Some aspects of using the crushed concrete under extreme conditions of the Russian Arctic

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Abstract. The limited choice of construction materials under the extreme conditions of the Russian Arctic and the necessity to solve the ecological problems after the intense development of territories in the USSR raise the issue of utilizing the unnecessary dwelling and industrial buildings and using the obtained wastes. The most widespread material is reinforced concrete. The authors propose using concrete with angular aggregate made of crushed concrete. Based on the properties analysis and the technology of producing and processing both materials, the authors regard the possibility and area of their application. The aim of the research was to prove the possibility of using the construction materials based on utilization of the secondary raw materials – crushed reinforced concrete – under the extreme conditions of the Russian Arctic and to define the spheres of application. The main method was comparing the experience of using crushed concrete on the continent and in the Arctic. The possibility is studied to use the crushed concrete for low-burden foundations and basements, and as coarse aggregate for concrete when erecting buildings, constructions, and motor roads in the Russian Arctic. The crushed concrete and the concrete with aggregate made of crushed concrete can be used in the Russian Arctic provided certain conditions are observed related to the volume of the crushed concrete in the mix and the maturing of concrete under positive temperatures till the critical strength is achieved.

1. Introduction
The modern stage of reclamation and development of the Arctic zone of the Russian Federation puts forward a new approach to forming the human environment. The course towards sustainable development, enunciated in 1987, is viewed as the possibility to change the paradigm in the system ‘biosphere-anthroposphere’. Two directions are evident – reducing extraction of natural resources and increasing the use of secondary raw materials. The realization of the finiteness of natural resources and the increase of waste led not only the specialists but also the governments of different countries to active measures aimed at reducing the harmful exhausts into the atmosphere and partial substitution of the traditional energy sources for alternative ones. Russia, as a large producer of traditional resources (oil and gas), is not yet enthusiastic about active application of alternative energy sources. However, the use of secondary raw materials as the second direction of sustainable development is actively implemented in architecture and construction.
Consumer economy is based on rapid change of goods; at that, the volume of waste grows not only in industry. In architecture, buildings and constructions are no longer erected ‘for centuries to come’.

![Figure 1. Gas production facility at Bovanenkovskoye](image)

In 2013, a technology of rapid skyscrapers demolishing (without exploding) was elaborated in Japan. Even the high-tech (as for the moment of their construction) buildings erected less than 30 years ago are rapidly becoming outdated and subject to dismantling and demolition. In a large city, it is easy to recycle the used construction materials and re-use them for new construction. Yet, the vast territories of the Russian Arctic with the remnants of the Soviet period constructions do not possess the appropriate infrastructure. Towns, settlements and garrisons with buildings of reinforced concrete stay half empty and are gradually destroyed. Demolition and secondary utilization of constructions and materials can significantly decrease the cost of new construction. In the Arctic region, the cost of transportation is extremely high – more than 60% of the cargo value; this inevitably increases the estimate of construction costs. Recycling of the abandoned houses and industrial constructions would make it possible to produce and utilize the construction materials with minimal transportation costs.

2. Literature review

The disintegration of the Soviet Union changed the territorial boundaries of the former Soviet Republics and Russia; the changes in transportation system affected not only the northern regions. The shift of the raw materials base towards the North Arctic Ocean lead to the acute need to develop the Northern Sea Route. Any sea route requires the coastal infrastructure. For almost three decades, the buildings and constructions erected during the intense development of the region during the Soviet times were being ruined. People who once came to work under the severe natural and climatic conditions for high salaries now moved to other regions. Before 2013, the Russian President approved the ‘Strategy of the Russian Arctic Zone development and of ensuring national safety up to 2020’. The priority directions enlisted in the document (including the comprehensive socio-economic, scientific and technological development of the Arctic Zone of the RF and provision of ecological safety) are directly linked to forming the human environment.

Architecture, as is well known, forms the artificial environment – ‘second nature’ and ‘third nature’ (by N.F. Reymers). The landscapes, transformed by man, as well as buildings and constructions – the
s-called ‘arti-natural’ environment – cannot maintain and organize itself. In the absence of people, the
cultural-architectural environment disintegrates. This processes goes on in the RF Arctic Zone –
numerous towns and settlements which are of no interest as centers of resources excavation or marine
bases will be abandoned.

