Advanced Materials Research Vol. 746 (2013) pp 285-288
© (2013) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/AMR.746.285

Preparation and Research of the High-strength Lightweight Concrete based on Hollow Microspheres

Evgeniy Valerjevich Korolev[1, a], Alexandr Sergeevich Inozemtcev[1, b]

[1]Yaroslavskoje shosse, 26, 129337, Moscow, Russian Federation

[a]info@nocnt.ru

[b]InozemcevAS@mgsu.ru

Keywords: High-strength lightweight concrete, energy efficient concrete, lightweight concrete for construction, nanotechnology.

Abstract. The paper presents the results of research aimed at development of nanomodified high-strength lightweight concrete for construction. The developed concretes are of low average density and high ultimate compressive strength. It is shown that to produce this type of concrete one need to use hollow glass and aluminosilicate microspheres. To increase the durability of adhesion between cement stone and fine filler the authors offer to use complex nanodimensional modifier based on iron hydroxide sol and silica sol as a surface nanomodifier for hollow microspheres. It is hypothesized that the proposed modifier has complex effect on the activity of the cement hydration and, at the same time increases bond strength between filler and cement-mineral matrix. The compositions for energy-efficient nanomodified high-strength lightweight concrete which density is 1300...1500 kg/m3 and compressive strength is 40...70 MPa have been developed. The approaches to the design of high-strength lightweight concrete with density of less than 2000 kg/m^3 are formulated. It is noted that the proposed concretes possess dense homogeneous structure and moderate mobility. Thus, they allow processing by vibration during production. The economic and practical implications for realization of high-strength lightweight concrete in industrial production (in particular, for construction of high-rise buildings) have been justified. The results of industrial testing of new compositions in precast concrete technology are shown.

Introduction and previous work

During the construction of unique buildings and structures the construction materials with enhanced mechanical and operational properties are required. The constructional concrete with a low average density and high strength is one of such materials.

It is obvious that the reduction of density of the material is achieved by replacing the solid phase. In concrete, cement-based solid phase formed by binder, fillers and aggregates, performs the primary stress and deformation resistance, providing the material strength. Thus, lowering of the proportion of solid substances inevitably leads to reduction in strength due to a reduction of the strong crystal lattice. Thereby, the actual problem of modern material science is the development of materials with a universal internal structure; such structure should be able to compensate and to redistribute internal stresses in the bulk.

The investigations carried out in many countries around the world [1...8] show that high values of specific strength (which is one the most universal characteristic of constructional concrete) achievable only if the average density is not less than 1800 kg/m^3. During further reduction of density the specific strength does not exceed 30 MPa. The best values of specific strength were achieved by researchers in Brazil and Japan. In particular, Japanese scientists have developed a lightweight concrete with an average density of 1800...1850 kg/m3 and strength 47...54 MPa (corresponding specific strength is 27.5...30.0 MPa). In Brazil, similar values of specific strength were obtained by means of using hollow fillers: the average density was 1450...1600 kg/m3, strength was 40...50 MPa. In Russian Federation, scientists [9, 10] developed so-called “nanoconcretes” based on aluminosilicate hollow microspheres with dispersed reinforcement (basalt fiber, nanomodified by carbon particles of fulleroid type). Currently, the construction industry needs high-strength lightweight concretes with a specific strength not less then 30 MPa.

Experiments and discussion

The development of the high-strength lightweight concrete requires selection of optimal components that provide the required strength of the matrix and allow filling the bulk with the necessary volume of gas. It was shown by practical experience that the most promising way to do these is to use the porous aggregates. The best values of specific strength (parameter which eventually characterizes the technical efficiency of the material) can be obtained by means of using hollow microspheres.

We have carried out the massive experimental research during development of the lightweight high-strength concrete. The dependencies between specific strength of the concretes, amount of microspheres, types and values of admixtures, and many more factors are examined in detail.

It was shown that for concretes with hollow microspheres characterized by average density 1300…1500 kg/m^3 the specific strength may be rather high. One of the reasons for that is the cement and mineral constituents evenly coats the aggregate particles and provides a uniform contact area. As it follows from the image of concrete structure (Fig. 1), the microspheres with radius 21.0±0.5 um are characterized by 13.5 um interlayer; thickness of the cement-mineral matrix around a single particle of aluminum silicate microspheres is 6.75 um.

