Industrial waste in concrete mixtures for construction of underground structures and minerals extraction

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Abstract: An increase in population leads to an increase in the density of inhabitants in megacities and leads to an increase in consumed raw materials. The paper presents the description of the problems that arise for builders when building density increases and for producers of raw materials that arise when raw material is intensified. The analysis of the impact of construction and mining waste on the environment was carried out. Compositions of concrete mixes and methods of their preparation are offered to improve the quality and safety of life in megacities, as well as the safety of mining operations along with reducing the human impact on the ecosystem. Aspects of preparation of concrete mixes and questions of improvement of its quality by activation of components are revealed. The possibility of activation of construction and mining waste used as an inert aggregate in considered. The possibility of realization of non-waste production is considered.

1. Introduction – the scope of the study
The development of society is a natural process of civilization. Since the middle of the twentieth century, this process has been proceeding at an accelerated pace. The population of the Earth has more than doubled: from 3 billion people in 1960 to 7 billion people in 2011, while the share of the urban population has grown from 33\% to 51\%, and this trend will continue according to sociologists and demographers (figure 1). An increase in population leads to an increase in the density of inhabitants in megacities and leads to an increase in consumed raw materials. Due to the fact that the area of megacities is limited, a constant influx of residents leads to an increase in the number of buildings. An increase in building density forces builders to increase the height of buildings, which leads to the creation of stronger foundations and their deepening, or to place many infrastructure facilities underground. High rates of reconstruction and construction of urban facilities necessitate rapid and high-quality construction of communication systems that ensure the supply of residential and public buildings with heat, water, electricity and communications. It is necessary to take into account the influence of each object on the underground space during the construction of deep foundations, underground parking spaces and shops, the subway and automobile tunnels, communication facilities.
a. the population of the Earth

b. the share [%] of urban population

Figure 1. Dynamics of an increase of human and urban populations

It is also necessary to take into consideration the integrated approach, the availability of complex relationships between all the underground objects of the megacity, the influence of buildings and structures on the surface. In addition, it also needs to consider the impact of many factors on the progress of urban construction, which are difficult to consider in advance (vibration from moving machines; vibration from construction equipment [1, 2], a sharp rise in groundwater after rains, etc.). All this predetermines the development and implementation of new technologies for the construction of underground structures in the megacity. The growth of scientific and technological progress occurs with the development of society. This leads to an increase in demand for natural resources, therefore, the volume of extraction of minerals from the depths increases. Mankind has been using minerals since ancient times, but the main volume of natural resource extraction has been carried out since the beginning of the twentieth century. So from the beginning of the last century to the present, it is extracted: oil - 99.5%, coal - 90%, iron ore - 87%, copper ore - 80%, gold - 70%. Population growth leads to an increase in the consumption of basic minerals in the world, which leads to a positive global vector of increase in mineral production over the past 50 years (figure 2). For the period 1970-2012 coal production increased 1.9 times, iron ore - 3.8 times, gold - 1.8 times, non-ferrous metals - 3 times, phosphate - 1.8 times. An increase in consumed resources determines the high rate of development of geotechnology, which is associated with certain risks, both industrial and environmental.
The graph on figure 3 shows that according to all predictions, the dynamics of coal extraction in the Russian Federation for 2010-2030 tends to increase rapidly. The frequency of geotechnogenic disasters during the extraction of minerals from the depth of the earth increases. 1986 - surface failure BKPRU-3 “Uralkali”, Perm Territory; 1999 - a rock blow at the “Umbozero” mine in the Murmansk region; 2007 - surface failure at BKRP-1 “Uralkali”, Perm Territory; 2014 - water breakthrough at the “Solikamsk-2” mine, Perm Territory; 2017 - water breakthrough from a spent quarry into an underground mine at the “Mir” enterprise in Yakutia (figure 4).

a. Failure in the territory of BKPRU-1 of OJSC «Uralkali»
b. Water breakthrough at the mine “Solikamsk-2”.
c. Breakthrough of water from a spent pit to an underground mine at the «Mir» enterprise
d. Rock blow at the “Umbozero” mine

Figure 4. Man-made disasters

All this may lead to environmental disasters, loss of deposits, and, accordingly, an increase in social tension, where enterprises are city-forming. In addition to accidents in mines, man-made disasters occur at facilities associated with extraction of minerals, for example, at tailings, which leads to environmental disasters (figure 5).

