Fortification of building’s foundations with eco-friendly materials as means to safer and more comfortable urban environment

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Abstract. In this paper we tested mechanical aspects of chemical reactions as means to fortification of clay soil. We also tested properties of soil-concrete using waste of dolomite and chrysotile asbestos. The composition and properties of the composites are presented along with the comparison with traditional reinforced cementing materials. Main testing means of properties were method of x-ray phase analysis, electric scanning microscopy, soil strength changes and soil internal friction angle changes.

1. Introduction

Traditional methods of foundation fortification are based on the use of cement, lime and organic binders, bitumen is a perfect example. However, it’s quite expensive, energy intensive and environmentally dangerous. Production of cement and lime are very energy consuming processes (firing temperatures can vary between 1100 and 1500°C) this accompanied by CO₂ emissions. [1-4].

We attempted to find untraditional fortification additives, which gathered from waste of mining sphere. In particular we looked into waste from dolomite and chrysotile field developments.

In recent years Russia experienced shortages of raw materials that are directly used for production of the building materials. Thus, production of building materials from industry waste has both economic and ecologic upsides.

This article aimed to develop the technology for material production from clay soil, which is suitable for foundation building and masonry material [5-8].

2. Materials and methods

Used soil composition is the following: reddish brown loam, brown loam with interbedded seams, coarse sand, with interlayers of sand, with the inclusion of gravel and rubble up to 7%, glacial.

Soil properties are shown in the table №1.

Table №2 contains comparison of physico-mechanical soil properties

Table 3 shows chemical composition of dolomite waste.

Waste of dolomite production have the following properties: finely dispersed powder with colour range from white to beige. Magnesium binding is created by firing of dolomite waste in the temperature range between 720 and 750°C. In this case, magnesium carbonate dissociates to form magnesium oxide → MgO + CO₂. Magnesia binders include caustic magnesite (MgO) and caustic
dolomite (MgO + CaCO₃) - these are finely dispersed powders, the active part of which is magnesium oxide. Calcium carbonate CaCO₃ (in dolomite) remains unchanged and is the ballast part of the binder [9-14].

Table 1. Normative and calculated soil property values.

| Soil classification based on GOST 25100-2011 | Normative values | Calculated values | Shear resistance |
|--------------------------------------------|------------------|------------------|------------------|
| Moisture | Plasticity index, Ip | Fluidity index, Il | Soil density, ρ, g/sm³ | Soil particle density, ρₚ, g/sm³ | Porosity coefficient, e | Water saturation coefficient, S | Filtration coefficient, Kₓ, m/day | MAX friction c, MPa | Deformation modulus, Е, MPa | Internal friction angle, φ, degree | Internal friction angle, φ, degree | MAX friction, с, MPa |
| Natural W | 0.175 | 0.28 | 2.07 | 0.536 | 0.99 | 15 | 0.0213 | 14 | 2.06 | 13 | 0.0134 | 0.0118 |
| At the fluidity stage, W₁ | 0.261 | 0.31 | 2.14 | 0.567 | 1.01 | 16 | 0.0327 | 17 | 2.76 | 14 | 0.0138 | 0.0118 |
| At the lamination stage, W₂ | 0.142 | 0.28 | 2.07 | 0.536 | 0.99 | 15 | 0.0213 | 14 | 2.06 | 13 | 0.0134 | 0.0118 |

Table 2. Results of physico-mechanical soil properties.

| Characteristic | Laboratory tests | Static Probe | SP 22.13330.2011 | Recommended Normative Values |
|----------------|------------------|--------------|------------------|-----------------------------|
| Internal Friction angle, φ₀ | 15 | - | 23 | 15 |
| Deformation modulus, Е, MPa | - | - | 14 | 4 |
| MAX Friction, с, MPa | 0.0213 | 0.0258 | 0.0333 | 0.0213 |

Table 3. Chemical composition of dolomite waste.

| SiO₂ % | Al₂O₃ % | Fe₂O₃ % | FeO % | CaO % | MgO % | LOI % | K₂O % | TiO₂ % |
|--------|--------|--------|------|-------|-------|-------|-------|--------|
| 2.80   | 0.47   | 0.21   | <0.05| 36.17 | 15.64 | 44.22 | 0.16  | 0.03   |
The chemical composition of the chrysotile used is: SiO₂ 41-43%, MgO 38-41%, Al₂O₃ 1-1.5%, FeO and Fe₂O₃ 0.3-4%, H₂O 13-14%. Chrysotile asbestos is an aqueous magnesium silicate in its mineralogical composition (3MgO 2SiO₂ 2H₂O) with a water content of up to 15%, and has the following dimensions: in cross section less than 0.0001 mm, in length from fractions of a millimeter to several centimeters). It has a very high tensile strength, which provides 20000 MPa, which is 2.57-2.66 g / cm³.

Traditionally clay soils are stabilized with cement and lime, in which case lime is used to quench humus and create an alkaline environment as the most favorable for cement hardening. In case of semi-fired dolomite need to use lime is eliminated as lime has an alkaline environment and is itself a type of magnesia cement.

The chemical postulate of “dissolving the similar in the similar” is illustrated in calculation of the modulus of the basicity of magnesian binder based on dolomite and clay soil. It is known that astringent properties appear in substances with Mos. > 1.5.

The modulus of basicity (hydraulicity) $M₀$,

$$M₀ = \frac{CaO + MgO + Na₂O + K₂O}{SiO₂ + Al₂O₃},$$

$M_{active} = \frac{Al₂O₃}{SiO₂}$

Each binder is characterized by its unique modulus of basicity. The hydraulic properties of the binder are more pronounced with a decrease in $M₀$ and an increase in $M_{active}$.

