Self-compacting concrete as a modern solution to small architectural forms

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Abstract. Modern Materials science in Construction is developing in a way of higher functionality, durability, ecological safety of the materials, which also must be easy to work with. The workability of concrete is provided by its property to fill the formwork under the influence of gravity. Small architectural forms (SAF) – are practical and art objects which complement outdoor spaces and enrich architectural, urban and landscape composition of the city. Manufacturing of SAF is complicated by its extraordinary geometric shapes with plenty of tiny elements. This fact limits the usage of traditional technologies of vibration for compaction. In this paper properties and composition of self-compacting concrete (SCC) are discussed, as well as the possibility of its application for thin-walled heavily reinforced constructions to produce unique SAF for landscape design. The obtaining of flowable segregation-resistant concrete mix with low water-cement ratio is studied. The hypothesis of applicability of SCC for SAF in landscape design is based on high deformability, flowability and consolidation by means of its own weight without segregation. The methodology of the research is based on the literature review concerning the usage of SCC for SAF with some special additives with plasticizing and anti-segregating affects. The investigation showed that SCC is applicable for SAF in landscape design.

1 Introduction

Small architectural forms (SAF) is an integral component of landscape design. SAF can be described as complex facilities for decoration with some special functional purpose: garden sculptures, flowerpots, busts, fountains, waterfalls, vases, pillars, podiums and different kinds of fences [1].

SAF could be classified as multifunctional, decorating, recreational and sports. Multifunctional SAF are commonly constructed to form urban environment: streetlamps, flowerpots, benches, garbage cans etc. Park sculptures and compositions, fountains, bridges, dry creeks, geometric forms (spheres) etc. are decorating SAF, created to bring harmony to the environment. Playgrounds and sport areas, specifically designed and equipped, could be classified as recreational and sports SAF. The application of self-compacting concrete is implemented in manufacturing of SAF due to its flowability, ability

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to consolidate by means of its own weight, to fill in the space between the reinforcement bars inside the formwork and its property to remove air bubbles from its structure [2-4].

The concept of SCC appeared in Japan in 80s of the 20th century. Technology of SCC became more available with usage of new polycarboxilate superplasticizer. Added in small amount, it provide long-time plasticizing effect [5-8].

According to these facts, the authors suggest that SCC could be successfully applied for manufacturing SAF of complicated forms.

2 Experimental

The selection of mixture components is based on the composition formulated by Japanese scientists [5-8] taking into consideration the higher ratio of flour particles, higher maximum size of coarse aggregate is 1 mm, its bulk volume exceeds 50% of concrete mass. Cement paste may contain 40% of pure sand and up to 0.3% of stabilizing components (by volume). Middle fraction is not normally used in preparation of SCC. Cement paste composition of SCC is presented in Table 1.

| Компонент | Quantity, kg/m³ |
|-----------|----------------|
| Cement    | 350            |
| Fly ash or grinded limestone | 200 |
| Water     | 170-180        |
| Sand      | 650            |
| Crushed stone | 950  |
| Plasticizer | 2-4  |
| Water-cement ratio | 0.49–0.51 |

In the article the authors referred to general scientific research methods, base theory of SCC and design solutions in SAF, illustrated in technical and scientific materials, mass media, license documents, scientific articles and reports.

3 Evaluation

Plasicizing additives for SCC are polycarboxylate superplasticizers (PC). PC combines two types of plasticizing effects: electrostatic and steric. Electrostatic repulsion disperses the flocculated cement particles by giving them negative charge. Steric stabilization results from the adsorption of PC molecules with long side chains on the surface of cement particles providing steric hindrance to agglomeration [11-12] (fig.1). Cement paste with low dosage of PC admixture retains long-time plasticizing action.
Admixtures containing sulfonaphtalene, phormaldehyde and sulfomelamine are also widely used in SCC in quantity of 0.8-1.3% by volume. They provide water-reducing effect and lower water-cement ratio, therefore promoting the growth of density. But density is not the main factor of segregation under high flowability of self-consolidating paste.

Viscosity and share resistance are the major reasons for SCC’s homogeneous structure. The resistance of SCC to segregation and bleeding process is due to the presence of additives, modifying viscosity, or fine mineral fillers:

- cellulose;
- polyethylene glycol;
- hydrolyzed starch;
- acrylic polymers;
- nature biopolymers (nature polysaccharides).

Incorporation of water-soluble organic stabilizer (0.05, 0.1, 0.15, 0.3 % by mass of cement according to the type of additive) causes the formation of stable micro-gel layer on the surface of cement grains. This gel contributes to the formation of structure-mechanical barrier between particles and builds the rigid supporting net, which prevents the system from segregation, but doesn’t prevent the motion of sand and crushed stone and doesn’t degrade the workability of the mortar.

