Organic-inorganic composition for stone masonry walls of ancient tower and necropolis buildings in the North Caucasus

D K-S Bataev1,2, S-A J Murtazaev1,2,4, Kh N Mazhiev2,4, M M Maloroev1, G K-S Bataev1, R U Goitemirov1,2, M A Gaziev1,4 and P D Bataeva1,4

1 Department of Materials Science, Kh. Ibragimov Complex Institute of the Russian Academy of Sciences, 21a Staropromyslovoe hw., Grozny, 364051, Russian Federation
2 Academy of Sciences of the Chechen Republic, 13 M. Esambaev, Grozny, 364024, Russian Federation
3 Faculty of Technology and Economics Specialty, Chechen State Pedagogy University, 62 Isaeva, Grozny, 364068, Russian Federation
4 Institute of Construction, Architecture and Design, Grozny State Oil Technical University named after Academican M.D. Millionshikov, 100 Isaeva, Grozny, 364051, Russian Federation

E-mail: kniiran@mail.ru

Abstract. Search works were performed based on archival and bibliographic research, which allowed us to get an idea of the monuments of archeology, history, and culture. For laboratory physical and physicomechanical studies, samples collection of the masonry wall solution was taken. Based on the conducted laboratory studies, a conclusion was made about the necessary grade strength of the masonry mortar of 25-75 kg/cm² with the following physical and mechanical properties of the solution are as follows: average compressive strength - 8.3 MPa; water absorption - 11.7%; porosity - 18.3%; volume weight - 1.56 g/cm³. Stress-related properties: average compression strength - 8.3 MPa; water absorption - 11.7%; porosity - 18.3%; volume weight - 1.56 g/cm³. The testing of new experimental compositions was performed in places accessible for observation and documented. Local inert, reinforcing, and binding materials were used to select the composition of the stone masonry solution for the walls of ancient tower and necropolis buildings. The research was carried out using existing methods, adjusted to take into account the peculiarities of the historical and cultural monuments under consideration. Based on the study results were developed organic-inorganic compositions of solutions of stone masonry walls of ancient tower and necropolis buildings in the North Caucasus.

1. Introduction

Research works (RW) are an integral part of the investment project for the repair and restoration of archaeological, historical, and cultural monuments. Research works begin at the preliminary studies stage and continue throughout the entire investment process, including its production stages.

Depending on the significance of the monument, the goals and scope of the proposed work, the availability of documentation on previously performed research, as well as the level of their professional performance, research work can be carried out in different volumes and with different degrees of elaboration of individual issues: either in the form of comprehensive research work, or in the form of...
separate studies that are not allocated to an independent stage, the need for which arises in the process of construction, repair, and restoration. In this work was performed a full-scale proportioning of mortar for stone masonry walls of ancient tower and necropolis buildings in the North Caucasus.

This research work includes the following preliminary studies:
- archival and bibliographic researches;
- development and selection of binders, fillers;
- physical and physicomechanical destructive and non-destructive laboratory studies;
- the complex of search and accompanying works.

2. Problem statement

Research work on the study and proportioning of mortar for stone masonry walls of ancient tower and necropolis structures in the North Caucasus was carried out by experienced specialists of CRDC named after Kh.I. Ibragimov RAS and the Construction Testing Laboratory LLC "Complex" (STL LLC "Complex") in the field of chemical technology, physicochemical, and physicomechanical research methods.

Before the start of complex research and experimental works was appointed a scientific supervisor of these works, who prepared a research program and selected responsible performers for the main sections of complex research and experimental works.

The scientific supervisor had experience in scientific and restoration work on this type of monuments, had the necessary professional qualities, and was responsible for the scientific completeness (validity) and quality of research and experimental work.

Archival and bibliographic research [1-5] allowed us to get an idea of the time of creation and the history of the existence of the considered monuments of archeology, history, and culture.

The composition of archival and bibliographic research included:
- photographs, copies, illustrations in printed publications, etc.;
- testimony, scientific publications, annalistic and other archival materials about monuments;
- selection of analogs;
- analytical processing of the collected material.

Archival and bibliographic studies [6-10] have shown that towers were built in the North Caucasus everywhere on the lime-stone mortar, and the top was covered with a thick layer of yellow or yellow-white plaster, the inside of the masonry joints were covered with mortar. This was a characteristic feature of all architectural monuments: military and residential towers, crypts, and shrines. According to legend were added milk or whey and chicken eggs to the limestone mortar.

Nondestructive (optical-analytical) and laboratory destructive and non-destructive (physical, physicomechanical) research types were used in the course of research work.

3. Materials and methods

For laboratory physical and physicomechanical studies, samples collection of the masonry wall solution was taken (Figure 2). Samples of the masonry wall solution were presented in the original.

Based on the conducted laboratory examination, a conclusion was made about the necessary grade strength of the masonry mortar of 25-75 kg/cm$^2$. According to the results of laboratory studies, it is clear that the masonry mortar is made on a lime binder in the ratio binder: filler (B/F) - 1:2.5÷3.0.

