Self-compacting fine-grained concrete for reinforced concrete frame joints filling

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Abstract. Self-compacting compositions of fine-grained concrete for filling the joints of the precast-monolithic reinforced concrete frame of multi-storey buildings have been developed. Glenium®51 and Glenium SKY® 505 superplasticizers, and fine-grained river quartz sand with a bulk module of 1.2 were used to prepare the compositions. A part of quartz sand was ground to a specific surface of 100 m$^2$/kg. The binder was a Portland Cement CEMI 42.5B with a specific surface area of 360 m$^2$/kg. The spreading of the mixture in the Hagerman cone was 240-270 mm. The self-compacting mixtures compositions containing 1.5% superplasticizers from the mass of cement have an increased fluidity and the ability to freely penetrate holes with a diameter of up to 4 mm. The water-cement ratio when using the superplasticizer Glenium®51 was 0.34, and with Glenium SKY® 505 0.36, respectively. Modified compositions are characterized by low early strength. On the third day of hardening under normal conditions, the strength of the samples was about 30% in comparison with the compressive strength after 28 days. It was found that with moderate heating at a temperature of 30-40 °C during the first three days, the early strength can be significantly increased. The compressive strength of the self-compacting composition with the Glenium® 51 additive at the content of the ground quartz filler of 15.6% at the age of 28 and 150 days gets strength of 54 and 90 MPa, respectively. The developed compositions of fine-grained concrete with superplasticizer Glenium®SKY 505 have passed the test for the ability to keep steel reinforcement from corrosion. Self-compacting fine-grained concrete with the Glenium®SKY 505 additive is used to fill the joints of reinforced concrete structures of a prefabricated-monolithic frame of a multi-storey building in winter with the use of moderate heating.

1. Introduction

Modern construction is based on increased requirements for speed, economy and quality of buildings constructing. Among the promising areas in the field of construction is the spread of industrial system based on the erection of buildings in a prefabricated frame construction with rigid monolithic joints. The assembled frame of multi-storey buildings with rigid monolithic joints is cost-efficient and provides a high speed of installation [1]. The speed and quality of the erection of prefabricated-monolithic structures also depends on the properties of the concrete mixtures used for embedding the joints.

To other fill the joints of precast concrete frames of buildings, self-compacting fine-grained concrete mixtures are required. They must possess a complex of technical properties: to have high fluidity, it is good to compact without vibration, to acquire high strength at compression and bending, not to give shrinkage at hardening and to protect the reinforcement in joints from corrosion. To the greatest extent these requirements correspond to modified fine-grained concrete mixes of filling type,
used as repair, restoration and finishing compounds. When mixed with water, they form non-shrinkable non-dispersible compounds having high workability: the spreading in the Hagermann cone test is 270-290 mm. With an average density of 2200 kg / m$^3$, the compositions can acquire compressive strength up to 85 MPa, and bending strength up to 9 MPa [2]. On the Russian market, the main suppliers of such mixtures are the construction companies "BASF", "Ceresit", "MAPEI", etc. The self-compactability of mixtures is based on the use of polycarboxylate type superplasticizers [2]. Self-compacting mixtures demonstrate a long-lasting mobility. According to the author Wolfram Schmidt, H J H Brouwers, Hans-Carsten Kühne, Birgit Meng, the long-term mobility of cement compositions, plasticized with polycarboxylate superplasticizers is ensured by selective adsorption with C$_3$A and C$_4$AF phases, as well as with the emerging ettringite phase [3].

Theoretical studies lead to the conclusion that it is possible to develop self-compacting fine-grained mixtures compositions for joints embedding corresponding to the above described requirements using ordinary cements and local mineral resources [4; 5]. The aim of the study was to investigate the effect of temperature and polycarboxylate plasticizers on the hydration processes of cement compositions in the early period of hardening and to develop, on the basis of the results of the study, qualitative compositions for embedment of joints of prefabricated reinforced concrete structures using natural quartz sand.

2. Materials and research methods

The development of compositions of self-compacting mixtures for joints embedment was carried out using local river fine-grained quartz sand with 1.2 module size. Quartz sand is suitable for glass production in the content of impurities. The grain composition of natural quartz sand is given in Table 1.

| Sieve holes size, mm | 2.5 | 1.25 | 0.63 | 0.315 | 0.16 | 0.16 |
|----------------------|-----|------|------|-------|------|------|
| Complete residues, % | 0.04| 0.12 | 1.79 | 24.89 | 93.26| 100  |

According to GOST 8736-2014 quartz sand module size refers to a group of very fine sands.

