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Ecological Impact of Production and Use of Concrete

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ABSTRACT

Ecological, technical and economical aspects of production and use of concrete and reinforced concrete are discussed in the paper. It shows that production and use of concrete and reinforced concrete are an ecological dominant. Over millennia the human activities to satisfy people's vital needs have been aimed at withdrawal of natural resources. These requirements grew with time, and the annual withdrawal of natural resources was measured by million tonnes with simultaneous pollution of natural environment. As far back as in the early 20th century Antoine de Saint-Exupery uprightly pointed out: "We are all passengers of one ship named "Earth", and there is nowhere for us to transfer." By the mid-century it became clear that the present model of the humankind development has charged a formidable fee to our planet and its natural resources. The consumer lifestyle started to deplete the Earth's natural vital resources, and the rate of man's impact on environment continuously increased.

INTRODUCTION and DISCUSSION

For the last century the world industrial production growth was more than 50-fold, and the four fifth of this growth fall to the second half of the 20th century. In this case just a little part of natural resources is converted into end products, while the rest is turned into waste. Over 60% of the Earth's natural ecosystems have been changed by human activity impacts.

In a varying degree the unfavorable habitat affects the life of the Earth's every third inhabitant. In Russia about 300 cities are in zones of environmental distress. It is estimated that one year of three of the average life time reduction of a Russian citizen is attributed to the unfavorable habitat.

Instead of unlimited "scientific and technological progress" a concept of sustainable development was set up with consideration of interests of not only the present but also the forthcoming generations. This is determined by the fact that "sustainable development of the society is a basis for surmounting the crisis being formed and presents a comprehensive program of actions of the whole world community including scientific, technological, engineering, social, economic and environmental solutions and measures for their implementation".

Let us note that the Russian Federation's environmental doctrine proclaims an important principle of equal attention to economic, social and ecological aspects of the national economy development and recognition of unfeasibility of human society development.

In implementation of the sustainable development concept quite an essential role belongs to the building complex and its important component – the building materials industry including that of concrete and reinforced concrete.

The building activities are a powerful factor of environmental impact. Construction of new projects, their operation, maintenance, rehabilitation, demolition, waste disposal and recycling – all these processes due to their immensity strongly affect environmental conditions.

The manufacture and use of building materials measured by billion tonnes are the most material-intensive component of modern civilization's production activities and far exceeds the manufacture of any other kinds of industrial and agricultural products.

One of the major consumers of natural resources is the building materials industry: the manufacture of binders, concretes, ceramic materials, etc. It can be also one of the main consumers of technogenic by-products.

Many by-products chemical and mineralogical composition are close to natural mineral raw materials and can fully or partially used in manufacture of cements, clinker-free binders, aggregates and concretes.

Of the total volume of waste produced by the building materials industry over 40% fall at the cement industry; 18-20% - manufacture of roofing and insulating materials; 10% - asbestos cement manufacturing; 15% - nonmetallic building materials; less than 10% - manufacture of concrete and reinforced concrete components and products.

Production of cement (the basic binder for concrete) is a major source of carbon oxide formation $\approx$ 1 tonne of CO_2 per 1 tonne of cement; nitrogen oxides – 1.5 to 9.5 kg per 1 tonne of clinker.

The manufacture of 1 tonne of Portland cement requires over 1 tonne of limestone, about 0.5 tonnes of clay and iron-bearing components, 200-220 kg of fuel equivalent and about 100 kW of electric power.

Table 1 gives the average specific consumption of fuel and electric power for cement production and transportation. In Russia. It follows from Table 2 that these amounts are rather ambiguous.

Table 1

Fuel and electric power consumption for production and transportation of different cement types and grades, kg of fuel equivalent per tonne

Cement type	Cement grades according to GOST 10178				
	300	400	500	550	600
Portland cement (ПЦ-ДО)	-	279.7/118	290.9/123	321.5/136	344.8/145
Portland cement with mineral admixtures (ПЦ-Д20)	-	236.9/100	258.1/109	306.9/129,5	334.9/141
Slag Portland cement (ШПЦ)	140/59	163.1/69	193.5/82	-	-

It should be noted that fuel consumption for cement production is Russia is essentially higher than in a number of other countries, because of the energy-intensive wet process used in this country.

Table 2 presents consumption of energy resources for manufacture of precast concrete products.