Masonry mortar of white color of a dense structure of uniform mixing with separate coarse particles on the ground lime. The masonry mortar surface of the seam is bumpy with separate large shells, the lateral area is dirty. Lime contains natural crystalline gypsum in an amount of 5.0-10.0%.

To prepare the masonry mortar was used as a filler in the form of a transparent fine of quartz sand of a rounded shape with a size of 0.1-0.2 mm, angular dark gray (black), and light gray particles of metamorphic rock of limy shales with a size from 0.3 to 5.0 mm. There are a lot of opus signinum particles in the size of 0.1-0.2 mm and crushed bricks in the size of 0.5-1.0 mm.

The physical and mechanical properties of the solution are as follows: average compressive strength-8.3 MPa; water absorption-11.7%; porosity-18.3%; volume weight-1.56 g / cm$^3$. The physical and
The mechanical properties of the masonry mortar are satisfactory, the solution strength is high and corresponds to the M-75 brand.

The testing of new experimental compositions was performed in places accessible for observation and documented. Recipes and methods for performing experimental work are described below.

The research was carried out using existing methods, adjusted to take into account the peculiarities of the historical and cultural monuments under consideration. Based on the study results were developed organic-inorganic compositions of solutions of stone masonry walls of ancient tower and necropolis buildings of the Republic of Ingushetia.

Local inert, reinforcing, and binding materials were used to select the composition of the stone masonry solution for the walls of ancient tower and necropolis buildings (Figure 1).

![Figure 1.](image)

(a) - slate powder; (b) - dolomitic sand; (C) - hydrated lime; (d) - fibre optic; (e) - technical casein; (f) - opus signinum fraction of 0-5 mm.

The proportioning of mortar of stone masonry walls of ancient tower and necropolis buildings was selected based on the following normative documents:

- AUSS 28013-98 construction solutions. General specifications;
- AUSS 5802-86 construction solutions. Test method;
- AUSS R557338-2016 construction solutions for stone masonry. Methods for determining the ultimate compressive and bending strength;
- AUSS 25818-91 flue ash of thermal power plants for concrete;
- AUSS 3056-90 casein glue in powder. Technical conditions;
- PSA 2007.3 Recommendations for conducting restoration work on monumental painting-cultural properties;
- BG 82-101-98 Preparation and application of construction solutions.
Figure 2. Samples of solutions selected from the masonry joints of the walls of ancient tower and necropolis buildings of the Chechen Republic and the Republic of Ingushetia.

4. Results and discussion
Experimental compositions for research (Table 1, Table 2) have been developed by studying the data of literary sources concerning the experience of construction, restoration, repair, and restoration of an ancient tower and necropolis structures, testimonies of mountain residents, as well as speculative analysis.

Table 1. Experimental compositions of mortar for stone masonry walls of an ancient tower and necropolis buildings on 1.0 m³ (set No.1)

| Composition No. | Lime paste, m³ | Slate powder, m³ | Dolomitic sand, m³ | Water, l | Casein glue, kg | Ash, kg | Egg mass, pcs | Serum, kg |
|----------------|----------------|-----------------|--------------------|--------|----------------|--------|--------------|----------|
| 1              | 0.43           | 0.91            | -                  | 182    | -              | -      | -            | -        |
| 2              | 0.38           | 0.994           | -                  | 197    | -              | -      | -            | -        |
| 3              | 0.33           | -               | 1.06               | 156    | -              | -      | -            | -        |
| 4              | 0.33           | 1.06            | -                  | 133    | -              | -      | -            | -        |
| 5              | 0.29           | 0.995           | -                  | 140    | 70.0           | 79.4   | -            | -        |
| 6              | 0.31           | 1.00            | -                  | 150    | -              | 85.0   | -            | -        |
| 7              | 0.30           | 0.88            | -                  | 55     | 58.0           | 62.0   | -            | -        |
| 8              | 0.30           | 0.87            | -                  | 95     | -              | 62.0   | -            | 90       |
| 9              | 0.17           | 0.95            | -                  | -      | -              | 117    | 156          | 115      |
| 10             | 0.28           | 1.03            | -                  | -      | -              | 117    | -            | 136      |
| 11             | -              | 1.0014          | -                  | -      | -              | 120    | 330          | -        |
| 12             | 0.17           | 1.0037          | -                  | -      | -              | 125    | -            | 144      |
| 13             | -              | 1.03            | -                  | -      | -              | 117    | -            | 226      |
| 14             | -              | 1.03            | -                  | -      | -              | -      | 203          |          |
At the initial stage were determined the humidity and dry bulk density of inert and matrix materials.

Lime paste:
- water-lime ratio 1/1;
- volume weight (p) - p = 1370 kg / m$^3$.

Shale sand:
- humidity (W) – W = 3.3%;
- bulk density (rd. d) - rd.d = 1414 kg / m$^3$.

Dolomitic sand:
- humidity (W) – W = 3.6%;
- bulk density (rd. d) - rd. d = 1496 kg / m$^3$.

Wood ash:
- bulk density (rd. d) - rd. d = 500 kg / m$^3$.

