Assessment of reliability of natural limestone cladding material

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Abstract. The goal of research was identifying possible application of natural limestone samples as a cladding material for facades by means of evaluation of physical and chemical properties and inclusive of external aggressive factors. As the object of research, there were used the samples of naturally occurring limestone, of Afanasyevskiy deposit, Moscow region, designated for face slabs manufacturing of ventilated facades. In compliance with the All-Union Standard (GOST) 30629-2011, the samples have been exposed to the following testing, namely determination of mean density and true specific gravity, kg/m³; pore-saturation coefficient with water; ultimate compressive strength, MPa; water fastness (lowering of compressive strength in the water-saturated state, %); ultimate bending strength, MPa; freeze-thaw resistance, cycles, acid fastness. Chemical (elemental) analysis was carried out by the method of scanning electron microscope investigation. The tests were implemented on the electronic microscope FEI Quanta 200. The microscope is equipped by X-ray spectrometer that is designated for elemental analysis (EDAX). Both masonry units have satisfactory freeze-thaw resistance. As far as acid fastness is concerned, only marmorized limestone has demonstrated satisfactory performance. Thus, only the second group of samples presented by marmorized limestone could be recommended as a reliable material for façade cladding.

1. Introduction
Regardless of the wide spectrum of modern facade cladding materials [1-5], masonry units of natural origin, in particular limestone, are still on the top of their relevancy. It stems from the fact that naturally occurring masonry units are characterized by high decorative value. Moreover, these materials are durable and eco-friendly, with the extensive diversity of color scale and texture, as well as good aesthetic qualities. Natural stone is a non-combustible material. The main drawbacks of cladding stone are high thermal conductivity and heavy weight hampering its transportation and assembly and imposing extra load on a foundation, as well as the necessity of regular maintenance. Due to this, cladding masonry units are mainly used for plinth cladding, whereas for façade cladding they are applied only for low-rise buildings [6-9].

The potential use of naturally occurring masonry units for cladding of building structures is determined by the complex of physical, mechanical and chemical properties, such as mean density, true specific gravity, porosity, water absorption by mass and volume, ultimate compressive and bending strength, water fastness (lowering of compressive strength in the water-saturated state), freeze-thaw resistance, acid fastness and chemical composition [10, 11]. The summary of the above-
mentioned properties allows assessing reliability of the erected structure, its resistance to external aggressive factors and, as a consequence, the life of a structure. Along with that, it is necessary to take into account the specific features of assembly and operation. If cladding materials are chosen correctly and on reasonable grounds, façade and plinth surfaces, as well as the insulating layer in sandwich walls will be weather-protected, their deterioration will be prevented, while life of buildings and structures will be extended [12-14].

As the object of research, there were used the samples of naturally occurring limestone, of Afanasyevskiy deposit, Moscow region, designated for face slabs manufacturing of ventilated facades. The goal of research was identifying possible application of natural limestone samples as a cladding material for facades by means of evaluation of physical and chemical properties and inclusive of external aggressive factors.

2. Methodology

Visual examination has shown that the samples do not have visual damages. The sample 1 (Figure 1a) is of light-grey color, of rather homogenous structure, visually free from inclusions. The sample 2 (Figure 1b) is of darker hue, if compared with the sample 1, of dense, modified structure, with discrete noticeable inclusions and typical glassy luster.

![Figure 1. External appearance of the sample 1 – a., and the sample 2 – b, correspondingly.](image)

In compliance with the All-Union Standard (GOST) 30629-2011, the samples have been exposed to the following testing, namely determination of mean density and true specific gravity, kg/m³, pore-saturation coefficient with water; ultimate compressive strength, MPa, water fastness (lowering of compressive strength in the water-saturated state, %); ultimate bending strength, MPa; freeze-thaw resistance, cycles, acid fastness. Chemical (elemental) analysis was carried out by the method of scanning electron microscope investigation. The tests were implemented on the electronic microscope FEI Quanta 200. The microscope is equipped by X-ray spectrometer that is designated for elemental analysis (EDAX).

3. Result and discussion

All-Union Standard GOST 9479-2011 for low-strength stone, such as limestone, does not state characteristic values for mean density. However, if the sample 2 is referred to as medium-strength stone (marmorized limestone), its mean density should not exceed 2600 kg/m³. This values is achieved allowing for measurement inaccuracy.

GOST 9479-2011 does not rate water absorption value for low-strength stone. At the same time, if the sample 2 is related to medium-strength stone, its water absorption by mass should not exceed 0.75% that is confirmed by the data in the table 1.
Table 1. The main quality indices of testes masonry units.

| N  | Index, measuring unit                                      | Characteristic value for limestone (GOST 9479-2011) | Sample 1 | Sample 2 |
|----|-----------------------------------------------------------|---------------------------------------------------|----------|----------|
| 1  | Mean density, kg/m³                                       | Not rated                                         | 2392     | 2597     |
| 2  | True specific gravity, kg/m³                              | Not rated                                         | 2586     | 2713     |
| 3  | Porosity, %                                               | Not rated                                         | 7.5      | 4.3      |
| 4  | Water absorption by mass, %                               | Not rated                                         | 2.9      | 0.5      |
| 5  | Water absorption by volume, %                             | Not rated                                         | 6.9      | 1.4      |
| 6  | Ultimate compressive strength, MPa                        | Not exceeding 40 MPa                              | 66       | 112      |
| 7  | Lowering of compressive strength in the water-saturated state, % | Not exceeding 30 %                                 | 12.0     | 9.8      |
| 8  | Ultimate bending strength, MPa                            | Not rated                                         | 13       | 8        |
| 9  | Freeze-thaw resistance, % of compressive strength loss    | Not exceeding 20 %                                 |          |          |
|    | 35 cycles                                                 |                                                   | 10.3     | 11.9     |
|    | 50 cycles                                                 |                                                   | 15.5     | 17.8     |
| 10 | Acid fastness, % of mass loss                             | Not exceeding 1%                                  | 1.09     | 0.96     |