Sustainable development requires reasonable approach to land expansion and to returning the
unused land into nature. The significant number of residential and industrial buildings in the Russian
Arctic (which appear outside the Strategy of the Arctic Zone development) represents, on the one
hand, a threat to the region’s ecology, and on the other hand, a large stock of secondary raw materials.
The raw materials economy requires moving from developed resource bases to new ones, which
leaves behind debris that adversely affects the environment. Hence, it is important to determine if it is
possible to use the construction waste, namely, the reinforced concrete of the abandoned buildings, to
recycle it into secondary aggregate for the concrete of future buildings and constructions, or any other
purposes in this region.

Due to the development of technological methods for processing the crushed concrete (which
separate the reinforced concrete constructions from other materials) there appeared a possibility to
obtain cheap material for new construction in the form of crushed stone for concrete; however, before
starting to use it, normative documentation and technological regulations are needed. Moscow State
University of Civil Engineering for the first time elaborated the technical specifications for crushed
stone obtained by crushing the concrete and reinforced concrete parts of demolished buildings and
constructions – TS 5711-001-40296246—99.

However, there are some drawbacks: the concretes containing such crushed stone require increased
cement consumption, and it is difficult to predict their properties due to the heterogeneity of the
composition and properties of the industrial waste. The crushed ordinary concrete may serve as a
secondary raw material for aggregate production. When crushing, siftings are produced; their volume
amounts to 20…30% depending on the concrete composition and its strength characteristics. These
siftings can be activated, i.e., milled together with chemical additives. The crushed concrete may have
secondary (residual) cementing properties due to the presence of incompletely hydrated clinker
particles, the volume of which in fresh concrete of cements type CEM-I amounts to 15…25%. After
fine grinding, weak secondary cementing properties are manifested; also, gel-like fibrous calcium
hydrosilicates of type C-S-H are formed. The quality criterion of siftings from the crushed concrete
grinding (as a raw material for active aggregate) is the presence of residual peaks of belite (0.286 nm)
and portlandite (0.49 nm) on the diagrams of roentgen-phase analysis (RPhA). In some cases, the
crushed concrete may manifest hydraulic properties after mechanical-chemical activation, if it contains
even residual amounts of alite and an intermediate phase of clinker in the form of vitrified tricalcium
silicate and calcium alumoferrite [1].

In the article [2], the authors propose to use the crushed concrete for obtaining a binder by burning
it at 600 °C to 800 °C, and further grinding it to siftings on sift No.008, similarly to standard Portland
cement (not more than 15%). It was found than the strength of the obtained solutions and concretes
grows with the age increase of the crushed concrete, and when using binder of burned crushed
concrete compared with unburned. Moreover, the density of the new concretes made of crushed
concrete is higher than that of the crushed concrete of which they were made. Besides, the higher the
density of crushed concrete, the higher the density of the concrete made of it.

The work [3] researches the ordinary concretes with partial substitution of natural coarse aggregate
for crushed concrete. It was found that up to 40% of crushed concrete within the concrete mix allows
the standard use of this mix. At over 40%, the concrete mix starts to stratify due to the significant
water consumption by the aggregate of crushed concrete. Thus, the water to cement ratio of the
concrete mix had to be raised. Besides, it was stated that substitution of natural coarse aggregate for
crushed concrete increased from 0 to 40%, the density of hardened concrete decreased, but its
compression strength slightly increased [3]. This may be due either to the fact that crushed concrete
was originally made of high-quality concrete, or to the fact that processed crushed concrete contains a
lot of open unreactive parts of cement grains, which is, to a certain extent, similar to adding cement to the concrete mix.

![Diagram of substandard concrete and reinforced concrete utilization](image)

**Figure 2.** Substandard concrete and reinforced concrete utilization [4]

The world practice of producing and using secondary aggregate made of crushed concrete is carried out according to three patterns:

1. The crushed concrete from the site of demolition is transported to a plant producing aggregates; the produced aggregate is transported to a concrete plant (two transportations).
2. The equipment for obtaining aggregate from crushed concrete is installed directly in the site of demolition; the obtained aggregate is transported to a concrete plant or a construction site (one transportation).
3. The aggregate of crushed concrete is obtained and used at the site of demolition (in-site transportation).

For the Arctic conditions, the second option is appropriate (Fig. 2). Such aggregate can already be used for constructing the base of access and low-burden roads, foundations of warehouses and industrial premises and basements of small facilities.

3. **Materials and methods**

The comparative analysis of towns and settlements of the Russian Arctic has shown the prospective directions for implementing the Strategy of the Arctic Zone development. The information-analytical method enabled to determine the abandoned and deteriorating sites which can serve as centers for concrete recycling.
The comparative analysis of construction materials utilization on the continent and in the Arctic shows it is possible to use crushed concrete for low-burden foundations and basements. This is substantiated by the fact that the ground is permanently frozen; it is not subject to periodic transition of temperature through 0 °C, consequently, there is no liquid phase in the ground. Thus, crushed concrete made of not very frost-proof concrete will stand these conditions.

