Case Studies of High-strength Lightweight Concrete Using Expanded Siliceous Aggregate

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Abstract. Structural lightweight concrete has various applications including the construction of multi-story buildings, bridges, offshore oil platforms and other reinforced concrete structural elements. Structural lightweight concrete also was used in offshore construction. The development of compositions of high-strength lightweight concrete with an average density of 1100-1500 kg/m³ may be in demand for the manufacture of most of the typical concrete products with an ordinary strength 20-35 MPa. This study have shown that granular expanded siliceous aggregates can be used as an alternative to hollow microspheres to obtain high mechanical characteristics of lightweight concrete. Based on the principles of producing high-strength lightweight concrete using the example of “Thermogran” granules the possibility of achieving strength of lightweight concrete of more than 45 MPa with an average density of less than 1600 kg/m³ is shown. In the same time, specific consumption of cement on 1 MPa of concrete strength is 8.1...8.8 kg/MPa.

1. Introduction
Structural lightweight concrete has various applications including the construction of multi-story buildings, bridges, offshore oil platforms and other reinforced concrete structural elements [1, 2]. The use of structural lightweight concrete allows to solve the problems of a large mass of buildings and structures and also stability of construction during operation. Such lightweight concrete with compressive strength in range of 35…41 MPa has been used successfully for almost four decades by precast and prestressed concrete manufacturers in North America [3]. For example, concrete with a density of 1850 kg/m³ was used to make the floors of the parking complex with 15...20 meter spans in Chicago. The first skyscraper, which was built in 1955 entirely using structural lightweight concrete, is the 18-story building of Dallas Statler-Hilton [4]. Subsequently, such structures became the highest objects in different years. These were the 180-meter towers of the 60-story Marina City in Chicago (1962), the Park Regis Tower of the Australia Square complex 184 meters high (1967); 196-meter Lake Point Tower in Chicago. There are examples of increasing the number of floors of buildings through the use of lightweight concrete [4]. Southwestern Bell Telephone Company has implemented a project to increase the height of an existing building from 14 to 28 floors. Another example is an office building in Ottawa with 22 floors according to the design. Replacing heavy concrete in structures allowed to increase the number of floors to 25. And the height of the Magnolia State Council in Jackson, Mississippi, builders were able to increase from 2 to 6 floors.
During World War II, lightweight concrete was used in offshore construction for the construction of 24 ocean ships and 80 sea barges. [5]. And at the end of the 20th century, such concrete structures were recognized as an effective material for floating oil platforms.

More than 800 bridge structures were constructed using lightweight concrete in North America, such as the 1965 Sebastian Inlet Bridge. [3]. The Chesapeake Bay Bridges are examples of the use of typical lightweight concrete solutions for bridge construction. The first of the two structures was erected in 1953, and the second in 1975.

The relevance of the development of structural or high-strength lightweight concrete is confirmed by research of reducing average density of materials and at the same time increasing strength. The authors [6-9] proposed the use of hollow ceramic or glass microspheres to obtain concretes and mortars. This concrete has a compressive strength of 60...70 MPa and an average density of 1300...1500 kg/m³ [6, 7]. However, the limited hollow filler is a deterrent to the development of such technology. Such concretes have high techno-economic efficiency [10, 11], but their use is limited to individual construction projects or construction of special-purpose facilities. Existing practice in Russia and the regulatory system for reinforced concrete products [12] show the need for lower strength concrete. An analysis of the Russian regulatory documents for prefabricated and monolithic structures shows that strengths of 20-35 MPa are the most common for heavy concrete. According to the classification of Russian standard GOST 25820-2014 “Light concrete. Technical conditions” lightweight concretes with average density 1100...2000 kg/m³ and specific strength 10.0-31.8 MPa (table 1) are called structural.

| №  | According to standard | Calculated value |
|----|----------------------|------------------|
|    | Density grade | Strength grade | Specific strength, MPa | Required strength², MPa |
| 1  | D1100       | B12.5           | 13.6                 | 27.5                   |
| 2  | D1200-D1300 | B12.5-B20       | 11.5-30.8            | 30.0-32.5              |
| 3  | D1400-D1500 | B12.5-B30       | 10.0-28.6            | 35.0-37.5              |
| 4  | D1600-D1700 | B15-B40         | 11.8-31.3            | 40.0-42.5              |
| 5  | D1800       | B20-B40         | 13.9-27.8            | 45.0                   |
| 6  | D1900-D2000 | B25-B40         | 17.5-26.3            | 47.5-50.0              |

² Required strength to provide a specific strength more than 25 MPa.

