Selecting shotcrete composition for Vostoktsvetmet mines

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Abstract. According to the results of the pilot trials in mines of Vostoktsvetmet, the combination shotcrete lining ensures stability and safety of underground excavation in complicated ground conditions. The paper presents the information on the conformity of the shotcrete mixture components to the standards. The compositions for the wet-mix shotcreting are selected. It is shown that inert materials used in the compositions have considerable influence on the properties of shotcrete mixes and shotcrete linings. The cost per unit of basic process materials (mixture components) is calculated in terms of Orlov Mine.

According to [1], shotcrete mixtures include binder, filler, admixtures and water. When required, shotcrete may include reinforcement fibers.

Shotcrete lining should use concrete having class and grade determined at the age of 28 days:
— compression strength classes: B22.5; B25; B30; B35; B40;
— axial tension strength classes: \( B_t = 1.6; 2.0; 2.4; 2.8; 3.2; B_{t0} = 3.6; 4.0; \)
— freeze resistance grades: \( F_{100}; F_{150}; F_{200}; F_{300}; \)
— water resistance grades: \( W_4; W_6; W_8. \)

Compression strength class of concrete should be B25 in line with [2] and B22.5 as per [3]. In B25 class, the average compression strength of concrete at the age of 28 days is 32.06 MPa, and recommended cement grade is 400. In concrete class \( B_t = 1.6 \), the average axial tension strength and bending tension at the age of 28 days is 2.06 MPa, and recommended cement grades is 20.

Based on the generalized experience of use of different cement grades from different manufacturers in East Kazakhstan, it is concluded that cement of Semey Cement Plant sometimes fails to exhibit the rated specifications as against cement of Bukhtarma Cement Company. Furthermore, Bukhtarma cement has higher strength characteristics than Semey cement as follows from practice of backfill preparation and use.

The laboratory tests on conformity between shotcrete mixes and standards and the selection of wet-mix shotcrete have been carried out in the Certification Testing Laboratory of the East Kazakhstan State Technical University, in a special construction and backfilling laboratory at Ridder–Kazzinc, BASF-Central Asia and Normet Company. The compression and bending testing results for different cement grades are given in Figure 1.

The best conformity with the strength standards is demonstrated by cement grades CEM II/A-Sh 42.5 N (Bukhtarma Cement Company) and PTs400-D20 (Semey Cement Plant). The cement grades have almost the same compression strength characteristic, while CEM II/A-Sh 42.5 N cement grade has the increased bending strength, which is one of the basic properties of shotcrete). The cement grades have approximately equal costs, too.
Figure 1. Compression and bending testing of different cement grades at the age of 7 days: 1—CEM II/A-Sh 42.5 N (Bukhtarma); 2—PTs400-D20 (Semey); 3—PTs400-D0 N (Bukhtarma); 4—PTs500-D0 N (Bukhtarma); 5—CEM V/A )Sh-P) 32.5 N (Bukhtarma); 6—CEM I/42.5 N SS (Bukhtarma); 7—cement from Orlov Mine.

Shotcrete mix filler may be:
— sand as per state standards GOST 8736, GOST 26633 and GOST 9757;
— break stone or grave by GOST 8267;
— light fillers by GOST 9757.

Sand and gravel mix should have characteristic described below:
— size modulus not less than 2 (in case that size modulus is less than 2, special experimentation equipment is required);
— moisture content to 7%;
— limit content of clayey particles and fine powder dust to 3%;
— clot clay content to 0.25%;
— content of grains smaller than 0.14 mm in size to 10%;
— limit content of particles larger than 8 mm no more than 10%. Particles larger than 8 mm in size should be eliminated while sifting, storing and processing of fillers.

The best conformity with the listed requirements is demonstrated by sand manufactured by Nonmetallic Materials Plant, except for a slight excess of standard contents of clayey and powder particles by 1.7%.

Making of trial batches of mixes using blast-furnace granulated slag, manufacture of specimens and the tests of all rated quality indexes has been carried out in the special construction and backfilling laboratory at Ridder–Kazzinc [4, 5]. Characterization of compositions for wet-mix shotcrete lining is given in the table 1.

