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The Influence of Superabsorbent Polymer on the Performance of Concrete

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ABSTRACT

Article describes experimental studies of the effect of superabsorbent polymer (SAP) on the strength of concrete. The aim of the study was to substantiate the effectiveness of usage of this type of SAP additive in concrete structures. The optimal dosage of SAP was revealed. The results showed that concrete strength remains same if a dosage of the SAP additive is equal to 0.5% of the cement mass.

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Introduction

Superabsorbent polymers (SAP) can absorb big amount of liquid, retain it for a long time and gradually release it back. This ability of SAPs can be used to increase concrete strength through the effect of internal curing. SAP particles will gradually release absorbed water back into the concrete and this will provide more complete hydration of the cement during the concrete hardening. Internal curing of concrete can reduce the risk of concrete cracking in the early time of hardening. This effect can be useful in modern construction, where high-strength concretes with low water/cement ratio are used. On the other hand, the addition of SAP increases the porosity of the hardened concrete and reduces its density that can negatively effect on the strength of the concrete. SAP can absorb a volume of liquid that can be 400 times greater than the mass of a SAP particle. As the result, every polymer particle greatly increases in volume that leads to a negative effect for concrete. Voids appear in places where SAP particles were located. These voids, that can be identified as macrospores which reduce the strength of concrete. Studies of Sung-Hoon Kang show that the volume of voids is depend on the absorption capacity of the used SAP [11]. Even if the dosage of SAP to concrete is small, the volume of voids formed in the hardened concrete may be large just because of the high absorption capacity of used SAP. The effect of addition SAP on the strength of hardened concrete depends both on the type of SAP additive used in mortar creation and on the characteristics of the concrete mixture. SAP particle size, production method and dosage also effects on mortar and hardened concrete characteristics. The most recent studies of SAP application in concrete were made by Babatunde J. Olawuyi, Adewumi J. Babafemi, William P. Boshoff [8]. They made experiments that had shown how different dosages of SAP to the cement mortar, its W/C ratio and the hardening time of the concrete effect on the strength of hardened concrete. Results showed that while the SAP dosage increases, the strength of the hardened concrete relatively decreases. The determining factor that effect on the strength of the concrete is the correct water/cement ratio of the mixture.

The addition of SAP also effects on the rate of concrete strength development. Li, L., Dabarera, A. G. P., & Dao, V. studied the properties of hardening concrete with the addition of SAP [9]. Results of their experiments showed that the strength of concrete samples with SAP on the 7th day of hardening is significantly lower than strength of concrete samples without SAP if W/C ratio remains constant. Samples with SAP and without SAP equal in compressive strength on the 14th day of hardening. On the 28th day of hardening, concrete with 0.33% dosage of SAP has up to 5% higher compressive strength. Tan, Y., Lu, X., He, R., Chen, H., & Wang, Z. also showed that SAP addition do not cause notable decrease in strength at 28 days of hardening [10].

Studies of Popova D., Lesovik V., Mechtcherine V. [1,2] shown that compressive strength of concrete increases up to 7% at 0.3% SAP dosage counted by mass of cement. Comparable results were obtained by Gemma Rodríguez de Sensale [12], Yawen Tan [13]. Jianhui Liu [14] obtained a slight increase in compressive strength only with the addition of 0.3% SAP together with an anti-shrink additive.

At the same time other researches show that dosages of SAP equal to 0.3% do not increase compressive strength. For example, Eugenia Silva made an experiment with three types of SAP and they all caused a 5-15% decrease in concrete compressive strength [15]. Comparable results were obtained by Laurence De Meyst, decrease in concrete compressive strength at 0.3% dosage of SAP was 10-12% after 7 and 28 days of hardening [16].

It can be summarized that the optimal dosage of SAP additive is different for each type of SAP. Experimental results are often not comparable due to differences in the type of SAP, concrete mortar composition and its W/C ratio. Addition of SAP will increase the water demand of the mixture that will negatively effect on the strength of the hardened concrete.

The use of SAP can be good for improving the quality of building materials. To substantiate the effectiveness of the use of the tested type of SAP, it is necessary to do experimental studies. First of all, it is important to determine the effect of the addition of SAP on the concrete strength. This result will help to determine further prospects for the application of the studied type of SAP in concrete structures. This article shows experimental studies of the effect of the addition of SAP on the compressive strength of hardened concrete and a review of the proposed experimental methods for determining the crack healing and autogenous shrinkage reduction ability of concrete with the addition of SAP.

Materials and Methods

Selected SAP additive was not studied before, that is why the research was started with the experiments with various dosages of SAP and W/C ratios of concrete mortar. These experiments will show the effectiveness of using this type of SAP as an additive to concrete.

