Strength properties of cement slurries with lightweights applied in oil and gas wells

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Abstract. The article is focused on the cement stone strength properties resulted from lightweight cement slurries that meet GOST-1581-96 (state Standards) requirements. Exfoliated vermiculite, hollow aluminosilicate microspheres (HAMS), diatomite and perlite were used as lightweighting additives.

1. Introduction
Nowadays well-drilling is being conducted in complicated geological conditions where conventional cement slurries do not provide required cement-pipe bonding. As a rule, the use of lightweight additives ensures appropriate density of the cement slurry to avoid circulation loss or hydraulic fracture of the formations around the well. However, the cement slurry density decrease results in weakening of cement stone.

2. Methodology
To study the issue a set of experiments was conducted to assess cement stone strength according to GOST 1581-96 (State Standard). Exfoliated vermiculite, hollow aluminosilicate microspheres (HAMS), diatomite and perlite were used as lightweight additives. To study the issue in details the basic parameters of the lightweight additives and their interactions with the cement slurry were initially studied.

Vermiculite is a cleavage-structured mineral of the hydromica group. It forms large tabular golden yellow or fulvous crystals. The mineral expands into worm-like strands and increases 15-25 times in volume when heated (up to 400-1000 ° C). After being added into cement slurry it tends to float up. High vermiculite concentration in slurry leads to coagulation, which makes the slurry grout have poor spreadability.

Diatomite is a weakly-consolidated soft opaline sedimentary rock that can range in color from white and grayish white to dark grey, fulvous, red and black. Its density ranges from 1.2 to 2.5 g/cm³, porosity value is 50-70%. It has good water absorption. When added into the cement slurry, it mostly floats up. It tends to collapse under high pressure.
HAMS are produced in the process of high temperature coal flame combustion. They have smooth surfaces and diameters ranging from 10 to several hundreds of µm with an average diameter of 100 µm. An average particle density is 2.5 g/cm$^3$. They are characterized by low density, high mechanical durability, chemical and thermal stability and low thermal conductivity. When added into the cement slurry grout, HAMS tend to float up and generate foamy film on the slurry surface.

Perlite is a glassy igneous rock, the structure of which represents the systems of spheroidal concentric cracks (perlitic structure). It can be of different tones of black, green, reddish fulvous, brown and white colors. Its bulk density varies from 45 to 200 kg/m$^3$.

Having analyzed the data mentioned above it can be concluded that each lightweight added into slurry grout has particular impact on the strength properties of the cement stone. [1]

A cement compression and flexural machine “Matest”, model E160 was used to conduct the experiments. The samples were cement bars with the additives 40×40×100 mm. The bars were kept in water at a temperature of 75ºC for 48 hours before being tested. Figure 1 shows the machine and the lay-out of bars under test.

**Table 1. Results of destruction of cement bars with exfoliated vermiculite**

| №   | Composition, % | Density, g/cm$^3$ | Flex. strength, mPa |
|-----|----------------|-------------------|---------------------|
| Oil-well portland cement | vermiculite fraction ≥ 0.6 | | |
| 1   | 95 5          | 1.36              | 2.28                |
| 2   | 95 5          | 1.36              | 2.33                |
| 3   | 95 5          | 1.36              | 2.29                |
| Oil-well portland cement | vermiculite fraction 0.6-0.3 | | |
| 1   | 95 5          | 1.44              | 2.76                |
| 2   | 95 5          | 1.44              | 2.79                |
| 3   | 95 5          | 1.44              | 2.66                |

3. Results and discussions
Tables 1-4 contain the results of strength properties measurement. Minimum 3 samples of each recipe of slurry grout with lightweight additives were tested [2-7].
The results of the cement bar destruction show that the increase in exfoliated vermiculite content decreases strength properties of the samples. It was determined that the samples with finer fraction have more strength properties. Thus, it is reasonable to use appropriate content of exfoliated vermiculite of fine fraction in the slurry grout.

