The use of the chrysotile cement waste as the secondary aggregate for the concrete

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Abstract. The article presents the results of research on the effective concrete with secondary chrysotile cement aggregate. One of the important problems of modern science of construction materials is the use of secondary resources for the production of construction materials, and a considerable part of them are the chrysotile cement waste and scrapped chrysotile cement products. The aim of presented research is the development of effective concrete for the production of foundation wall blocks with the use of crushed chrysotile cement products as a secondary aggregate. The main characteristics of the secondary chrysotile cement aggregate have been determined. The concrete with different compositions and with different content of secondary chrysotile cement rubble has been studied. The dependences of the strength and the specific strength of concrete with a constant W/C ratio and constant binder consumption on the consumption of the secondary aggregate have been obtained. It is stated that the introduction of secondary chrysotile cement aggregate does not significantly effect the water resistance and frost resistance of the concrete. It is shown that the variation of the fractions of secondary aggregates and the binder makes it possible to obtain the effective concrete with a wide range of strength values.

1. Introduction
One of the important trends in the resource economy in construction is the use of recycled resources in the production of building materials [1]. This allows us to expand the resource supplies for the production of building materials, and it is one of the solutions to important national economic problems caused by the environmental pollution.

2. Review of published works
The chrysotile cement wastes are a considerable part of secondary resources [2-3]. The chrysotile cement industry has a significant impact on the environment. The chrysotile cement plants produce specific waste: chrysotile cement dust, wet waste, crushed sheets and pipes, trash from the use of paper bags [2]. Each chrysotile cement plant has a waste storage. According to [4], the waste output in the chrysotile cement industry is 7 – 10 % of the weight of the products, including the dry waste (3 – 5 %) and the wet waste (4 – 5 %). According to the "Chrysotile Association" Society, there were produced about 1.26 million tons of chrysotile cement products in 2010 [5]. Thus, the waste output was equal to about 126 000 tons per year. In this regards the use of chrysotile cement waste is a quite acute question. In addition, the construction waste landfills have accumulated a large amount of overage chrysotile cement products (pipes, sheets, slate). Reliable methods of disposal of chrysotile cement waste are costly; therefore the development of technologies of the use of chrysotile cement...
waste in the building materials industry is promising. Disposal of waste will free up their disposal space and solve important environmental and economic problems [2, 4].

There are various methods of disposal of dry chrysotile cement waste, i.e. crushed sheets, scraps, and overage chrysotile cement products. The simplest of these is the crushing of waste and their following use as a secondary aggregate for concrete. For example, in the middle of the last century, some chrysotile cement plants in our country periodically manufactured the masonry units from a mix of chrysotile cement waste, slag and cement. They have been used for the erection of rural low-rise buildings [4]. In this paper, it was suggested to use crushed chrysotile cement sheets in the production of foundation wall blocks.

The safety of chrysotile cement products has been confirmed by many years of research done by both Russian and foreign scientists, the results were adopted by the World Health Organization (WHO) [6].

It is known that the asbestos minerals include serpentine group minerals (for example, chrysotile) and amphibole minerals [5]. The structure and properties of serpentinite and amphibole differ much. Currently, the amphibole asbestos is recognized by the International Agency for Research on Cancer (IARC) and the WHO as the 1st group carcinogens and is forbidden to be used [4]. In the construction they use exclusively the chrysotile asbestos, which has a less biological activity. Combining these minerals under generally accepted term "asbestos" caused in its time the asbestos phobia and led to the restriction of the use of materials containing chrysotile asbestos.

In [2], it is shown that the destruction of corrugated chrysotile cement sheets (roofing slate) may occur inside the cement matrix or inside the chrysotile fiber. In this system, the contact zone "fiber – cement matrix" has the highest strength, which eliminates a spontaneous emission of fibers from the material. The fibers can leave the products only in case of their mechanical damage [2]. Asbestos-containing serpentine rock is widely presented in nature, therefore the air contains a certain amount of asbestos fibers (natural asbestos background) [7]. There is a threshold dose of asbestos in the air, below which it does not have any negative impact on human health.

In [8-9], it was shown that all emitted chrysotile fibers from the chrysotile cement surface were almost completely covered with the hydration products and the subsequent carbonization clinker phases. In [8], an active sorption of the products of Portland cement hydration by chrysotile fibers is shown. It is found that all chrysotile fibers in the cement matrix chemically react with the cement hydration products, changing their composition and structure. Thus, it is proved that the surface of chrysotile cement products cannot extract the fibers with their initial properties. According to [10], the chrysotile fibers coated with cement hydration products have a reduced biological activity.

The environmental-and-health studies [11] showed that chrysotile cement materials are not any significant sources of air pollution by chrysotile asbestos fibers inside or outside buildings. Even the process of machining of products by high-speed equipment, producing some dust does not make the content of chrysotile fibers higher than the maximum permissible concentration (MPC).