Table 1. Characteristics of wet-mix shotcrete compositions

| Consumption, kg/m³ | Density, kg/m³ (factual) | Stiffness (Vebe consistency) | Different age compression strength, MPa |
|-------------------|--------------------------|----------------------------|----------------------------------------|
|                    |                          |                            | 3  | 7  | 28   |
| Cement            | Sand | Blast-furnace granulated slag | Break stone | Water |                  |                |
| 400               | 1175 | –                           | 585 | 190 | 2443 | 32  | 20.57 | 24.07 | 32.14 |
| 420               | 1160 | –                           | 580 | 190 | 2317 | –   | 21.96 | 26.15 | 33.01 |
| 440               | 1150 | –                           | 575 | 190 | 2313 | 41  | 22.63 | 27.43 | 35.76 |
| 380               | 1185 | –                           | 590 | 190 | 2460 | –   | 16.98 | 22.82 | 31.45 |
| 360               | 11195| –                           | 600 | 190 | 2427 | 28  | 13.86 | 20.20 | 30.35 |
| 400               | –    | 1200                        | 555 | 225 | 2278 | 63  | 10.52 | 15.61 | 20.95 |
| 420               | –    | 1185                        | 550 | 225 | 2160 | –   | 13.60 | 16.23 | 23.49 |
| 440               | –    | 1170                        | 545 | 225 | 2153 | 38  | 14.27 | 18.63 | 24.59 |
| 380               | –    | 1210                        | 560 | 225 | 2160 | –   | 8.62  | 13.18 | 18.77 |
| 360               | –    | 1220                        | 570 | 225 | 2117 | 72  | 8.00  | 12.43 | 16.46 |
Based on the tests in the Ridder–Kazzinc laboratory, the curves of compression strength and cement consumption at water flow rate of 190 l/m³ have been plotted for different mixes (CEM II/A-Sh 42.5 N by Bukhtarma, sand and break stone by Nonmetallic Materials Plant) in Figure 2.

It is seen in the figure that the strength of concrete 7 days old is 27.43 MPa, which is nearly the required strength at the age of 28 days (28.83 MPa); the concrete acquires the required compression strength at the age of 28 days even at the cement consumption of 360 kg/m³. The tests of concrete batches with blast-furnace granulated slag show that this mix of concrete becomes stronger less intensive. When granulated blast-furnace slag is used as inert material, the wanted strength is not reached in concrete 28 days old (at binder consumption to 440 kg/m³).

By the data of tests of shotcrete bars 40×40×160 mm, the tensions strength of concrete and cement consumption are related (see Figure 3).

On the basis of the laboratory tests, the accepted design for the wet-mix shotcrete is:
—cement 440 kg/m³ (CEM II/A-Sh 42.5 N by Bukhtarma manufacture);
—water 175 l/m³;
—sand 1176 kg/m³ (Nonmetallic Materials Plant);
—break stone 588 kg/m³ (Nonmetallic Materials Plant);
—plastifier TamCem 60 (0.3–1.0 kg of liquid additive agent per 100 kg of cement) 1.32 kg/m³ (Normet company) or GLENIUM® T 803 (0.8–1.5 kg per 100 kg of binder 3.52 kg/m³ (BASF);
—setting accelerator TamShat 80 AF (5–6% of cement weight) 22 kg/m³ (by Normet) or MasterRoc SA 160/167 (3–10% of binder weight) 13.2 kg/m³ (by BASF).

![Figure 2. Compression strength of concrete versus cement consumption at water flow rate of 190 l/m³ without granulated slag.](image1)

![Figure 3. Vending strength versus cement consumption for test concrete bars.](image2)

Overall cost of mix components per 1 m³ of concrete is USD 54.01 (Figure 4).

![Figure 4. Specific cost of basic process materials (mix components) in Orlov Mine.](image3)
Additional expenditures in shotcrete mix preparation may be reinforcement fibers. Concrete reinforced with fibers preserved structural integrity owing totally to stress redistribution inside a specimen and due to high plasticity.

Normet Company recommends to add shotcrete lining mixes with:
—super plastifier TamCem 60 (TamCem 66);
—hydration regulator TamCem HCA (TamCem HCA Plus); it preserves properties of shotcrete and can be used to keep the mix workability from 2 h but not longer than 48 h;
—setting accelerator TamShot 80AF (TamShot 90AF);
—propylene fiber BarChip 54.

Conclusion
Based on the performed tests, the compositions of wet-mix shotcrete are recommended, and it is shown that inert materials have an essential influence on properties of shotcrete mixtures and shotcrete lining, which implies that the final selection of shotcrete mix components should be made after additional full-scale testing of shotcrete properties.

References
[1] Organizational Standard Requirements ST TOO 050140000656-01-33.1 GU-03-2011: Mine support at Kazakhmys Corporation Technical Department, Geotechnical Management 2011 (in Russian)
[2] Departmental Construction Requirements VSN 126-90: Transportation and metro tunnel support with shotcreting and rock bolting. Design and implementation standards (in Russian)
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[4] NOSTROI Code. Development of underground space. Underground construction with mining method and shotcrete lining. Work rules, control and requirements Moscow 2013 (in Russian)
[5] State Standard GOST 27006-86 Concrete. Composition selection rules (in Russian)