2. Industrial waste in concrete mixtures

One of the ways to minimize geotechnogenic disasters and reduce the environmental impact of mining enterprises is to use technology with the backfilling of working space [3, 4]. Due to the limited ability of the biosphere to self-regulation and self-reproduction, it is necessary to create gentle technologies that ensure sustainable development of the region [5]. Mining waste, as well as secondary concrete from demolition work in civil engineering, may be suitable for large earthworks, provided that it has a neutral impact on the environment regarding the spread of chemical pollution or other sources of pollution [6]. Several land management attempts with particular regard to the potential use of coal tailings have been presented at the Ostrava Technical University (VSB - TUO), Czech Republic, [7]. The development and implementation of new technologies for the construction of underground structures in a megacity and the use of development systems with artificial maintenance of the treatment space is not possible without the creation of new concrete mixtures that preserve strength characteristics, reduce the cost of the construction process and extract useful components and at the same time reduce the environmental impact. The concrete mixture used in the construction of
underground structures and used in the extraction of minerals is a composite material that hardens in underground conditions. This mixture has in its composition: astringent material; inert aggregate; mixing water and chemical additives. The hardened mixture is a created artificial mass, which is a foreign body inside the rock mass. Several indicators determine its quality: strength, compression, rheological properties, as well as stability in exposure. It is technologically important to guarantee those concrete properties that are necessary for specific underground conditions.

The properties of the hardened concrete mixture are significantly affected by: quality, the granulometric composition and the ratio of large and small aggregates, as well as their amount per unit volume; amount of water (water-binding ratio); method of preparation, transportation and filling; conditions (temperature regime) and age of hardening.

Analysis of the cost structure of the concrete mix used in the construction of underground structures or used in the extraction of minerals by the underground method shows that specially mined materials for inert aggregate have the best qualities, but their cost is the highest. So, the cost of aggregate in the filling complex of some Russian mines is 25-35%. Therefore, the main vector here should be the use of industrial and mining waste. These wastes are cheap and, with the appropriate technology of preparation, can replace specially extracted aggregate without deterioration of the characteristics of the erected concrete mass, while their share in the prime cost of the mixture will not exceed 5-8%.

Figure 5. Man-made disasters at tailings

| a. Dzhidinsk tungsten-molybdenum plant, Zakamensk town, Republic of Buryatia, Russia |
| b. Dust storm from the beaches of the Dzhidinsk tailing dump |
| c. Dam break at the Karamken cyanide tailing site, Karamken village, Magadan region, Russia |
| d. Breakthrough of the tailings dam at the “Pioneer” mine, Petropavlovsk, Amur Region, Russia |
The use of mining and construction waste is an important issue worldwide [8-14]. But it has a very local size and meaning. Understanding the problems also depends on the experience of the people involved in the analysis. From the point of view of a civil engineer (academician working as an industry consultant), this is mainly the possibility of using large volumes of crushed stone (dump material from mines) for large infrastructure projects: roads and railways, flood protection systems, dams [15].

The following issues related to this feature may be listed below:

- The suitability of the waste in terms of its durability and environmental “cleanliness”.
- The environmental costs of preparing for implementation (crushing, sorting, filling formation) are widely discussed in [16-20].
- Availability in the right place and at the right time.
- Environmental costs for transportation and storage [21, 22].

A fundamentally new technology for the preparation of hardening concrete mixtures is necessary to compensate for the negative characteristics of aggregates and ensure stable predicted properties of the mixture and hardened stone [14]. It is based on the use of the property of thixotropic dilution of moistened dispersed materials under mechanical action on them. In such structures, when a mechanical action is applied, the bonds between the individual particles become vanishingly small and the structures turn into a sol state, which, when the mechanical action is removed, reversibly turns into a gel and then hardens. Thus, when using the described technology, it is possible to obtain fluid mixtures that are easily and efficiently mixed, deliver them through pipes over long distances and with high completeness to fill in a given space, as well as ensure their quick hardening and better conditions of structure formation.