Indirectly, the safety of chrysotile cement products is proved by current hygiene regulations, according to which it is allowed to apply pressure asbestos cement pipes in the networks of hot and cold potable water supply [6].

Thus, it was assumed that the use of crushed chrysotile cement sheets as an aggregate for the concrete completely eliminates the emission of fibers from the concrete due to a double "conservation" of fibers in the concrete. And the use of this concrete for the foundation blocks completely eliminates the negative impact of asbestos fibers on humans.

The use of secondary aggregates in the concrete technology has been the subject of numerous studies. Considerable experience of using concrete and reinforced concrete waste as aggregates for concrete was accumulated [12], which is one of the most important reserves of saving material and energy in the production of building materials [13]. The question of the use of crushed chrysotile cement products as a secondary aggregate for concrete has not been studied yet.

The aim of the present research is the development of effective concrete for the production of foundation wall blocks with the use of crushed chrysotile cement products as a secondary aggregate.
3. Materials and methods

According to the State Standard of Russian Federation GOST 13579-78 "Concrete fundament wall blocks. Specifications", the strength class for the fundament wall concrete blocks is C 12/15. The composition of the concrete was taken with respect to the required strength of 19.5 MPa, with consideration of the coefficient of the required strength equal to 1.3 (GOST 18105-10 "Concrete. Rules for monitoring and evaluation of strength") with a coefficient of variation of the concrete strength equal to 13.5 %.

According to the recommendations [14], it is advisable to take the Portland cement Holcim CEM II/B-S 32.5 N with slag (GOST 31108-2003 "Cements. Specifications") as the binder. As a fine aggregate, the medium size silica quarry sand (GOST 8736-93 "Sand for construction works. Specifications") was used. The properties of the sand were determined according to the standard procedures in accordance with GOST 8735-88 "Sand for construction works. Test methods". The bulk density of the sand was equal to 1596 kg/m$^3$, the true density was equal to 2650 kg/m$^3$. The air volume coefficient for the sand was determined analytically and was equal to 39.8 %. The sand satisfies the requirements of the State Standard of Russian Federation with respect to the grain composition. The gradation factor of the sand was equal to 2.1, the water demand was equal to 7.5 %.

As a coarse aggregate, the rubble granite (fraction 5-20 mm) according to GOST 8267-93 "Rubble and gravel from dense rocks for construction work. Specifications" was used. The properties of the rubble were determined by standard methods in accordance with GOST 8269.0-97 "Rubble and gravel from dense rocks and industrial waste products for the construction work. Test methods". The grain composition of the rubble satisfies the requirements of the State Standard of Russian Federation. The average rubble density (in a piece), determined by hydrostatic weighing, was equal to 2640 kg/m$^3$, the bulk density was equal to 1437 kg/m$^3$, the air volume coefficient was equal to 45.6 %.

As a secondary aggregate, the crushed chrysotile cement flat sheets were used. The properties of chrysotile cement rubble are determined primarily by the properties of the original chrysotile cement products. The chrysotile cement material is dispersed reinforced material with anisotropic properties [3]. The strength of the chrysotile cement along the rolling direction is 1 to 1.25 times higher than the strength across the rolling direction and is significantly higher than the strength in the direction perpendicular to the layers. The average density of the chrysotile cement is 1870...1900 kg/m$^3$. The compressive strength of the chrysotile cement products is more than 24.5 MPa [15]. The tensile bending strength of chrysotile cement sheets is 17...35 MPa. The porosity is equal to 20...25 %, the pores are mostly open. The water absorption is 20...24 %. A great open porosity determines a low frost resistance of the chrysotile cement products. According to [15], the strength of chrysotile cement on average is reduced by 10 % after 25 freeze-thaw cycles for the average density of 1570 kg/m$^3$ after 50 freeze-thaw cycles for the average density of 1670 kg/m$^3$ and after 100 freeze-thaw cycles for the average density of 1800 kg/m$^3$.

The mineral composition of the chrysotile cement wastes, according to [16], is presented by hydroxides, hydroaluminates, calcium hydroxide and calcium carbonate, and chrysotile asbestos. The content of clinker minerals hydrates is 53...58 %, that of calcium hydroxide and magnesium is 27...35 %, that of calcium carbonate is 15...20 % and that of asbestos is 6...20 %.

The chrysotile cement flat sheets were crushed using a jaw crusner. The derived secondary rubble was fractionated for the production of rubble with a grain structure similar to the used granite rubble. Due to the laminate structure of asbestos sheets, the rubble obtained from them was characterized by a higher content of grains with elongate form, which determined its higher air volume coefficient. The average density of chrysotile cement rubble was determined by hydrostatic weighing and was equal to 2028 kg/m$^3$, the bulk density was equal to 843 kg/m$^3$, the air volume coefficient was equal to 58.4 %. The water absorption by mass of the rubble was equal to 19.2 % that by volume was equal to 38.9 %. The strength characteristics of the rubble were determined by the compression in the cylinder in accordance with GOST 9758-86 "Aggregates porous inorganic for construction work. Test methods". The value of squeezing strength is 3.9 MPa, the softening coefficient is 0.57. The frost resistance grade is 50 cycles.
As a plasticizer, we used the superplasticizer C-3; the dose was equal to 0.75 % by mass of the cement in terms of dry matter.

