Fibre-reinforced foam concrete with hollow glass microspheres

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Abstract. The article covers the results of research and experimental studies aimed at determination of the impact of hollow glass microspheres on the properties of light fine-aggregate foam concrete. The authors determined the physical and mechanic characteristics of foam concrete containing a different amount of microspheres, polymer and basalt fibres using different foaming and superplasticising agents. It was determined that optimal content of hollow glass microspheres with respect to quartz sand is 50%. As a result strength properties increased by 16-23%. Foaming agents PO-6 and PB-2000, superplasticising agent Sika ViscoCrete 5-800, polypropylene fibre VSM and basalt fibre were selected as the most efficient. The authors found out that the introduction of coated hollow glass microspheres MS-VP-A9* facilitated the improvement of the pore space structure and the increase in interpore partition strength.

1. Introduction
The use of reinforced concrete products that are light but provide for required strength is becoming very important in construction nowadays. Thus, the interest to the use of light heat insulation elements of fencing structures providing for required strength, high crack resistance and durability is growing [1-7].

2. Relevance
The performed analysis of the studies of the use of different fibres in mesh materials has shown that their strength is higher, shrinkage strain is lower, and crack resistance and durability are higher. Use of fine-grained fibre fillers in cement concrete exerts positive impact on structurization, physical and mechanical properties as well as operational characteristics of concrete. This is achieved by means of better adhesion of fibres to cement matrix, a relatively high strength and elasticity modulus of fibres. Polymer and basalt fibres are most widely spread as components for reinforcement of concrete matrix. They have low density, but provide for three-dimensional increase of strength and prevent from the formation of micro-fractures [8-15].

3. Problem statement
When fibre-reinforced foam concrete are used not only for heat insulation, but also for the construction of low-rise energy-saving fencing structures of buildings and facilities it is necessary to find an optimal ratio between high strength and low density, i. e. it is necessary to increase the strength-density ratio. For that it is necessary to study and develop optimal composition of fibre-
reinforced foam concretes using polymer and basalt disperse fibres, microporous fillers and highly efficient superplasticising agents and modifying agents which improve the physical and mechanical properties and heat insulation capacity by means of optimization of the structure of fibre-reinforced foam concrete at micro- and nano-levels.

4. Theoretical part
We have theoretically substantiated the possibility for the results of density, improvement of strength and crack resistance of fibre-reinforced foam concrete by means of introduction of coated hollow grass microspheres [16-24].

The properties of the materials are to be adjusted at the micro- and nano-levels at the initial moment of the formation of the structure of fibre-reinforced foam concrete. We have analyzed the use of fine-aggregate fibre fillers, superplasticising agents and hollow glass microspheres in mesh concrete. The possibility to improve the efficiency of the process of production of modified fine-aggregate fibre-reinforced foam concrete mixture with the view to improve its compressive strength and tension in bending using components than strengthen the fibre-reinforced foam concrete structure the micro-and nano-level has been substantiated.

The aim of the scientific research into increase the strength of fibre-reinforced foam concrete maintaining a relatively low density. We managed to reduce the density of fibre-reinforced foam concrete and improve its strength and crack resistance at micro-level by means of introduction in it of coated hollow glass microspheres MS-VP-A9* manufactured as per technical specification TU 6-48-91-92 in OAO NPO Stekloplastik.

Hollow glass microspheres are a white loose powder consisting of tiny thin-wall balls with a diameter of 20-160 mcm and wall thickness less than 2 mcm. The composition of glass and almost regular spherical shape provide for their high compression strength, low water absorption, low thermal conductivity, high resistance to chemical agents and radiotransparency.

We have considered different concentrations of hollow glass microstructures both combined with sand and without sand, i. e. completely replacing sand.

All specimens series were manufactured using cement manufactured by ZAO Oskolcement grade CEM I 42.5N (Portland cement, M500 D0), sand by ZAO Orlovskiy Sand Pit with fineness modulus 1.91, polypropylene construction micro-reinforcing fibre (CMRF) or basalt fibre and using one of foaming agents or general-purpose fire-fighting foam PO-6 or foaming agent PB-2000.

