow in a vacuum in a perpendicular direction of freezing, g/cm²; N – degree of structural inhomogeneity, units; g_1 – the capillary rate of mass flow, set under normal conditions, g/cm²•0,5h; *FRE* – forecasted exploitational frost resistance of the samples, in cycles.

Estimated results of frost resistance of the concrete are presented in Figure 8. In this figure the extent of mass losses during the testing of samples in accordance with the freeze-thaw cycle methodology can be seen. According to the alternative CF/CDF test method of testing methodology LST CEN/TS 12390-9:2006/P: 2007, the largest mass loss in one sample can reach 15 g. The results presented in Figure 8 show that mass loss did not exceed the acceptable limits in any of the samples. During the inspection of the samples after 28 testing cycles, the decision was made to continue tests because only small cracks were noticed in some samples. After 56 testing cycles full fragmentation of one sample (E1) was observed. Cracks developed in the following samples: in the two samples - E1 and V51, as well as in one sample V52. Other samples examined after 56 testing cycles had small cracks. The V71 and R1 samples showed the best results - the lowest mass loss and the smallest cracks.

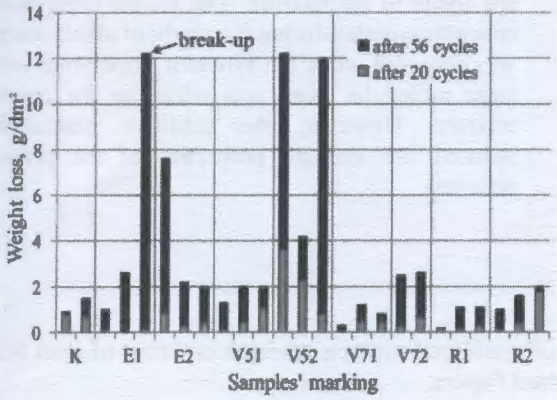

Figure 8. Results of the estimation of samples' frost resistance

Cracks and fractures after 56 testing cycles are clearly seen in Figure 9.

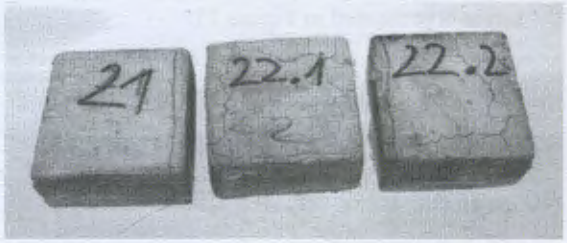

Figure 9. View of the samples V51 after 56 testing cycles

Given the results obtained during the frost resistance testing, V71 and R1 samples can be singled out as the most resistant to freeze-thaw cycles in aggressive conditions. In addition, R2 samples, as well as the reference samples K, can be marked as formation masses, which could be employed in the conditions of moderate aggressiveness.

Upon comparing the results in Table 4, showing predicted performance frost resistance of the samples and the results in Figure 8, it can be concluded that the forecast methodology cannot be used to clearly predict frost resistance results when samples are tested in accordance with the described experimental method. The authors (Nagrockienė et al., 2004) suppose that this prediction methodology is most suitable for the evaluation of frost resistance when samples are tested by applying the one side freeze-thaw method. However, as we can see from the results, this methodology cannot be used to predict frost resistance when CF/CDF testing methodology is applied.

Moreover, during the alkali corrosion the expansion of the samples prepared from the analysed mixtures

was determined. Expansion values of the samples after 28 days of investigation in an aggressive alkaline environment are shown in Figure 10. As seen in this figure, during testing V52, V71, V72, R2 samples did not reach the expansion limit. Expansion of R2 samples was minimal and reached only 0.02 %.

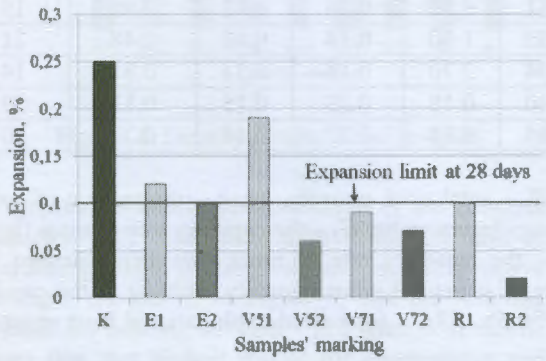

Figure 10. Expansion of the samples after 28 days

Expansion of the reference samples (K) and V7 series is presented in Figure 11.

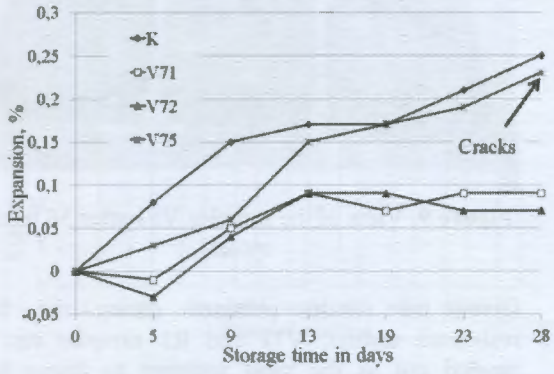

Figure 11. Results of the estimation of sample expansion

It can be observed that upon adding the copolymer additive from vinyl acetate and ethylene with higher vinylesters and mineral additives to the concrete mixture, sample expansion in aggressive alkaline environment does not exceed the defined limits. For comparison, the samples with 5 % (in relation to the cement mass) of this polymeric additive (V75) were prepared. It can be observed from the V75 curve in Figure 11 that the larger amount of the additive influences the behaviour of the concrete in the aggressive environment, and expansion of the samples is similar to the one of the reference samples. Moreover, after 28 days of testing in the alkaline environment, not only expansion was observed in the above mentioned sample (V75), but also cracks appeared.

CONCLUSIONS

1. To conclude, it can be stated that the studied polymeric additives reduce the compressive and bending strength. However, sample density remains similar to the reference samples (prepared without additives).
2. The effect produced by additives on the water absorption parameter was also examined. . The extent of influence depends on the amount of polymeric additive. By adding 1% (by cement mass) polymeric additives water absorption decreases to 25%. By adding 2% (by cement mass) polymeric additives water absorption increases and exceeds the absorption value of the reference mixture for vinyl acetate copolymer (E) and copolymer from vinyl acetate and ethylene with mineral additives and protective colloid (V5) by ~6%, at the same time, causing a decrease of water absorption by 5% as a result of using synthetic copolymer with large molecular mass (R).
3. CF/CDF testing methodology was employed to determine the frost resistance of concrete samples. The best results were observed in the samples, which had the following chemical additives (1 % of each): V7 – copolymer from vinyl acetate and ethylene with higher vinylesters with mineral additives and protective colloid R – synthetic copolymer with large molecular mass.
4. The examined polymeric additives influence the processes occurring in concrete samples during the alkali corrosion. Concrete expansion during alkali corrosion can be reduced when additives in question are added to the mixture. The lowest expansion of concrete samples during the study of alkali-reaction was achieved when the synthetic copolymer with a large molecular mass was added to the concrete mixture. However, this additive considerably reduced the strength properties of the prepared concrete.

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