To increase mixtures resistance to delamination, part of the dry natural quartz sand was ground to a specific surface of 100 m$^2$/kg. Mixtures of quartz sand and quartz filler were added into the compositions. Superplasticizers based on polycarboxylate esters - Glenium®51 and Glenium®SKY 505 manufactured by BASF - were used to prepare the self-compacting mixtures compositions.

As a binder, portland cement CEMI 42.5B (GOST 31108-2003) produced by JSC Mordovcement with a specific surface area of 360 m$^2$/kg was used. Portland cement had the following mineralogical composition: C$_3$S = 62.0%, C$_2$S = 14.0%, C$_3$A = 6.5%, C$_4$AF = 12.0%. Portland cement contained 4.5% of the active mineral additive - the flask.

Samples were filled from the compositions - cubes with an edge of 70 mm, which were stored under normal conditions at a temperature of + 20 ± 2 °C and an air humidity of 95 ± 5%. The compounds strength increase kinetics were studied by testing specimens with a size of 20 × 20 × 20 mm.

3. Analysis of results and discussion

The effect of Glenium®51 additive on cement contraction during the first three hours of hardening was studied. The experiment was performed in a KD-0.7 contractionometer. The Composition contraction is shown in Table 2.

| Composition | 0.1% | 0.2% | 0.3% | 0.4% |
|-------------|------|------|------|------|
| Contraction | 1.5% | 2.0% | 2.5% | 3.0% |

The study showed a decrease in the volume of contraction with an increase in the Glenium®51 additive content from 0.1 to 2%. Thus, from the first hours of hardening, the additive reduces the cement hydration rate.
The kinetics of hydration of cement stone under the influence of temperature and the content of polycarboxylate plasticizer Glenium®51 was studied. X-ray phase analysis of cement stone was performed at the age of 24 hours. 3 compositions were compared. The first composition did not contain a superplasticizer and hardened at a temperature of 20 °C. The second formulation contained 0.5% Glenium®51 and was hardened at 20 °C. The third formulation contained 0.5% Glenium®51 and solidified at 40 °C. The results of the study are shown in Table 3.

### Table 3. Cement stone phase composition after 24 hours hardening

| Composition number | W/C | T, °C | Glenium® 51 additive content in % of cement mass | Phase composition, content % by weight |
|--------------------|-----|-------|-------------------------------------|--------------------------------------|
|                    |     |       | %                                  | C₃S  | C₃A  | Ca(OH)₂ |
| 1                  | 0.29| 20    | -                                   | 40   | 10   | 15      |
| 2                  | 0.23| 20    | 0.5                                 | 52   | 10   | 16      |
| 3                  | 0.23| 40    | 0.5                                 | 30   | 3    | 17      |

The results also confirm that Glenium®51 inhibits the hydration of clinker materials. Increasing the temperature from 20 °C to 40 °C accelerates the modified cement stone hydration process in the first day of hardening. In further studies for cement compositions modified with additives of polycarboxylate plasticizer, heating technology was used to intensify hardening.

Self-compacting compounds with spreadability of mixtures in the Hagerman cone 240-270 mm were obtained with 1.5% of the cement mass superplasticizer content. The water-cement ratio when using the superplasticizer Glenium®51 was 0.34, and with Glenium®SKY 505 0.36, respectively. Modified fine-grained concrete compositions are given in Table 4.

### Table 4. Modified fine-grained concrete compositions

| №     | Dry mixture composition, % |
|-------|--------------------------|
|       | cement | quartz sand | filler |
| 1     | 50     | 37.5        | 12.5   |
| 2     | 50     | 34.4        | 15.6   |
| 3     | 50     | 31.3        | 18.7   |
| 4     | 50     | 37.5        | 12.5   |
| 5     | 50     | 34.4        | 15.6   |
| 6     | 50     | 31.3        | 18.7   |

| №     | The superplasticizer content, % by the cement weight |
|-------|------------------------------------------------------|
|       | Glenium®51 | Glenium®SKY 505 |
| 1     | 0.34       | 1.5           | -
| 2     | 0.34       | 1.5           | -
| 3     | 0.34       | 1.5           | -
| 4     | 0.36       | -             | 1.5
| 5     | 0.36       | -             | 1.5
| 6     | 0.36       | -             | 1.5