The modulus of basicity of a composite of clay soil and semi-fired dolomite and chrysotile is $M₀ = 1.9$, $M_{active} = 0.36$, which characterizes it as a quite suitable binder [14-18].

Building composition "binder-soil" including binders (Portland cement) or semi-fired waste of dolomite, clay soil, to create water-resistant structures of phosphates and chrysotile (hydrasilicates) are shown in Table 4.

### Table 4. Composition of fortified soils.

|       | GBD-1 | GBD-2 | GBD-3 | GBD-4 | GBD-5 | GBC-1 | GBC-2 | GBC-3 |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Clay soil | 63    | 63    | 63    | 63    | 63    | 83    | 85    | 90    |
| Cement | -     | -     | -     | -     | -     | 17    | 15    | 10    |
| Dolomite | 20    | 18    | 16    | 14    | 12    | -     | -     | -     |
| Chrysotile | 10    | 12    | 14    | 16    | 18    | -     | -     | -     |
| KH₂PO₄ | 7     | 7     | 7     | 7     | -     | -     | -     | -     |

Tests of compressive and tensile strength of the synthesized material were carried out in accordance with DIN EN 206-1 / DIN 1045-2.

Compressive and tensile strength tests were performed on the 28th day.

3. Results and discussion

Comparative Table 5 shows physico-mechanical properties of the fortified soils.

### Table 5. Physico-mechanical properties of fortified soils.

|                | GBD-1 | GBD-2 | GBD-3 | GBD-4 | GBD-5 | GBC-1 | GBC-2 | GBC-3 |
|----------------|-------|-------|-------|-------|-------|-------|-------|-------|
| Compressive strength, MPa (28th day) | 10.5  | 11.2  | 11.9  | 12.3  | 12.8  | 20    | 15    | 10    |
| Water absorption, mass% | 6     | 5.8   | 5.9   | 5.4   | 5.4   | 7.2   | 7.6   | 8     |
| Frost resistance | 16    | 17    | 20    | 20    | 21    | 17    | 14    | 7     |
| Thermal conductivity, W/m*K | 0.55  | 0.59  | 0.65  | 0.71  | 0.72  | 0.78  | 0.70  | 0.64  |
Comparison of 2 soil samples before and after fortification is shown in the Figure 1.

![Soil samples comparison diagram](image)

**Figure 1.** Sample tests before and after fortification

Comparison of the soil properties before and after fortification are shown in the Table 6

|       | $\rho$  | $\rho_s$ | $\phi$ | $W_e$ | $W_L$ | $W_{\rho}$ | $I_p$ | $I_L$ | $S_r$ | $R_{c\gamma}$ |
|-------|--------|---------|-------|------|------|---------|------|------|------|-----------|
| **Before fortification** | 2.07   | 1.76    | 2.71  | 0.174| 0.540| 0.540   | 0.23 | 0.87 | 0.87 | 10.5-12.8 |
|       | 2.2    | 2.05    |       |      |      |         |      |      |      |            |
| **After fortification**  | 2.83   | 0.07    | 0.260 | -    | 0.260| 0.260   | -    | -    | -    |            |

*The results of the study of the microstructure of fortified soil are presented in Figure 2, 3*
Figure 2. XRF of the fortified soil.

Figure 3. SEM of the fortified soil.
It is clearly seen from the 3rd figure that soil-concrete with dolomite and chrysotile contains strong brucite crystals, which provide high strength properties of this composite.

Wide variety of today’s technological solutions to integration of fortified additives into the soil depends on the end usage of the newly obtained material. In case of interlayer fortification (thickness up to 40 cm) horizontal augers are used, which play role in mixing of soil with additives. In the next stage 3АТВОПИТЕ/Иб is applied and the rolling of the fixed layer is performed. In the process of soil-pile creation, soil from the future pile body is extracted, then the extracted soil is mixed with additives and grouting fluid and then it’s placed back in.

In the core of zonal pressing in technology "Russian swing" [19, 20] lies imitation of the effect of the natural process called “Flowing wedge” which is usually used for thixotropic soils capable of creating an extremely dense structure. Excess of moisture and air can be removed by means of special equipment to create and stabilize the achieved sealing.

Technology of “Russian swing” is in the core of this research and is vital in creation of fortified clayey foundations and development of technology for masonry materials from the same clay substances without the need for firing of these materials.

The advantages of the proposed technology include:
• Ability to work in weak water-saturated soils
• High economic performance due to the extensive use of mining waste
• High productivity of the method due to the rapid setting of the complex binder
• Low requirements for compliance with the regulated calcining temperature of dolomite (700°C), since if it is exceeded, the resulting lime does not interfere with the strengthening of the soil, as in the case of production of magnesia binder.

Due to semi-fired dolomite and phosphates, water absorption occurs and a change in the structure and properties of the soil leads to an increase in its carrying capacity due to the formation of hydroaluminates and aluminosilicates of calcium and magnesium.

4. Conclusion

The importance of this research lies in solve environmental problems:
• Impervious soil screens for harmful chemicals;
• Liberation of land from mining dumps. Of the total dolomite mining, only 30–40% is used in construction, the rest goes to dumps;
• Utilization of soils which are left over after digging of pits.

Nanodisperse particles (1-100nm) of chrysotile and semi-fired dolomite possess high chemical activity towards the solid phase of dispersed mineral components of clayey soil. In the process of treating clayey soil with a fortifying composition, nanodispersed alumina, iron and alkali hydroxides are extracted from the crystal lattice of the clayey soil. This contributes to the synthesis of binders, accompanied by the synthesis of hydrosilicates, hydroaluminate hydroferrites [22].

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