Studies have shown that for the implementation of such a technology, it is necessary that the concrete mix must have at least 30% fine particles with a particle size of less than 44 microns; the water content in the mixture was in the range of 78–82% [3, 10, 14]. At the same time, in the process of preparing the concrete mixture, its primary structure must be destroyed. It is especially important that such mixtures will not contain excess water.

3. Inert aggregate activation processing

Tests and Additional activation, both of the mixture as a whole and of each component separately, can improve the strength properties and homogeneity of the created mass when using waste from mining and industrial production [11, 24]. One of the promising activation methods is mechanical activation in disintegrators (figure 6).

![Disintegrator Diagram](image_url)

**Figure 6.** The scheme of the disintegrator
Waste treatment is carried out before mixing with other components. Preliminary grinding of the waste is necessary when supply it to the working body of the disintegrator. When using enrichment waste, due to its finely divided composition, preliminary grinding is not required. But in some cases, due to their high water cut, it is necessary to remove excess moisture [25]. In the working body of the disintegrator, large internal stresses occur, which are caused by an uneven redistribution of speeds. In this case, the hydrate bonds on the surface of the inert aggregate are destroyed.

The concrete mixtures obtained on the basis of activated waste is less prone to delamination, since it is more difficult to "give" water, is more fluid and homogeneous in composition (figure 7). The use of a disintegrating activation method allows to increase the strength by 25-30 % while reducing the cement amount by 40%. The last mentioned aspect reduces the carbon footprint of the geotechnology [21].

![Figure 7. The effect of the duration of activation of enrichment waste](image)

4. Technological scheme of preparation of concrete mix

The preparation of a hardening filling mixture based on waste includes the following operations (figure 8):

- transportation and storage of waste to the site of the complex;
- shredding waste or removing excess moisture;
- supply of waste into the loading hopper;
- activation treatment of waste;
- supply of waste to the feeder - dispenser after activation processing;
- delivery of astringent material by cement trucks to the filling complex and reception in silos;
- supply of astringent material to the loading hopper;
- delivery by pipeline of water or a specially prepared solution;
- supply of water / solution to the loading hopper;
- delivery and storage of activating additives to the site of the complex;
- supply of activating additive to the loading hopper;
- dosing of water / solution and activating additive and their mixing in the mixing compartment;
- dosing of astringent material and aggregate and supply of them into the mixing drum by conveyor;
- supply of a solvent (water/solution and activating additive) through a pipeline to the mixing drum;
- mixing the components and preparing the filling mixture;
- supply of the finished filling mixture to the pipeline through the switchgear;
- technological control over the preparation of the filling mixture.

The technology for preparing filling mixtures depends on the selected composition, therefore filling plants should provide the possibility of varying the volume of dosing of the mixture components.
5. **Non-waste mining concept**

Mankind is facing a huge problem: environmental degradation as a result of human activity, both during construction in megacities, and especially in mining. Utilization of mining wastes is practically impossible due to their large volume and specific features. Use of industrial waste [5-7, 9, 15, 19, 21] along with mining waste [3, 10, 11, 26-29] is the most important environmental aspect in the whole world.

One of the main tasks of Comprehensive Exploitation of Mineral Resources is the creation of non-waste mining. Activation of components of concrete mixtures allows us to implement the concept of production, eliminating the formation of waste and involving the use of intermediate products in a closed cycle of primary and secondary production (figure 9).
6. Conclusion

Activation treatment of waste from both industrial and mining allows the use of waste in concrete mix. This makes it possible to dispose of these wastes, reduce the cost of concrete mix, therefore, reduce the cost of the final product. It also makes it possible to implement the principle of organizing mining production, eliminating the generation of waste and estimating the use of intermediate products in cyclic production.

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