Egg mass:
- density (r$_{e.m}$) - r$_{e.m}$ = 1050 kg / m$^3$.

Milk whey:
- density (r$_{m.w}$) - r$_{m.w}$ = 1024 kg/m$^3$.

Technical casein:
- physical properties were not determined because the preparation of the test mix requires casein glue ("Ordinary", "Extra").

In laboratory conditions based on experimental compositions of a solution for stone masonry walls of ancient tower and necropolis buildings in standard forms were made:
- cubes 70, 7x70, 7x70, 7x70, 7 3 PCs. for each test to determine the compressive strength (cube strength) (Figure 3, a);
- 4x4x16 beams of 5 pcs. for each test to determine the prism strength and bending tensile strength (Figure 3, b);
- paired and glued on mortar compositions samples of quarry stone and concrete to determine the adhesion of the solution in rubble and stone masonry (Figure 3, c).

![Experimental samples](image)

**Figure 3.** Experimental samples: (a) - cubes 70, 7x70, 7x70, 7; (b) - beams 4x4x16; (c) - paired and glued on mortar compositions of concrete and quarry stone.
Table 2. Experimental compositions of mortar for stone masonry walls of an ancient tower and necropolis buildings on a single beam 4cm*4cm*16cm (set No. 2)

| Composition No. | Lime paste, gr. | Slate powder, gr. | Dolomitic sand fr. 0-2.5, gr. | Opus signinum, gr. | Water, gr. | Casein glue, gr. | Powder lime, gr. | Wood ash, gr. | Egg mass, gr. | Curd degrease, gr. | Fibre-optic gr. | Curdled milk gr. |
|----------------|-----------------|------------------|-----------------------------|-------------------|------------|-----------------|-----------------|--------------|-------------|-------------------|----------------|-----------------|
| 1              | -               | 180              | 310                         | 40                | 80         | 25              | 7               | -            | -           | -                 | -              | -               |
| 2              | -               | 180              | 310                         | 35                | 78         | 24              | 8               | -            | -           | -                 | -              | -               |
| 3              | 84              | 165              | 280                         | 35                | 7          | 7               | 17              | 15          | 13          | -                 | -              | -               |
| 4              | 84              | 165              | 280                         | 31                | 8          | -               | -               | 14          | 15          | -                 | -              | -               |
| 5              | -               | 235              | 150                         | 25                | 96         | 35              | 9               | -            | -           | -                 | -              | -               |
| 6              | 90              | 230              | 150                         | 26                | 30         | -               | -               | -            | 9           | -                 | -              | -               |
| 7              | 84              | 168              | 299                         | 26                | 47         | 2               | 14              | -            | -           | -                 | -              | -               |
| 8              | 85              | 220              | 143                         | 25                | 35         | 2               | -               | -            | 1           | -                 | -              | -               |
| 9              | 84              | 161              | 300                         | 19                | 24         | 5               | 13              | -            | -           | -                 | -              | -               |
| 10             | 70              | 272              | 86                          | 18                | 22         | 7               | 10              | -            | -           | -                 | -              | -               |
| 11             | 70              | 272              | 86                          | 25                | 22         | 7               | 10              | -            | -           | -                 | -              | -               |
| 12             | -               | 330              | 60                          | 40                | 43         | 30              | -               | -            | -           | -                 | -              | -               |
| 13             | 360             | 103              | 30                          | 88                | 37         | 55              | -               | -            | -           | -                 | -              | -               |
| 14             | 350             | 60               | 32                          | 88                | 58         | -               | -               | -            | -           | -                 | -              | -               |
| 15             | 350             | 30               | 32                          | 88                | -          | -               | -               | -            | -           | -                 | -              | -               |
| 16             | 360             | 60               | 32                          | 88                | 58         | -               | -               | -            | -           | -                 | -              | -               |
| 17             | 365             | 30               | 32                          | 88                | 58         | -               | -               | -            | -           | -                 | -              | -               |
| 18             | 365             | 39               | 10                          | 55                | 40         | -               | -               | -            | -           | -                 | -              | -               |

5. Conclusion

Based on the analysis of the physical and mechanical properties of the solution for stone masonry walls of ancient tower and necropolis buildings in the North Caucasus, the following compositions are recommended:

**Composition A** (consumption per 1.0 m³)
1. Slate powder – 628 kg.
2. Dolomitic sand – 1172 kg.
3. Lime paste-328 kg.
4. Wood ash – 50 kg.
5. Opus signinum - 75 kg.
6. Casein glue - 20 kg.
7. Water-1.

**Composition B** (consumption per 1.0 m³)
1. Slate powder – 644 kg.
2. Dolomitic sand - 1094 kg.
3. Lime paste-328 kg.
4. Wood ash – 27 kg.
5. Opus signinum - 137 kg.
6. Curd degrease-20 kg.
7. Water - 27 l.

**Composition C** (consumption per 1.0 m³)
1. Slate powder – 1289 kg.
2. Powder lime - 234 kg.
3. Chicken egg-168 kg.
4. Wood ash-156 kg.
5. Curdled milk - 117 kg.

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