Interesting results have been obtained while estimating pore-saturation coefficient of the material with water. Thus, for the sample 1, the value accounted for 0.92, i.e. 92% of pores remain open that would result in low freeze-thaw resistance of the material. The sample 2 exhibited the water-saturation coefficient equal to 0.33 (33% of open pores), i.e. its freeze-thaw resistance should be rather high.

Conforming to the All-Union Standard GOST 9479-2011, the minimum value of ultimate strength for limestone makes out 40 MPa for limestone, 50 MPa – for marmorized limestone, respectively. Both tested masonry units meet the specified requirements.

According to the GOST 9479-2011, lowering of compressive strength in the water-saturated state should not exceed 30%. Both tested masonry units satisfy the stated requirements. Judging by the water fastness index, both tested masonry units could be regarded as water-resistant.

The results of freeze-thaw resistance tests have shown that both masonry units had withstood 50 cycles of alternating freezing and thawing, as compressive strength reduction had not exceed 20%. The data in the table 1 demonstrate that the second group of samples has higher values of mean density and true specific gravity; shows lower strength loss in the water-saturated state, and is of lower porosity and water absorption by mass and volume, if compared with the group 1. However, freeze-thaw resistance of the second group of samples turned out to be lower than of the first group. It appears that chemical composition of the mineral has the most significant impact on limestone’s resistance to alternating freezing and thawing. As could be seen from the data of the tables 2 and 3, sulfur and aluminum compounds are present in the chemical composition of the second group of samples whereas in the first group, these elements are not found. It is well known that silicates of alumina enhance freeze-thaw resistance of artificial stone [15-17]. This enables to eliminate the
probability of their presence in the chemical composition of the tested samples. According to the color, density and elemental composition, the maximum conformance is observed for aluminite mineral, being basic aluminum sulfate. Apparently, the presence of the insignificant amount of this compound in the composition of the second group facilitated lowering of their freeze-thaw resistance over against the first group of samples.

Masonry units designated for external cladding of buildings and structures are supposed to be resistant to aggressive media. Stone resistance to aggressive or corrosive medium is assessed, in particular, by the test results on acid fastness.

Carbonate rocks are regarded as resistant to acid if the mass loss of a masonry unit after 10 test cycles does not exceed 1%.

The results of chemical analysis are presented in the tables 2 and 3 and figures 2, 3.

**Table 2.** Elemental analysis of the sample 1.

| Element | Wt, % | At, % |
|---------|-------|-------|
| C       | 13.10 | 22.15 |
| O       | 44.05 | 55.92 |
| Ca      | 42.10 | 21.34 |
| Mg      | 0.46  | 0.39  |
| Si      | 0.28  | 0.20  |

As seen from the table 2, the tested stone (sample 1) consists of 99% of calcium carbonate, with possible inclusions of carbonate of magnesium and quartz-carbonate.

**Figure 2.** Microstructure of the sample 1.

**Table 3.** Elemental analysis of the sample 2.

| Element | Wt, % | At, % |
|---------|-------|-------|
| C       | 14.10 | 23.66 |
| O       | 42.96 | 54.12 |
| Ca      | 40.34 | 20.28 |
| Al      | 0.53  | 0.40  |
| Si      | 0.74  | 0.53  |
| S       | 0.48  | 0.30  |
| Mg      | 0.85  | 0.70  |
As the data of the table 3 show that the tested stone (sample 2) is also composed mainly of calcium carbonate (within 95÷96 %), except that the portion of inclusions is higher as against the sample 1 (also proven by visual examination). The inclusions are most likely presented by carbonate of magnesium, quartz and basic alumina sulfate.

![Figure 3. Microstructure of the sample 2.](image)

Having compared the microstructure images of the samples 1 and 2, it may be noted that the second stone has denser, modified structure. This accounts for improved physical, mechanical and hydrophysical properties of the second tested stone over against the first one.

Thus, having investigated the summary of physical and chemical properties of the samples of naturally occurring limestone, the conclusion was drawn that one of the tested sample groups, namely the group 2, could be related to marmorized limestone. This group is characterized by darker color, denser, modified structure, with discrete inclusions and specific glassy luster, as compared to the group 1 samples. The values of mean density and true specific gravity of marmorized limestone samples are significantly higher than of the first group’s samples. Significantly lower values of porosity (lower by 70%) of water absorption by mass (nearly six times less) and by volume (five times lower) of marmorized limestone with respect to non-marmorized one are considered as an advantage when it is used as a façade cladding material. Marmorized limestone loses its compressive strength in the water-saturated state to a lesser degree. Both masonry units have satisfactory freeze-thaw resistance. As far as acid fastness is concerned, only marmorized limestone has demonstrated satisfactory performance. All the above-mentioned enables the authors to draw a conclusion that only the second group of samples presented by marmorized limestone could be recommended as a reliable material for facade cladding.

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