The composition of the concrete was taken by the conventional method \cite{14} with the use of the Bolomey-Skramtaev formula, the equation for the absolute volume and the equation for the filling of voids in the coarse aggregate. The secondary chrysotile cement rubble in the concrete mix is characterized by the water demand by 30...50 % less than the water absorption of the rubble in the water, which was considered in the process of calculation.

4. Results and discussion

The properties of concrete with different content of second aggregate have been studied. The mobility of all concrete mixtures was equal to 2...4 cm. The following concrete compositions have been studied: the control one (without secondary aggregate), the one with the content of chrysotile cement rubble equal to 10 %, 30 %, 50 % and 100 % of the mass of granite rubble (9 %, 23 %, 33 % and 50 % of the mass of coarse aggregate), and the one with secondary rubble without granite rubble. The calculation of the concrete composition in this case was carried out in order to ensure the conditions of constant water-to-cement ratio of the concrete mix, which, with the consideration of the water demand of secondary rubble, led to an increase of up to 50 % of the cement consumption in the process of increasing the proportion of the secondary aggregate. The increase of the cement consumption also contributes to a higher air volume coefficient of the secondary rubble.

The properties of the concrete and concrete mixes were determined by standard methods in accordance with the State Standard of Russian Federation. The compressive strength of the concrete was determined on the cube samples with the edge length of 10 cm with actuation by means of a scaling factor 0.95 to the strength of standard samples with the edge length of 15 cm. The results are shown in Table 1.

Table 1. The properties of concrete with secondary chrysotile cement rubble.

| Characteristics, dimension | Control sample (0 % of chrysotile cement) | The values of characteristics with respect to granite rubble, % | 100 % of chrysotile cement |
|---------------------------|------------------------------------------|-------------------------------------------------|--------------------------|
| Compression strength, MPa | 19.5                                     | 22.6                                           | 21.5                     | 22.2 | 26.8 | 27.3 |
| Average density of concrete, kg/m³ | 2425                                    | 2395                                           | 2280                     | 2310 | 2235 | 2120 |
| Specific strength, MPa    | 8.0                                      | 9.4                                            | 9.4                      | 9.6  | 12.0 | 12.9 |

As one can see from Table 2 that average density of the concrete decreases but its strength increases with the increase of the content of porous secondary aggregate in the concrete; and the higher the content of the secondary aggregate in the concrete is, the greater is the strength (Figure 1). That increase is up to 40 %. Accordingly, the specific strength of the concrete with secondary aggregate increases up to 60 % compared with the control composition (Figure 2). This effect is due to increased cement consumption with the water-to-cement ratio in the concrete being unchanged. In addition, it is known that porous aggregates, such as crushed chrysotile cement, play a positive role in the concrete structure formation by absorbing the water at the initial stage of hardening, thereby compacting the contact zone "cement stone - aggregate", and then giving out the absorbed water during the concrete strength set contributing to a more complete hydration of the binder.
It has been found that the introduction of secondary chrysotile cement aggregate into the concrete does not affect the water resistance and frost resistance of tested concrete samples.

The composition of the concrete, in order to maintain the constancy of the water-to-cement ratio in this case is not entirely correct, since the excess water in the concrete mixture is absorbed by the porous aggregate, and so it has no significant effect on the strength of the cement matrix. The strength of concrete with various contents of secondary aggregate at a constant consumption of Portland cement has been determined; it turned out to be the same as for the control composition. The dependence of the concrete strength on the content of secondary rubble is shown in Figure 3.

Figure 3 shows that the strength of the concrete decreases with the increase of the content of secondary aggregate. But this is due not only to a low strength of the aggregate, but also to the shortage of cement paste in these compositions, since the secondary aggregate has a higher air volume coefficient (58.4 %), which implies an increase in the sand consumption.

5. Conclusions
The studies confirmed the possibility of using the crushed chrysotile cement products as a secondary aggregate for concrete production; the effective concrete for the production of foundation wall blocks with compressive strength values up to 15 MPa has been developed. The economic and ecological efficiency is achieved through the use of secondary chrysotile cement aggregate. Figure 4 shows the
dependence of the strength of the concrete with different contents of secondary chrysotile cement rubble on the content of Portland cement CEM II/B-S 32.5 N. The graphs show that, through the variation of the proportion of the secondary aggregates and the binder, it is possible to obtain the effective concrete with a wide range of strength values. There exists a reserve for further widening of the range for the strength values of the concrete with such aggregate due to the use of the cement with higher strength values. In the process of mass production of some types of products, it is possible to replace completely the granite rubble by the secondary rubble without decrease in physical, mechanical and maintenance characteristics of the products as well as without any increase in the products cost.

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