Table 2

Average specific consumption of energy resources for manufacture of 1 m^3 of different heavy concrete grades (based on PC 500-DO)

Concrete class	Energy consumption in fuel equivalent, kg/%, for				Total consumption per 1 m^3 of concrete, kg of fuel equivalent	Relative changes of energy consumption with regard to concrete grade
	cement	aggregate and water	steam curing	other process stages		
1	2	3	4	5	6	7
B7,5	57/53.3	5.3/5	26/24.3	18.5/17.3	106.8	0.89
1	2	3	4	5	6	7
B15	70/58,4	5.3/4.4	26/21.7	18.5/15.5	119.8	1.0
B22,5	58/65	5.3/4	22/16.8	18.5/14.2	130.8	1.09
B30	110/69.8	6.97/4	22/14.1	18.5/11.7	157.5	1.31
B40	142/74.9	6.97/4.4	22/11.4	18.5/9.7	189.5	1.58
B45	170/78.2	6.97/3.2	22/10.1	18.5/8.5	217.5	1.82

In addition to total consumption of fuel equivalent making up 106.8 to 217.5 kg of fuel equivalent per 1 m^3 of heavy concrete (Table 2), every cubic meter of concrete requires approximately 0.9 m^3 of coarse natural aggregate and 0.5 m^3 of natural sand (not taking into account limestone and clay needed for cement manufacture).

The output of cement in Russia in 2008 was over 50 mln tonnes, which were used for manufacture of about 90 mln m^3 of concrete and mortar. The latter required approximately 60 mln m^3 of dense aggregate and 30-40 mln m^3 of sand.

The above data show that concrete and mortar manufacturing requires enormous amounts of natural, material and energy resources. Their reduction is possible by extensive use of various kinds of waste now to be considered not as waste but as recoverable resources.

For instance, Russia's fuel and energy complex is a major environmental polluter. Its share is 48.4% of harmful substance atmospheric emissions, 26.7% of polluting wastewater discharge and over 30% of solid waste. The amount of ash and slag waste accumulated on Russia's territory exceeds 1 bln tonnes. Major thermal power plants of Russia annually produce about 50 mln tonnes of ash-and-slag waste consisting of 85% of fly ash trapped mainly by the wet process and rarely by the dry process, and 15% of slag. Over 80% of this waste are dumped.

At the same time the steam power plant ash is a valuable mineral raw material that can be used in manufacture of cement and concrete as a mineral admixture, in brick and porous aggregate manufacturing, in road construction, agriculture and other industries.

To concrete aggregates manufactured with the use of ash and slag one refers: ash-aggloporite gravel, non-fired ash gravel, fired ash gravel, clay-ash haydite. However, such aggregates are not produced presently on a commercial scale, in spite of the available manufacturing process. There are standards for thermal power plant ash. Specialists of NIIZhB, MISI (MGSU) and other organizations have developed numerous recommendations on its use in concretes. However, the volume of thermal plant ash use in Russia is very low, not more than 4% of its annual output, while the USA and UK use 20-25%; Germany and France – 60-70%, Finland – 90% of the current output.

Small-scale application of ash in Russia is due to the fact that this is a hydraulically removed ash. Other countries mainly use dry ash and have national policies encouraging its application.

Considerable amounts of slags of ferrous metallurgy (blast-furnace, steel-smelting, ferroalloy cupola slags) were used previously by the USSR building materials industry (56.3% of metallurgical slags were processed into granulated slag for the cement industry, 26.9% - into various aggregates – pumice, crushed stone, gravel, mineral wool, etc.).

In the present period the data on types and quantities of ferrous metallurgical slag formation and use in Russia are not available. One can just suppose that their yield was reduced in proportion to the metal output. The same refers to their processing methods into building materials; there are some data on lesser application volumes of blast-furnace granulated slags by the cement industry.

In manufacture of ferroalloys and crystalline silicon the silica fume (SF) is trapped by scrubbers.

The volume of SF trapping in Russia is roughly 30 to 40 thou. tonnes. Silica fume is the most valuable waste presenting a superpuzzolana. It is used as a mineral admixture in manufacture of high-strength concretes together with superplasticizers.

Large quantities of solid waste are formed in non-ferrous metal smelting (non-ferrous metallurgical slags, mill tailings, and overburden).

Non-ferrous metallurgical slags can be used as components of the raw meal in Portland cement production. Such catalytic elements as titanium, magnesium, sulfur, lead, zinc, copper, nickel, etc. comprised by them allow intensifying clinker-formation processes, reducing the firing temperature.

Non-ferrous metallurgical slags can be also used as concrete aggregates.

However, these slags comprise heavy metals. Their impact from the environmental-hygienic viewpoint is yet to be studied in more detail.

Many wastes have, as a rule, increased concentration of elements comprised by the Earth crust in small quantities. Therefore the waste can be considered as fresh raw materials enriched with rare elements.

Compounds leading to quality deterioration are referred to technologically harmful impurities in any raw materials including the waste used in manufacture of various building materials as well as concretes.