5. Results of experimental studies
Table 1 shows the results of the study of the impact of hollow glass microspheres on physical and mechanical properties of fibre-reinforced foam concrete with polypropylene fibre, general-purpose fire-fighting foam PO-6 and superplasticising agent Sika ViscoCrete 5-800.

The performed studies have demonstrated that the use of hollow glass microspheres results in the increase of compression strength compared to the composition of the mixture containing only sand. The highest compression strength has the composition with equal content of sand and hollow glass microspheres, i. e 50 %. The compression strength increased by 16.4 %, bending strength increased by 23 %.

When adding into foam concrete coated hollow glass microspheres MS-VP-A9*, they are evenly distributed in the mixture and form a uniform structure thus increasing strength and crack resistance and improving bonding with cement matrix.

The increase of strength and crack resistance of fibre-reinforced foam concrete occurs because the local fracture formed under mechanical pressure always meets on its way hollow glass microspheres having relatively high strength and fibre that bonds the cement matrix.

The performed research allowed obtaining the compositions of fibre-reinforced foam concrete with improved physical and mechanic properties by means of strengthening of at micro- and macro-levels.
Table 1. Impact of hollow glass microspheres on the properties of fibre-reinforced foam concrete with foaming agent PO-6, superplasticising agent Sika ViscoCrete 5-800 and polypropylene fibre.

| Percentage of sand (S) and spheres (SH), % | Quantity of sand, g | Quantity of glass spheres, g | Quantity of water, ml | Density kg/m³ | Strength of fibre-reinforced foam concrete, MPa |
|------------------------------------------|---------------------|----------------------------|----------------------|---------------|---------------------------------------------|
| Reference (100 % sand)                   | 240                 | -                          | 210                  | 698.67        | 3.13                                        |
| Spheres, 100 %                           | -                   | 48                         | 270                  | 529.67        | 3.43                                        |
| SxSH=50x50                               | 120                 | 24                         | 240                  | 534.33        | 3.85                                        |
| SxSH=75x25                               | 180                 | 12                         | 220                  | 574.00        | 3.55                                        |
| SxSH=25x75                               | 60                  | 36                         | 255                  | 594.67        | 3.58                                        |

During further experiments we have tested the specimens with superplasticising agent Sika ViscoCrete 5-800, polypropylene fibre and using hollow glass microspheres and foaming agent PB-2000. Table 2 shows the results of the study of the impact of hollow glass microspheres on physical and mechanical properties of fibre-reinforced foam concrete with polypropylene fibre, foaming agent PB-2000 and superplasticising agent Sika ViscoCrete 5-800.

The analysis of the obtained data showed that strength increased as a result of the use of hollow glass microspheres and superplasticising agent Sika ViscoCrete 5-800. The highest compression strength was obtained with 100 % concentration of hollow glass microspheres, i. e. without sand. The obtained strength is higher than that of reference specimens without spheres by 28.5 %, and bending strength increased by 23.3 %.

Table 2. Impact of hollow glass microspheres on the properties of fibre-reinforced foam concrete with foaming agent PB-2000, superplasticising agent Sika ViscoCrete 5-800 and polypropylene fibre.

| Percentage of sand (S) and spheres (SH), % | Quantity of sand, g | Quantity of glass spheres, g | Quantity of water, ml | Density kg/m³ | Strength of fibre-reinforced foam concrete, MPa |
|------------------------------------------|---------------------|----------------------------|----------------------|---------------|---------------------------------------------|
| Reference (100 % sand)                   | 240                 | -                          | 210                  | 598.67        | 2.96                                        |
| Spheres, 100 %                           | -                   | 48                         | 270                  | 527.33        | 3.65                                        |
| SxSH=50x50                               | 120                 | 24                         | 240                  | 573.67        | 3.21                                        |
| SxSH=75x25                               | 180                 | 12                         | 225                  | 583.33        | 3.41                                        |
| SxSH=25x75                               | 60                  | 36                         | 255                  | 528.33        | 3.59                                        |