Superabsorbent polymer (SAP) produced by Korean company «GV Holdings Co» was selected. Absorption capacity of SAP is 400 g of water per 1 g of SAP; average particle size is 300 µm. These parameters influence on porosity of hardened concrete.

Two series of concrete specimens were examined. In the first type of composition, fine-grained river sand of a fraction of 0-2.5 mm was used. For the second composition, the same sand and dolomite-crushed stone of 5-10 mm fraction were used.

Portlandcement CEMI 42, 5 R produced by «Gornozavodskcement» was used as a binder. Superabsorbent polymer (SAP) was added into the dry sand and dry cement mixture and mixed manually before adding water.

Specimens were formed in accordance with the current regulatory documents. The first series of specimens was formed as beams of the size of 4*4*16 cm, the second series of specimens was formed as cubes with an edge size of 10 cm. Heavy concrete specimens were formed with the constant W/B ratio of 0.55. Slump flow was determined after mixing each composition. The compositions of the experimental samples are shown on Table 1.

Table 1: Experimental mixtures for heavy concrete specimens

Mixture №	SAP, % of cement mass	W/C ratio	Materials for 1m3 of mixture, kg				
			Cement	Sand	Crushed aggregate	Water	SAP
1	0	0,55	365	850	1200	200	0
2	0,5	0,55	365	850	1200	200	1,825

Two series of specimens with both 4 different compositions were made for specimen with fine-grained concrete. The first 4 mixes were made according to the normal consistency of the concrete mixture and paste cone flow of each mixture was 106-115 mm. For the other 4 compositions, the W/B ratio of 0.5 was set constant for all mixes. This value of W/B was selected to get mixture cone flow equal to 106-115 mm when SAP dosage is equal to 1%. Paste cone flow was determined after mixing each composition. The compositions of the experimental samples for fine-grained concrete specimens are shown on Table 2.

Table 2: Experimental mixtures for fine grained concrete specimens

Mixture №	SAP, % of cement mass	W/C ratio	Materials for 1m3 of mixture, kg			
			Cement	Sand	Water	SAP
1-1	0	0,42	650	1950	273	0
1-2	0,25	0,44	650	1950	286	1,625
1-3	0,5	0,46	650	1950	299	3,25
1-4	1	0,5	650	1950	325	6,5
2-1	0	0,5	650	1950	273	0
2-2	0,25	0,5	650	1950	286	1,625
2-3	0,5	0,5	650	1950	299	3,25
2-4	1	0,5	650	1950	325	6,5

Concrete specimens were stored under normal temperature and humidity conditions for 28 days before compression tests. Each of specimen series was tested on the 28th day of hardening.

Results

Increasing of the SAP dosage increases the water demand of the mix. The dependence of the W/C ratio on the dosage of SAP for normal consistency of concrete was determined while molding experimental samples №1-4 from fine-grained concrete. When the SAP dosages range from 0 to 1% the obtained dependence of the W/C ratio on the dosage of SAP turned out to be linear. This dependence is shown on Figure 1 and it is applicable only for the raw materials used in this experiment and only if studied SAP dosage range from 0 to 1% of cement mass.

Figure 1: W/C ratio for cone flow 106-115 mm depending on the dosage of SAP

Increasing of the SAP dosage caused a decrease of the cone flow at a constant W/C ratio = 0.5. This dependence does not appear to be linear and it is limited by the acceptable dimensions of the cone flow. The dependence of cone flow on SAP dosage is shown in Figure 2. and it is also applicable only for the raw materials used in this experiment and only if studied SAP dosage range from 0 to 1% of cement mass.

Figure 2: Cone flow depending on the dosage of SAP at a constant W/C ratio equal to 0.5

Figures 3 and 4 show the dependence of the bending strength and compressive strength of the concrete specimens on the dosage of the studied SAP. Strength values determined in accordance with standards and average strength values are listed. Figure 3 shows the dependence for constant cone flow 106-115 mm and figure 4 shows the dependence for constant W/C ratio equal to 0.5.

Figure 3: Dependence of the bending strength and compressive strength on the SAP dosage at a constant cone flow equal to 106-115 mm

Figure 4: Dependence of the bending strength and compressive strength on the SAP dosage at a constant W/C ratio equal to 0.5

Figures above can be represented as a surface area shown on Figure 5. Surface area is formed by three values: W/C ratio, % of SAP dosage and concrete strength in MPa. This allows to see a more understandable result of the study.

Figure 5: Dependence of the bending strength and compressive strength on the SAP dosage and concrete W/C ratio

It can be seen from the above that at dosages of SAP up to 0.5%, the bending strength and compressive strength of fine-grained concrete does not decrease. However, with a further increase in the dosage to 1%, the strength of hardened concrete decreases by 20-25%. It can be concluded that for further studies of this type of SAP, it is necessary to choose its dosage of not more than 0.5% of the cement mass. The compressive strength of concrete slightly increased at dosages of SAP equal to 0.25% of the cement mass.