Thus, we can conclude that structural high-strength lightweight concrete with an average density of more than 1100 kg/m³ can be used for the manufacture of typical reinforced concrete. That is, the development of compositions of high-strength lightweight concrete with an average density of 1100-1500 kg/m³ may be in demand for the manufacture of most of the typical concrete products with an ordinary strength 20-35 MPa. And concrete compositions of the D1600-D2000 brand with a strength of 40-50 MPa are required for special structures and construction in earthquake-prone areas. Based on this, the practical task in the technology of high-strength lightweight concrete is to achieve a minimum average density with sufficient strength characteristics. The solution to this problem is to use aggregates alternative to hollow microspheres.

2. Material and methods

The extensive mineral resources base of Russian regions forms the prerequisites for the development of technologies for the production of expanded aggregates based on local raw materials. One of the promising theme for the construction industry is the manufacture of granular glass-ceramic aggregates from glass or amorphous volcanic rocks. [13, 14]. Expanded siliceous aggregate granules have the following properties [15]:

1 High-strength lightweight concrete is the concrete with specific strength more than 25 MPa.
• Bulk density – 140…180 kg/m³;
• Compressive strength – 0.7…7.0 MPa;
• Water absorption – less than 2%;
• Fractional composition – 0.2…15.0 mm.

Granular siliceous lightweight sand “Thermogran” (EGA) of fraction 0…1 mm was used in this study (figure 1).

Figure 1. Granular expanded siliceous aggregate.

Figure 2. Servo-hydraulic press «Advantest 9».

Portland-cement CEM-I 42.5 (PC), quartz sand fraction of 0.16-0.63 mm (QS), stone powder (SP) with a specific surface area of 700-800 m²/kg, microsilica (MS), polycarboxylate plasticizer «Melflux 1641F» (A) were used for preparation of concrete mixture. The mixing of concrete was carried out using a mortar mixer «Automix». The servo-hydraulic press «Advantest 9» (figure 2) was used for determination of strength in 1 day after heat-humid treatment according to ASTM C39/C39M-14. The structure of HSLWC was researched using a microscope «Eclipse MA200».

3. Results and discussion

In this work, high-strength lightweight concrete compositions were obtained by partial replacement of aggregate (silica sand) in heavy fine-grained concrete with granular lightweight aggregate with a ratio of components according to table 2.

| №  | Composition | Content | PC | MS | SP | EGA | QS | W | A  |
|----|-------------|---------|----|----|----|-----|----|----|----|
| 1  | Com. 1      |         | 0.200 | 0.040 | 0.010 | 0.527 | 0.017 | 0.219 |    |
| 2  | Com. 2      |         | 0.192 | 0.037 | 0.009 | 0.507 | 0.015 | 0.238 | 0.002 |
| 3  | Com. 3      |         | 0.129 | 0.036 | 0.075 | 0.496 | 0.045 | 0.217 |    |
| 4  | Com. 4      |         | 0.541 | –     | –     | 0.541 | –     | –     |    |

The studied compositions of structural lightweight concrete have a high degree of filling of lightweight fraction (0.541), which allows a low average density. The introduction of expanded siliceous aggregate in the indicated amount into a finely dispersed cement-mineral matrix forms a close-packed material structure (Figure 3) with a saturated gas phase. Features of the technology of producing expanded siliceous aggregate provide the formation melted shell on the surface of the granules. This helps to achieve low water absorption and high resistance to external loads. It also reduces the water demand of mixtures and allows to not saturate the granules with water to ensure mobility observing W/C-ratio (0.35…0.54).
Figure 3. Structure of lightweight concrete on expanded granular aggregate (magnification ×50).

It is established that the filling of cement high-strength matrix by expanded siliceous aggregate provides the formation of a structure with high strength properties (Figure 4). The use of expanded siliceous aggregate allows to reduce the consumption of binder (Figure 5) in contrast to compositions with fine micro-sized aggregate like hollow microspheres [16]. The compressive strength of high-strength lightweight concrete on expanded granular siliceous aggregate is 48.4...52.7 MPa with an average density of 1420...1620 kg/m³.