It was found that samples containing superplasticizers Glenium®51 and Glenium®SKY 505 at 1.5% of cement mass are characterized by low early strength: after 3 days of hardening, the compressive strength of the samples amounted to about 30% of the strength of the formulations at the age of 28 days. In this case, formulations No. 1-3 modified with Glenium®51 superplasticizer at the
The studies have shown that the resulting compositions of self-compacting mixtures exhibit increased fluidity, expressed in the ability to freely penetrate holes with a diameter of up to 4 mm. Testing of cubes measuring 70.7×70.7×70.7 mm samples on the third day of hardening showed that their compressive strength does not exceed 13.5 MPa. The results of the Compositions 1-6 compressive strength kinetics study are shown in Figures 1 and 2. Analysis of the results showed that all compositions have similar hardening kinetics.

With further storage, the samples continue to gain strength. At the age of 150 days, formulations No. 1-3 modified with Glenium®51 superplasticizer acquire an average strength of 23% higher than the strength of formulations No. 4-6 supplemented with Glenium®SKY 505. The obtained results are explained by the index of the water-cement ratio (Table 4), which determines the formation of the density of the investigated compositions and its effect on the compressive strength formation.

It is known that superplasticizers can reduce the cement stone hardening rate during the early hardening period [5]. The effect of heating on the cement stone, modified by the superplasticizer Glenium®51 in the amount of 0.5% of the cement mass early strength kinetics, was studied.
Samples were hardened for the first three days at temperatures of 30 and 40 °C. Further hardening took place under normal conditions. The results of hardening are presented in Figures 3,4.

Comparison of the studies shown in Figures 3,4 results shows that the polycarboxylate superplasticizer slows down the cement stone early strength growth. Moderate heating at a temperature of 30-40 °C during the first 3 days significantly increases the early strength.
According to the increased requirements for self-compactness and fluidity of the mixtures used to fill the joints by pumping through a hole 4 mm in diameter, for practical use, formulation No. 4 with the Glenium®SKY 505 modifier is recommended. Composition No. 4 has a spread of 270 mm when tested in a Hagerman cone and compressive strength of 37 MPa after 28 days.

Studies were made to assess the ability of a self-compacting mixture to protect steel reinforcement from corrosion. For this, a layer of a self-compacting mixture 3 mm thick was applied to sand-blasted surfaces of steel plates 0.5 mm thick and 100 × 100 mm. For the test, composition No. 4 was used with the superplasticizer Glenium®SKY 505 and the control composition without the modifier. Samples of the plate with coatings were stored under laboratory conditions in desiccators over water for 4 years. After every 150 days, the plates were inspected for signs of rust. The last evaluation was made 4 years after the application of the formulations.

Figure 5 (a, c) shows a coating composition without a modifier, where corrosion marks are clearly visible, which indicates a low ability of the composition to protect the reinforcement from corrosion. After 150 days, no signs of detachment of the modified compositions were found on the plate with the modified composition and there were no signs of corrosion of the steel (Fig. 5, b). Inspection of the plate with a modified composition after four years showed a high ability of the composition to protect steel reinforcement from corrosion (Fig. 5, d).
Composition No. 4 were used to seal the joints of the prefabricated monolithic reinforced concrete frame of a multi-storey building in winter with heating at 40 °C where it provided an intensive strength gain in the hardening early stages. The composition complied with the requirements of fluidity, non-dissipation and the ability to pump through narrow mounting holes in the cavity of joints of reinforced concrete structures.

4. Conclusions

Formulations of self-compacting fine-grained concrete for filling joints of reinforced concrete structures of prefabricated-monolithic frame with the use of ordinary Portland cement, local quartz sand, Glenium®51 and Glenium®SKY 505 superplasticizers have been developed.

The developed compositions of fine-grained concrete with Glenium®SKY 505 superplasticizer have passed the test for the ability to keep steel reinforcement from corrosion.

Studies show a decrease in the degree of cement hydration under the influence of polycarboxylate superplasticizers in the early stages of hardening. To accelerate self-compacting compositions with superplasticizers Glenium®51 and Glenium®SKY 505 early strength growth kinetics is possible by moderate heating use.

Self-compacting compound with Glenium®SKY 505 additive was used to fill the joints of reinforced concrete structures of a prefabricated-monolithic skeleton of a multi-storey building in winter with the use of moderate heating.

References

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