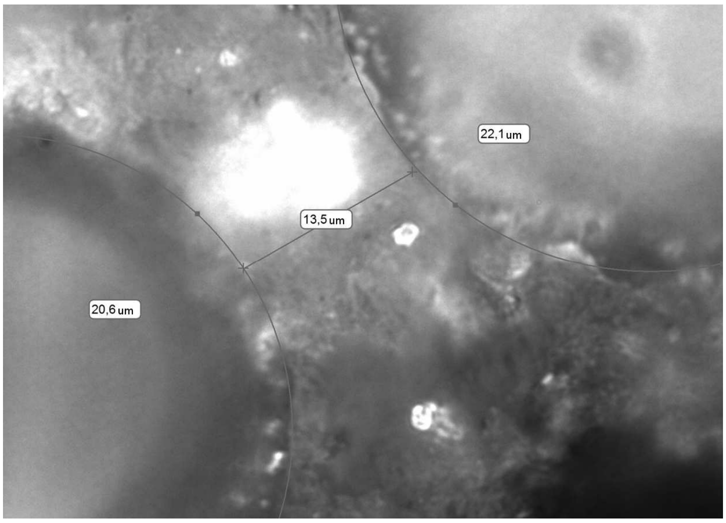

Fig. 1. Structure of the lightweight high-strength concrete

Considering that the average size of the microsphere is 70 um, and the volume content of cement matrix is 0.455, then the uniform distribution over the surface of the filler particles is achieved at theoretical thickness of 8.71 um. The similarity between theoretical and experimental results confirms the possibility of obtaining material with uniform “honeycomb” crystal frame.

It was also shown during the investigation process that most of the dependencies between control variables and specific strength are characterized by single maximum. The presence of this maximum corresponds to the optimal structure and can be explained with the assistance of percolation theory. Indeed, it is known [11] that there are two critical levels of volume fraction of disperse phase. The high level is about 0.34 and corresponds to the formation of the dense framework. Because of the specific arrangement of microspheres, formation of such framework leads to crack branching and increasing energy loss during crack propagation. Thus, the rate of strength decrease of lowers, but the rate of decline of average density is unchanged. In addition, the increase in the volume content of the microspheres in the concrete is accompanied by reduction of the proportion of quartz aggregates (of irregular angular shape), which acts as stress concentration points and initiates the propagation of microcracks. So the crack propagation and opening occurs at high loads due to uniform distribution of stresses acting on the particles. The hard shell of the microspheres provides a closed porosity, while keeping the high operational properties of the concrete (Table 1).

Table 1. Properties of lightweight high-strength concretes

#	Volumetric rate, [%].	Thickness of mineral layer, [um]	Average density, [kg/m^3]	Compressive strength at 24h age, [MPa]	Specific strength, [MPa]
1	0.438	11.15	1462	46.5	31.9
2	0.485	9.81	1356	45.9	33.8
3	0.532	8.71	1252	45.3	36.2

Dependence between volumetric rate of lightweight filler and properties of concrete

During the loading process variation of physical and mechanical properties, deviation of dimensions of the components of concrete and presence of defects lead to internal stresses. The highest stresses are at the boundaries, various point and line imperfections of structure (i.e. in the contact zone between dispersed medium and dispersed phase). Therefore, providing the required strength of cement paste and aggregate enables the provision of a solid boundary.

A number of researchers [12...16] described the physical and chemical processes on the surface of the glass microspheres, and investigated the activity of aluminosilicate microspheres. The ion exchange process between the shell of the microsphere and the cement matrix during hydration is also examined. This process contributes to the formation of calcium hydrosilicate, ettringite, aluminosilicate minerals and silica at the inter-phase boundary. The presence of amorphous silica and active zones on the shells of the microspheres ensures reinforcement in the contact zone.