Figure 4. Physico-mechanical properties of concrete.

Figure 5. Specific characteristics of concrete.

The calculation of the specific indicators of the studied compositions of structural lightweight concrete (Figure 5) shows the possibility of achieving of specific strength of more than 25 MPa. In this case, the most important indicator of the specific consumption of cement, which shows the consumption of binder on 1 MPa of concrete strength, can be reduced from 12.4...12.9 to 8.1...8.8 kg/MPa.

Thus, the study of lightweight concrete on expanded granular siliceous aggregate shows the possibility of obtaining composites with high physical and mechanical properties. This concrete has a lower consumption of cement and a lower specific consumption of binder per unit of strength compared to high-strength lightweight concrete on hollow microspheres. Based on this, such aggregate prepared from local raw materials is a good alternative to expanded ceramic aggregates and hollow microspheres for structural lightweight concrete due to the lower cost of production.

4. Conclusion

Studies have shown that granular expanded siliceous aggregates can be used as an alternative to hollow microspheres to obtain high mechanical characteristics of lightweight concrete. Based on the principles of producing high-strength lightweight concrete using the example of “Thermogran”
granules the possibility of achieving strength of lightweight concrete of more than 45 MPa with an average density of less than 1600 kg/m$^3$ is shown. In the same time, specific consumption of cement on 1 MPa of concrete strength is 8.1...8.8 kg/MPa.

5. References

[1] Kenneth S, Harmon P E 2006 Engineering properties of structural lightweight concrete (Carolinastalite company – united states)

[2] Faust T., Konig G. 1998 High strength lightweight aggregate concrete Proceedings 2nd International Ph.D. Symposium in Civil Engineering (Budapest: Technical University of Budapest) p 8

[3] Holm T A, Bremner T W 2000 State-of-the-Art Report on High-Strength, High-Durability Structural Low-Density Concrete for Applications in Severe Marine Environments

[4] Zareef M A M E 2010 Dissertation. Conceptual And Structural Design Of Buildings Made Of Lightweight And Infra-Lightweight Concrete (Berlin) p 119

[5] Holm T A, Bremner T W , Vaysburd A 1988 Carbonation of marine structural lightweight concrete Second International Conference on Performance of Concrete in Marine Environment Andrews St N B (Canada. ACI SP) p 109

[6] Inozemtcev A S 2015 High-strength lightweight concrete mixtures based on hollow microspheres: technological features and industrial experience of preparation IOP Conference Series: Materials Science and Engineering 71(1) 012028

[7] Inozemtcev A S, Korolev E V 2017 Features of the defectiveness of nanomodified high-strength lightweight concrete based on hollow microspheres Key Engineering Materials 743 68–72

[8] Oreshkin D V, Semenov V S, Rozovskaya T A 2014 Light-weight backfill mortars with antifreeze additives for the permafrost conditions Neftyanoe khozyaystvo - Oil Industry 4 42–45

[9] Perfilov V A, Oreshkin D V, Semenov V S 2016 Environmentally Safe Mortar and Grouting Solutions with Hollow Glass Microspheres Procedia Engineering 150 1479–1484

[10] Inozemtcev A S, Korolev E V 2014 Technical and economical efficiency for application of nanomodified high-strength lightweight concretes Advanced Materials Research 1040 176–182

[11] Inozemtcev A, Duong T Q 2019 Technical and economic efficiency of materials using 3D-printing in construction on the example of high-strength lightweight fiber-reinforced concrete E3S Web of Conferences 97 02010

[12] Reference and legal system "Guarantor": [Electronic resource] NPP “Garant-Service”. [updated 2019 Oct 24; cited 2097 Dec 11]

[13] Orlov A D 2015 Optimized single-stage technology of granular foam glass based on low-temperature synthesis of glass phase Building materials 1 24–26

[14] Orlov A D 2014 Foam glass ceramic from mineral raw materials: the new one-stage technology “Thermogran” based on low-temperature synthesis of glass phase and its prospects Bulletin of SIC Construction 11 40–45

[15] Orlov A D , Nezhikov A V 2017 Foam glass ceramics as a filler for high-tech lightweight concrete Bulletin of SIC Construction 14 163–171

[16] Inozemtcev A S 2014 Average density and porosity of high-strength lightweight concrete Magazine of Civil Engineering 51(7) 31–37

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