Organic compounds influence only rheological properties of cement mixtures, when fine mineral additives improve rheological, structure-mechanical and functional
characteristics of SCC, making the process of flowing into the heavily reinforced formworks easy. Combination of mineral additives with organic superplasticizers and reasonable aggregate grain size distribution gives high-strength SCC (not less than 70 MPa) [13,14].

Mineral additives are:
• Ground-granulated blast furnace slag (GGBFS);
• Lime dust;
• Fly ash;
• Microsilica;
• Silica fly ash;
• Metakaolin.

Mineral additives can be divided into two groups: those which dilute cement (fly ash, GGBSF etc. with close parameters of particle size of additive and cement) and compacting ones (microsilica, metakaolin with particle size 100 times smaller and with volume of specific surface area in the range of 20-30 m²/g) [15]. Mineral additives can also influence the hydration process, prevent cement material from sulfate corrosion and from formation of shrinkage cracks in concrete while hardening in the formwork [16-17].

SCC has compressive strength of 40-80 MPa at days, 55-100 MPA at 91 day; flexural strength of 4.8-6.8 MPa; elastic modulus of 30-36 GPa; shrinkage of 0.6-0.8 mm; air volume of 4.5-6%; workability of about 70 cm [18-19]. This data confirms that SCC can refer to modern innovative material for construction.

SCC can be applied as ultramodern architectural and decorative cement based material for SAF. It can easily flow into forms of different construction especially heavily reinforced, which allows to manufacture SAF of all styles, even with filigree details: park furniture, sculptures, garden lamps etc. It’s applicable for creation bulk SAF: fountains, artificial waterfalls, concrete planters (fig.2) – bulk flower pots. Perfectly compatible with natural landscape they can be placed outdoor and unite all the elements of park ensemble.

SCC special properties enable its application in 3D-printing technology to produce multifunctional, decorating, recreational and sports SAF of various surface forms.

Fig.2. SAF made of SCC.
4 Conclusions

Theoretical study of scientific and technical literature, media resources, patents, scientific articles and reports concerning SCC with special plasticizing and anti-segregation additives confirm the possibility of using such type of concrete for SAF due to the combination of its high flowability and property to consolidate under the influence of gravity without signs of segregation.

SCC is a modern innovative solution for any extraordinary and contemporary landscape design concept. This material provides unique opportunity for developing art ideas in private gardens as well as in public places.

References

1. D. M. Loktev, Stroiizdat 122 (2005)
2. V. S. Lesovik, Yu. V. Degtev, V. V. Voronov, Vestnik BGTU im. V.G. Shuhova 5, 85-90 (2014)
3. А. K. Solov’ev, K. A. Solov’ev, N. V. Stekolnikov, Architecture and Modern Information Technologies 2(43), 171-184 (2018)
4. Ya. A. Aleksandrov, Tehnologia Betonov 3-4, 18-19 (2011)
5. H. Okamura, Concrete International 19(7), 50-54 (1997)
6. K. Ozawa, K. Maekawa, H. Okamura, Proceedings of JSI 11(1), 699-704 (1989)
7. M. M. Ouchi, Concrete at the turn of the third millennium: proceedings of the 1st All-Russian conference on concrete and reinforced concrete, 209-215, Moscow (2001)
8. K. Ozawa, K. Maekawa, M. Kunishima, H. Okamura, Proceedings of the second East-Asia and Pacific Conference Engineering and Construction (EASEC-2) 1, 445-450 (1999)
9. S.V. Samchenko, O.V Zemskova., I.V. Kozlova, Russian Journal of Applied Chemistry 87(12), 1872-1876 (2014) DOI: 10.1134/S1070427214120131.
10. S. Samchenko, I. Kozlova, O. Zemskova, MATEC Web of Conferences, 193, 03050 (2018) DOI: 10.1051/matecconf/201819303050.
11. S. Samchenko, I. Kozlova, O. Zemskova, D. Zamelin, A. Pepelyaeva, Advances in Intelligent Systems and Computing 983, 817-827(2019) DOI: 10.1007/978-3-030-19868-8_80.
12. E. Sakai, K. Yamada, A. Ohta, Journal of Advanced Concrete Technology 1(1), 16–25 (2003)
13. A. V. Batudaeva, G. C. Kardumyan, S. S. Kaprielov, Beton i Zhelezobeton 4, 14-18 (2005)
14. A. V. Usherov-Marshak, Beton i Zhelezobeton 2, 20-25 (2009)
15. Yu. M. Bazhenov, Tehnologii Betonov 6, 6-8 (2005)
16. V. S. Dorofeev, V.N. Virovoi, Odessa 168 (1998)
17. A. V. Usherov-Marshak, Stroitelnie materiali 10, 8-12 (2006)
18. P. L. Domone, Cement and Concrete Composites 29, 1-12 (2007)
19. P. L. Domone, Cement and Concrete Composites 28, 197-208 (2006)