The strength at the interphase boundary can be increased by means of using the nanoscale surface modifiers or using traditional mineral admixtures. We propose to use an integrated nanoscale modifier based on iron hydroxide sol and silica sol. Production of the modifier based on a new method of synthesis of silica sol [17]. This method includes chemical binding of positively charged sodium ions in precursor. Because of the formation of calcium hydrosilicates of type I and formation of a new phase (represented by goethite FeOOH [18]) there is an increase of adhesion between the shells of the microspheres and cement-mineral matrix. Application of the developed modifier increases the strength of lightweight concrete by 15% [19].

During the investigation of the effect of mineral supplements it has shown that silica fume (added in amount up to 20%) enhances the strength of the concrete to a value of 60 MPa. Tiny particles of silica surround each grain of cement. Sealing the grout, they fill the voids between solid hydration products and improve adhesion.

The rheological properties of the concrete mix are very important for the construction industry. The examination has shown that the microspheres lead to high water demand, which in turn leads to an increase of water consumption. However, the use of super plasticizers solves this problem. The rheological properties of lightweight concrete meet the requirements for the production of precast and reinforced concrete. It was found that most effective plasticizing agents are those based on polycarboxylates. By means of using such modifiers it is possible to keep good rheological properties of the mix and achieve dense structure of the hardened lightweight concrete.

Conclusion

Thus, by means of using hollow glass or aluminum silicate microspheres and optimal combination of cement, mineral, quartz components and modifiers it is possible to improve the adhesion at the interphase boundary and produce lightweight concrete with high strength.

The developed energy-efficient nanomodified lightweight concretes based hollow microspheres have a versatile combination of physical, mechanical, thermal and operational properties. This combination can significantly expand the area of application of such concretes. We propose to use them as a structural material for construction of high-rise buildings. The concretes can also be used for pre-cast construction, building bridges, road junctions and special structures.

By means of using of developed concrete the weight of the constructions can reduces by 40%. This reduces the demands on the grounds and foundations. The number of floors can be increased. The construction process can be performed in areas with poor soils.

Developed concrete has a low coefficient of thermal conductivity, which reduces the cost of heat insulation and reduces energy consumption during normal operation of the building.

Acknowledgements

This work is partially supported by Grant MD-6090.2012.8 of Russian Federation President.

References

[1] J. Alduaij et al., in: Cement and Concrete Composites, Vol. 21 (1999), p. 453-458.

[2] A.P. Proshin et al., in: Building materials. #3 (2002), p. 14-15.

[3] A.I. Bedov et al., in: Reports of MGSU. #3. (2012), p. 76-84.

[4] S.P. McBride et al., in: Journal of materials science. Vol. 37 (2002), p. 4217-4225.

[5] J. A. Rossignolo et al., in: Cem. Con. Compo. Vol. 25 (2003), p. 77-82.

[6] Yasar E. et al., in: Materials Letters. Vol. 57 (2003), p. 2267-2270.

[7] Evaluation of fatigue durability precast PC slab lightweight high-strength // Technical Report Ishikawajimaharima, Vol. 44, #2 (2004), p. 83-90.

[8] A.A. Andrianov. Abst. diss. … cand. tech. science. Moscow (2007), 15 p.

[9] A.N. Ponomarev, M.I. Yudovich, RF Patent 2355656 (2009).

[10] O.L. Figovsky et al., in: Nanotechnologies in construction, #3 (2012), p. 4-17

[11] A.N. Bobryshev et al. Synergistic of composites. Lipeck (1994), 153 p.

[12] J.Y. Wang et al., in: Cement and Concrete Research. Vol. 42 (2012), p. 727.

[13] Kretova U.V. Abst. diss. ... cand. tech. science. Moscow (2012), 22 p.

[14] D.V. Oreshkin et al., in: Oil industry engineer, #3 (2010), p. 43-44.

[15] A.V. Klochkov. Abst. diss. ... cand. tech. science. St. Petersburg (2012), 22 p.

[16] A.N. Grishina et al., in: proceedings of the second conf. «Sol-gel». Sevastopol (2012), p. 28.

[17] Information on http://ntsr.info/science/library/2906.htm

[18] A.S. Inozemtcev et al., in: Nanotechnologies in construction, #1 (2013), p. 4-17

[19] A.S. Inozemtcev et al., in: Reports of Povolzh'je. (2012), p. 198-206.