During further experiments, we used the above described composition of fibre-reinforced foam concrete with basalt fibre, superplasticising agent Sika ViscoCrete 5-800 and foaming agent PO-6. The data obtained during the experiment are given in Table 3.
Table 3. Impact of hollow glass microspheres on the properties of fibre-reinforced foam concrete with foaming agent PO-6, superplasticising agent Sika ViscoCrete 5-800 and basalt fibre.

| Percentage of sand (S) and spheres (SH), % | Quantity of sand, g | Quantity of glass spheres, g | Quantity of water, ml | Density kg/m³ | Strength of fibre-reinforced foam concrete, MPa |
|------------------------------------------|---------------------|------------------------------|----------------------|---------------|---------------------------------------------|
| Reference (100 % sand)                   | 240                 | -                            | 210                  | 614.67        | 3.29                                        |
| Spheres, 100 %                           | -                   | 48                           | 275                  | 578.00        | 3.99                                        |
| SxSH=50x50                               | 120                 | 24                           | 240                  | 434.67        | 3.61                                        |
| SxSH=75x25                               | 180                 | 12                           | 220                  | 553.67        | 3.78                                        |
| SxSH=25x75                               | 60                  | 36                           | 255                  | 481.67        | 3.97                                        |

The experiments have shown that the highest compressive strength is demonstrated by the composition with 100 % content of hollow glass micro-spheres. Strength increased by 33.8 % if compared to the reference specimen having no microspheres. Bending strength increased by 21.3 %.

In the course of further experiments we have tested the specimens with superplasticising agent Sika ViscoCrete 5-800, basalt fibre and using hollow glass microspheres and foaming agent PB-2000.

The results of tests are presented in Table 4.

Table 4. Impact of hollow glass microspheres on the properties of fibre-reinforced foam concrete with foaming agent PB-2000, superplasticising agent Sika ViscoCrete 5-800 and basalt fibre.

| Percentage of sand (S) and spheres (SH), % | Quantity of sand, g | Quantity of glass spheres, g | Quantity of water, ml | Density kg/m³ | Strength of fibre-reinforced foam concrete, MPa |
|------------------------------------------|---------------------|------------------------------|----------------------|---------------|---------------------------------------------|
| Reference (100 % sand)                   | 240                 | -                            | 215                  | 458.33        | 3.11                                        |
| Spheres, 100 %                           | -                   | 48                           | 270                  | 455.67        | 3.94                                        |
| SxSH=50x50                               | 120                 | 24                           | 240                  | 539.00        | 3.25                                        |
| SxSH=75x25                               | 180                 | 12                           | 225                  | 563.67        | 4.56                                        |
| SxSH=25x75                               | 60                  | 36                           | 255                  | 455.67        | 3.38                                        |

The analysis of the obtained data showed that compression strength in-creased as a result of the use of hollow glass microspheres and superplasticising agent Sika ViscoCrete 5-800. Maximum compression strength was obtained in the specimens where hollow glass microspheres completely replace sand, it increased by 32.5 % if compared to the reference specimen. Bending strength increased by 26.7 %. 
Presence of a large quantity of hollow glass microspheres allowed to receive a fibre-reinforced foam concrete structure with open air voids as a result of the use of foaming agent, and closed voids as a result of the use of rather strong microspheres. The space between these air voids is bonded by rather strong basalt reinforced baffles of the matrix.

6. Conclusions
Thus, introduction of coated hollow glass microspheres MS-VP-A9* into fibre-reinforced foam concrete mixture increased strength and homogeneity of the mixture and some reduction of the density of fibre-reinforced foam concrete compared to the compositions without microspheres. The best results showed that compositions where the concentration of coated hollow glass microspheres equaled 50 % and 100 %. However, taking into account the microspheres are rather expensive, their price is 300 rubles for 1 kg, during further experiments we used microspheres in quantity not exceeding 50%.

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