The experimental data prove that the increase in diatomite content does not significantly influence the slurry grout density. However, it should be taken into consideration that finer fraction of diatomite grains increases bulk density of the lightweight. Thus, the fracture and bulk density inhomogeneity results in slurry density tolerance, which, in its turn, influences cement stone properties.

| №  | Composition, % | Density, g/cm³ | max. stress, mPa |
|----|----------------|----------------|------------------|
|    | Oil-well portland cement |                 |                  |
| 1  | 92             | 8              | 2.08             |
| 2  | 92             | 8              | 2.45             |
| 3  | 92             | 8              | 2.23             |
|    | Oil-well portland cement |                 |                  |
| 1  | 90             | 10             | 1.98             |
| 2  | 90             | 10             | 2.08             |
| 3  | 90             | 10             | 2.23             |
|    | Oil-well portland cement |                 |                  |
| 1  | 87             | 13             | 2.46             |
| 2  | 87             | 13             | 2.59             |
| 3  | 87             | 13             | 2.5              |
Table 3. Results of destruction of cement bars with HAMS

| №  | Composition, % | Density, g/cm³ | Max. Stress, mPa |
|----|----------------|----------------|-------------------|
|    | Oil-well portland cement | HAMS          |                   |
| 1  | 97             | 3              | 3.41              |
| 2  | 97             | 3              | 3.39              |
| 3  | 97             | 3              | 3.31              |
|    | Oil-well portland cement | HAMS          |                   |
| 1  | 96             | 4              | 3.31              |
| 2  | 96             | 4              | 3.32              |
| 3  | 96             | 4              | 3.29              |
|    | Oil-well portland cement | HAMS          |                   |
| 1  | 94             | 6              | 3.21              |
| 2  | 94             | 6              | 3.18              |
| 3  | 94             | 6              | 3.18              |
|    | Oil-well portland cement | HAMS          |                   |
| 1  | 92             | 8              | 2.16              |
| 2  | 92             | 8              | 2.39              |
| 3  | 92             | 8              | 2.3               |

The data obtained while testing the bars with HAMS show that the most appropriate HAMS content in slurry grout varies from 4 to 6%. With necessary density, the samples cement+HAMS have greater strength properties if compared to the samples cement+vermiculite and cement+diatomite. It should be noted that with 3% of HAMS, the slurry grout is poorly spreadable, which impairs transport property of the grout. More than 8% of the additive content leads to density reduction, which does not meet OB-5 GOST-1581-96 (state Standards) requirements.
Table 4. Results of destruction of cement bars with perlite

| №  | Composition, % | Density, g/cm³ | Max. Stress, mPa |
|----|----------------|----------------|-----------------|
| 1  | Oil-well portland cement perlite | 98             | 2               | 3.79  |
| 2  | 98             | 2              | 1.53            | 3.83  |
| 3  | 98             | 2              | 3.89            |       |
| 1  | Oil-well portland cement perlite | 96             | 4               | 3.57  |
| 2  | 96             | 4              | 1.52            | 3.46  |
| 3  | 96             | 4              | 3.41            |       |
| 1  | Oil-well portland cement perlite | 94             | 6               | 2.98  |
| 2  | 94             | 6              | 1.50            | 3.09  |
| 3  | 94             | 6              | 3.10            |       |
| 1  | Oil-well portland cement perlite | 92             | 8               | 2.43  |
| 2  | 92             | 8              | 1.49            | 2.39  |
| 3  | 92             | 8              | 2.37            |       |

The results obtained by testing cement bar samples with perlite are similar to those of the tests with other additive.

4. Conclusion.
It can be concluded that it is reasonable to apply lightweight additives in cement slurries. However, the cost of the additives should also be taken into account since it contributes to the cost of well drilling. Rheological properties are another aspect to be paid attention to. Thus, when HAMS being used as additive, poor slurry spreadability was constantly observed, this impedes proper slurry motion in the annulus. On the contrary, the application of exfoliated vermiculite resulted in sufficient reduction of slurry density with the rheological properties being the same.

References
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