These results can be compared with the results obtained on heavy concrete specimens. In this case, only the dosage of 0.5% of the cement mass and only concrete compressive strength was investigated (Figure 6).

Figure 6: Compressive strength of heavy (A) concrete and fine-grained (B) concrete

Results show that the addition of SAP in a dosage of 0.5% of cement mass increases the compressive strength of heavy concrete by 9% at a constant W/C equal to 0.55. The strength of fine-grained concrete increased by 7% at a constant W/C = 0.5.

Discussion

We can assume that the investigated type of SAP does not reduce the strength of concrete in SAP dosages up to 0.5% of the cement mass. This means that this type of SAP can be used to improve other characteristics of concrete. The addition of SAP into the concrete leads to an increase of W/C ratio, so for a more effective use of SAP in concrete, the effect of its addition with plasticizing and anti-shrink additives should be considered. For the future experiment planning with the SAP additive under study, it is necessary to consider options and methods for further research. The ability absorbing a large amount of water and increasing in volume of particles allows to use SAP in creating self-healing concrete and reducing the autogenic shrinkage of concrete. Self-healing concrete can increase the durability of a concrete structure. Cracks in concrete can appear due to shrinkage and overload of the concrete structure. They also can appear as a result of different external factors such as an influence of aggressive environment. H.X.D. Lee, H.S. Wong, N.R. Buenfeld proved that concrete structure can become weak after the appearance of cracks more than 0.2 mm thick. Harmful substances penetrate into these cracks, that lead to corrosion of the concrete reinforcement and later causes destruction of concrete structure [7].

The effect of increasing of the volume of SAP particles while absorbing water can be used to create self-healing concrete. This phenomenon was studied by Pattharaphon Chindasiriphan, Hiroshi Yokota, Paponpat Pimpakan [5]. According to their research, the effectiveness of crack healing depends on different parameters such as crack width, water pressure, temperature. Authors proposed their own method for determining the ability of concrete self-healing with SAP. Specimens formed as cylinders were enclosed in a polyvinyl chloride shell. A compressive load was applied to the lateral side of the cylinder, which led to deformation of the shell and the appearance of cracks on the concrete specimen. This method allowed the authors artificially create 0.2 - 0.3 mm cracks. To determine the possibility of crack-healing, the authors have developed a special apparatus that allowed to create necessary hydrostatic pressure of water on a crack in the sample. Byoungsun Park, Young Cheol Choi proposed a similar method, but the test samples were coated with an epoxy coating before testing [6]. These methods allowed the authors to reveal the effectiveness of

concrete with SAP in healing of 0.3 mm cracks.

Autogenous shrinkage deformations also lead to cracks in the concrete. It is possible to reduce the shrinkage of concrete by reducing the amount of water or increasing the mass fraction of aggregates, but this will negatively effect on the compressive strength of the hardened concrete and the workability of the concrete mixture [1]. The addition of anti-shrinkage additives can solve this problem, but their effect on the shrinkage of hardened concrete when used together with plasticizing additives has not been sufficiently studied. The superplasticizer can both decrease and increase the effectiveness of the anti-shrink additive [2]. Thus, these areas of research in concrete with SAP can be considered promising and relevant.

Conclusion

The following results were obtained:

1. Increasing of the SAP dosage increases the water demand of the concrete mix.
2. Dependence of the W/C ratio on the dosage of SAP for cone flow 106-115 mm achievement turned out to be linear
3. Increase of the SAP dosage cause a decrease of the cone flow at a constant W/C ratio.
4. The compressive strength of concrete slightly increased at dosages of 0.25% SAP
5. Dosage of 0.5% SAP do not decrease the bending strength and compressive strength of fine-grained concrete.
6. Dosage of 0.5% SAP increase the compressive strength of fine-grained concrete to 7% at a constant W/C = 0.5.
7. Increase of SAP dosage up to 1% decrease the strength of hardened concrete to 20-25%.
8. It is necessary to choose SAP dosage not more than 0.5% for further studies.
9. Dosage of 0.5% SAP significantly reduce the workability of heavy concrete.
10. Dosage of 0.5% SAP increase the compressive strength of heavy concrete to 9% at a constant W/C = 0.55.

We can suggest that the studied type of SAP can be effective for reducing the autogenous shrinkage of concrete without reducing its strength, as well as it can be used for creating self-healing concrete.

Results allow us to do further comparative experiments for determining autogenous shrinkage and the possibility of crack healing. Obtained results will help to substantiate the effectiveness of using this type of SAP in concrete structures.

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