The use of concrete with aggregate of crushed concrete is limited. Here, first of all, the following factors should be considered:

Consumption of crushed concrete aggregate must be reduced compared to crushed rock concrete aggregate, because the former contains numerous contact zones between the rock stone and cement stone. These zones consist of brittle minerals: portlandite (Ca(OH)₂) and ettringite (hexacalcium aluminate trisulfate hydrate 3CaO•Al₂O₃•3CaSO₄•31H₂O). Therefore, the only possible option is to physically reduce the number of such zones, namely, decreasing the consumption of crushed concrete. It will allow obtaining concrete with low content of crushed stone and high content of cement and sand; as the water consumption of this mix will be higher, it is necessary to use superplasticizing agents (Fig. 3), which is common of monolithic concreting.

![Figure 3. Action of superplasticizer on cement particles. (a) Flocculated cement particles; (b) dispersing cement particles by repulsive force generated by negatively charged superplasticizer; (c) releasing of entrapped water][6]

When preparing the concrete mix before pouring it into the construction, it is necessary to maintain its positive temperature (from 12 to 20 °C) until the critical strength is achieved (35% for the concrete of B20 strength class). For the standard Portland cement the holding period is 1-2 days. Besides, it is advisable to use a low temperature binder (LTB) for winter concreting [1]. The analysis of the pore structure of cement stone with this binder showed that the number of capillary pores with the diameter of over 0.1 micrometer in it is only 23%, while in cement stone with standard Portland cement it is 67%. The number of thin pores (0.1-0.01 micrometer) is, on the contrary, higher in cement stone with LTB (65%) than in cement stone with Portland cement (28%). In thin pores, water freezes at significantly lower temperatures, which allows economizing on heating concrete for achieving the critical strength when using LTB.

4. Results

Demolishing the reinforced concrete buildings and constructions solves the problem of ecological safety of the Arctic Region. The demolished constructions harm both the human and natural environment. Utilization and recycling reduce the cost of concrete made with secondary crushed stone by 25%. Energy consumption while excavating the natural crushed stone is 8 times higher than for producing crushed stone from secondary raw materials.

The possibility to use crushed concrete for low-burden basements and foundations in the Russian Arctic is substantiated. Using this material as coarse aggregate for concrete when constructing buildings in the Arctic is possible, provided this aggregate is used for concrete with low content of crushed stone aggregate, and the positive temperature of the concrete mix is maintained till the critical
strength is achieved. The quality of the obtained material determines its place in the structure of developing the Arctic Region.

Table 1. Using the secondary concretes [4]

| Category of the secondary concrete | Sphere of utilization                                                                 | Maximal compression strength, MPa |
|-----------------------------------|--------------------------------------------------------------------------------------|-----------------------------------|
|                                   | General low-storey construction, block residential low-storey construction, individual residential low-storey construction, foundations of storing and industrial premises | Projected (standard) Actual       |
| I                                 | I                                                                                     | 18                                |
| II                                | Concrete blocks of foundations, garages and low-weight barns, beds of machines and mechanisms, etc. | 15                                |
| III                               | Foundations of wooden constructions of gates, fences, low-weight beds of machines and mechanisms, etc. | 12                                |

The construction of roadway is the main area of using this material, taking into account the acute need for extending transportation routes, especially motor roads. In towns and settlements, the secondary crushed stone may be used as bedding for all kinds of pavements, parking lots, foundations, and in landscape architecture.

5. Conclusions
The cost and term of developing the Arctic Region can be reduced by using the local construction materials. In the absence of such, they can be substituted by recycled wastes. Demolition of buildings and processing concrete on the site allows cleaning up the territories for their regeneration and using the crushed stone in construction.

The crushed concrete, as well as the concretes with aggregate of crushed concrete, can be used in the Russian Arctic provided certain conditions are observed related to the volume of the crushed concrete in the concrete mix and the maturing of concrete under positive temperatures till the critical strength is achieved. The probable climatic changes, i.e., warming, will broaden the use of this material. The broad utilization of crushed stone obtained from demolished buildings and constructions solves two tasks of sustainable development of the Russian Arctic. On the one hand, it broadens the transportation network and reduces the construction costs, and on the other hand restores of the ecological balance in the system ‘biosphere–anthroposphere’ [5].

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