Diversive particles filler forms influence on mechanical properties foam concrete mixes

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Abstract. Problems of energy saving in the building complex require the development of gas-filled concrete technologies. The existing level of knowledge about the regularities of the formation of high-strength structures is insufficient for the qualitative management of technological processes in production. Therefore, an attempt to analyze the effect of the recipe and the surface properties of raw materials on the rate of phase transitions in foam concrete mixes and their strength has been made. The positive qualitative and quantitative influence of the aggregate fibrous form on the properties of the foam concrete mixes has been established.

Introduction
Modern building complex is in need of fireproof, strong and cheap wall materials from concrete [1, 2, 3]. Materials that meet the requirements for fire safety and economy are best matched with cellular concrete (foam and aerated concrete) [3, 4]. However, their strength and crack resistance often do not meet the consumers’ demands [5, 6, 7]. Therefore, experts in the field of materials science, relying on the results of the fundamental science development, offer new ways to improve the properties of such concretes [8, 9].

Dispersed reinforcement of foam concrete mixes with synthetic fiber pieces practically does not affect the structural properties of foam concrete in terms of compressive strength [10, 11], but it has ability to change their tensile strength and as a consequence crack resistance, shrinkage deformability and fracture energy intensity [12, 13, 14]. The foregoing predetermines the relevance of scientific research of problems relating to the specific features of the foam concrete mixes structure formation, depending on the shape and size of the dispersed particles of raw materials used for their manufacture.

The problem definition
The goal of the presented work is a systematic analysis of the factors controlling:
- sedimentation resistance (stratification) of foam concrete mixture structure;
- aggregative stability (ability to maintain dispersed gas phase) of foam concrete mixture structure;
- phase transition speed of mixtures from viscoelastic to elastic condition.

Scientific substantiation of the objective solution
The listed factors are chosen because they predetermine the possibility or impossibility of obtaining foam concrete with given mechanical properties [2, 9, 10]. In the period between the completion of the mold mixing and the beginning of setting cement between the dispersed particles of foam concrete mixtures only weak bonds act. They consist of the capillary bonding liquid phase forces and surficial van der Waals forces. Those mixtures are considered to be water-bearing and three-phase disperse systems. The dispersed gaseous phase, depending on the design density of the concrete, belongs to 85 - 50% of the volume (foam concrete with an average density of 300 to 1000 kg / m³ respectively). Water takes in its volume from 450 to 250 liters (respectively) before the foam concrete solidification and drying.

We believe that the existing differences in the raw materials dispersed particles individual density are very important and affect the stability of mixtures. They exceed 100 times (air density 0.023 kg / m³, water 1 kg / m³, and cement in average of 3 kg / m³). In addition, there are technologically justified differences in sizes of dispersed particles of the solid phase, which as a result of the gravitational forces action can affect the sedimentation stability of mixtures in a negative way [15]. And in case of prevalence of viscous bonds between components the prescription conditions for coalescence of foam films [16] arise, then due to the development of ejecting forces, prerequisites for aggregate stability violations foam concrete mixes [17] are developed.

90% of the cement particles have a size of less than 0.08 mm and a granular or lamellar shape. Particles of mineral aggregate from ground sand as a rule have a granular shape and size of 0, 01 to 0, 6 mm. The dispersed gas phase is characterized mainly by a spherical shape with a particle diameter of 0.1 to several mm [18]. Dispersed reinforcement structure is the only component of the mixtures considered, which has the shape of a fiber with length (from 12 to 40 mm) and is at least 1000 times larger than the cross-sectional dimensions (0.01 to 0.02 mm) and has density close to the density of water (polypropylene 0.96 g / cm³, polyamide 1.14 g / cm³, etc.).

Formation of the foam concrete structure begins in the viscous-plastic phase after completion of mixing and placing the mixtures in molds. In this initial period of the structure formation the following processes in the material under consideration take place:
- adsorption and chemical intensive dispersion of the binder cement particles [19]. As a result the following factors are increased:
  * total area of the interface;
  * The proportion of mixing water that is physically firmly bound to solid particles;
  - the clusters formation from dispersed particles of a solid phase in the structure of interporous partitions. Since the inherent property of clusters is their high density at the center and smaller at the periphery [20], some of the physically weakly bound water will move towards the water shells of the foam films and thus contribute to the increase in their elasticity;
  - the hydration of clinker minerals and the formation of percolation gratings from hydrated phases will eventually lead a foam concrete mix to a phase transition from viscous-plastic to elastic state.

The duration of the last considered process determines the degree of the solidified foam concrete defectiveness and as a consequence its strength. This occurs because during the initial structure, the mixtures under consideration are in a complex temperature and mass exchange state. The hardening cement heats the mixture [21] and adversely affects the capillary bonding forces in a dispersion medium consisting of water and surface-active substances (surfactants). With action of gravitational forces the surfactant concentration change as well as physically weakly bound water interporous partitions separation may occur. If this phenomenon takes place before the transition phase, it leads to a deterioration of the mechanical properties of concrete. After the cement setting process is completed, the described phenomenon is safe. Therefore, the shorter the duration of the phase transition, the better can be the mechanical properties of the foam concrete [22, 23].

**Methodology and experiment results**

In the course of experimental studies, the influence of the shape of the raw components and the consumption of the foaming agent has been under study:
- foam concrete mixture sedimentation resistance;
- foam concrete mixture structure aggregative stability;
- speed of phase transition of mixtures from viscoelastic to elastic condition.

For this purpose, foam concrete mixes are produced in a turbulent mixer using a one-stage technology with a constant "cement-filler" ratio, fixed consumption of mineral binder and water-cement ratio. As a filler quartz sand with the particle size from 0.1 to 0.6 mm and a polyamide fiber of 0.014 mm in diameter with a length of 20 mm was used. The ratio between the consumption of cement and aggregate was C:Z = 2:1. Fibro-foam-concrete mixes contained 2% of the cement volume (corresponding to 4% of the sand volume).

**Table 1.** Influence of the flow of foaming agent and forms aggregates on the value * of plastic strength at foam concrete mixes

| Duration of structure formation, min | Plastic strength of mixtures at foaming agent consumption, % |
|-------------------------------------|-------------------------------------------------------------|
| 0                                   | 36/69  45/75  49/81  47/81  47/81  48/78  46/74          |
| 15                                  | 45/76  68/82  70/90  49/96  49/98  49/95  48/88          |
| thirty                              | 45/80  70/80  73/88  56/92  56/95  52/95  51/90          |
| 45                                  | 49/88  92/102 98/12 8 70/127 70/133 68/112 65/112       |
| 60                                  | 55/107 89/126 95/15 8 65/164 63/152 60/149 60/133       |
| 75                                  | 52/110 112/135 122/165 90/158 87/145 78/136 78/128      |
| 90                                  | 65/136 126/162 142/188 131/194 77/170 60/170 59/146      |
| 105                                 | 73/152 111/194 134/219 106/236 93/204 88/198 76/162      |
| 120                                 | 77/165 108/226 130/274 116/280 102/245 102/218 102/200   |
| 135                                 | 80/177 100/236 145/292 116/292 130/288 124/244 118/256   |
| 150                                 | 86/190 98/267 140/336 129/342 125/336 111/290 102/287    |
| 165                                 | 95/207 114/298 162/372 162/403 144/384 127/313 111/321   |
| 180                                 | 118/26 129/352 192/438 207/497 169/412 154/366 133/354   |
| Presence of signs **                | I S+ / S S / S- S-/ S-/                                      |
|                                     | G/ G+ / G- G+ / G                                        |
| Stability of the structure, % | 78/88 | 92/97 | 96/100 | 97/100 | 95/100 | 93/99 | 91/97 |
|-----------------------------|-------|-------|--------|--------|--------|-------|-------|

Notes:
- the parameters of foam concrete mixes are in the numerator, the parameters of fiber - foam concrete mixes are in the denominator;
- ** presence of aggregative instability (loss of gas phase) signs G, sedimentary instability S.

The sign "+" emphasizes the intensity of the process, "." - its minor manifestations.

The consumption of foaming agent “Arekom-4” was assigned as a percentage of the mixing water volume and it varied in the range of 0.2 ... 0.5%. The resulting mixtures were placed in 5-liter containers to evaluate the kinetics of the plastic strength set. In addition, sample cubes with an edge of 100 mm and sample beads measuring 40x40x160 mm were molded. For mixtures placed in 5-liter containers, the following properties were monitored during 3 hours of hardening at an interval of 15 minutes:

- the density of the mixture immediately after preparation and after the setting is completed, based on the values obtained, the stability measure of the obtained structure in % was established by the ratio of the volumes of the viscous-plastic and elastic mixtures;
- the presence of sedimentary or aggregative instability signs;
- the value of plastic strength at a specific time of hardening in Pa.

From the data presented in Table 1 it follows that the plastic strength of the mixtures studied depends on the consumption of the foaming agent nonlinearly. The foam concrete mixtures obtained in the course of the experiment in the foaming agent (FA) consumption range from 0.2 to 0.35 % had sedimentary instability. As the FA = 0.35 % approaching the flow rate, the signs of sedimentation decreased, but have not completely disappear. At a software consumption of 0.4 to 0.5 %, all foam concrete mixtures showed a partial loss of the dispersed gas phase involved in mixing. That is, the foaming agent reaching a critical micelle concentration resulted the coalescence of foamed films. Thus the foam concrete mixtures under consideration possess:

- the optimum surfactant consumption in the range 0.35 ... 0.40% in relation to the flow rate of water;
- sensitivity to the accuracy of dispensing foamer less than 0.05%.

Replacing part of the sand volume with a dispersion arm in the recipe made it possible not only to increase the absolute values of the plastic strength of the mixtures (Table 1), but also to establish the range of the foaming agent consumption, within which they had no signs of sedimentation or disruption of aggregative stability. In our experiments this content of foaming agent is 0.3 ... 0.4 %. In the indicated range, fibro-foam-concrete mixtures retained the properties they obtained while being mixed during the transition phase from the viscous state to the elastic state. The latter testifies that:

- the presence of synthetic dispersed reinforcement within the concrete mixtures allows their structure to become resistant to fluctuations, which occur during the transition phase from the viscous state to the elastic state;
- sensitivity to the accuracy of foaming mixtures dosing in fibro-foam-concrete mixtures is reduced to 0.1%.

Summary
The performed experimental researches have shown that the replacement of 4 % of the volume of granular aggregate particles with fibrous ones provides the following technologically important advantages in the production of foam concrete:

1) sensitivity of the mixtures to the accuracy of the foaming agent dispensing is reduced at least 5 times;
2) the structural strength of the mixtures is 1.5 ... 2.0 times increased.

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