GOST 26633 (Annex 2) refers to harmful impurities the following rock refuse and Rassian national standard minerals: amorphous silica varieties (chalcedony, opal, flint, etc.), sulfates (gypsum, anhydrite, lamellar silicates (micas, hydromicas, chlorites, etc.), magnetite, ferrous hydrosilicates (hematite, etc.), apatite, nepheline, phosphorite, halides (lalite, sylvite, etc.), zeolites, asbestos, graphite, carbon, coal slate.

The basic harmful impurities reducing concrete strength and durability include carbon, graphite, coal slate (lamellar silicates, micas, hydromicas, chlorites, etc.), zeolites, apatite, nepheline, phosphorite.

The basic harmful impurities deteriorating the surface quality and resulting in concrete corrosion include alkali-soluble amorphous silica dioxide varieties (chalcedony, opal, flint, etc.), chlorite and some zeolites, sulfur, sulfides (pyrite, marcasite, pyrrhotine, etc.), sulfates (gypsum, anhydrite, etc.), zeolites, apatite, nepheline, phosphorite

The basic harmful impurities resulting in corrosion of reinforcing steel in concrete are halides (lalite, sylvite, etc.) including water-soluble chlorides, sulfur, sulfides, sulfates.

The contents of these elements is regulated by standards or specifications on every type of the material (natural or technogenic) used to manufacture binders, aggregates, mineral additives and concretes on their basis.

Ionization radiation is one of the most important factors characterizing the quality of living environment.

Various building materials including concretes have different radioactivity characteristics determined by radioactivity of initial raw materials in compliance with National standard GOST 30108-95. It presents the methods of identifying natural radioactive nuclides (NRN) and assessment criteria for decision-making on the use of building materials with regard to NRN values.

It ought to be noted that the use of waste in manufacture of building materials including concretes is related to solution of a number of additional problems:

- technological (connected with assessment of the impact of the waste used on construction and engineering properties, first of all, durability);
- economic (connected with the necessity to gain profit from waste utilization instead of natural raw materials);
- environmental (connected with the presence of hazardous (toxic, carcinogenic, radiation, etc.) substances in the waste and their environmental emissions).

In connection with the abovesaid the problem of environmental safety becomes particularly acute (Federal programs "Environmental Safety" and "Waste").

Building materials including concrete are regarded to be environmentally safe, if their ecological properties (sanitary and radiation-hygienic) meet the requirements to contents of natural radioactive nuclides, radon and hazardous substances in conformance with current maximum permissible concentrations (MPC).

And if they have values relating to these properties within the rated ranges, they can obtain an environmental safety certificate.

However, such estimate of environmental safety is not quite correct.

When estimating environmental safety, one has to consider not only the impact of building materials (and concrete) on natural environment (i.e. “here and now”), but also the influence of the processes that accompany production and use of building materials (and concrete), from extraction of raw materials for their manufacture to their abatement – burial or, preferably, recycling, i.e. the life cycle shall be closed thereby providing resource-saving and environment protection to the greatest extent. Therefore estimation of environmental safety shall be implemented all over their life cycle (i.e. “everywhere and always”). And the relevant procedures are being developed for this estimation nowadays.

Let us remind that the notion of life cycle was introduced by international standard ISO 14000.
Life cycle is series-connected stages and all essential input and output flows of materials and energy, starting from natural resource development and finishing with recovery of all materials taking account of used waste and energy.

From this viewpoint none material (concrete is not an exception) can be environmentally safe “outright”, since none material can be made without using material and energy resources.

The problem is still aggravated by the fact that commercially available building materials are often of poor quality, and non-durable, when waste is used, and eventually unsafe including those environmentally unsafe.

Despite the above, using the life cycle estimate one can select building materials preferable from the viewpoint of environmental safety. In this case it is desirable to keep in mind the requirements of the European Council’s expert commission on prospects of construction development in Europe until 2025 in compliance with which the progressive building materials shall meet the following basic requirements:

- minimum withdrawal of natural resources for manufacture of building materials and their maximum replacement by waste;
- high esthetic and architectural qualities;
- high strength and durability;
- possible combination with other kinds of materials;
- cost effectiveness;
- environmental safety of their manufacture and use.

Thus, manufacture and use of building materials including concrete shall be carried out not in isolation but from the viewpoint of their environmental impact according to the following scheme:
extraction of raw materials – manufacture – use – disposal, i.e. all over the life cycle.

This scheme also shows that production and use of building materials shall be environmentally safe.

Among many building materials being “friendly” to environment there is an absolute leader. This is concrete. Its production and use practically do not pollute the environment, and as to the energy/output ratio it is much more efficient than manufacture of brick and steel. This material is basic for construction of not only buildings but also infrastructure projects most harmoniously combined with nature – roads, bridges, canals and other hydraulic structures. One may say that these structures belong to the environmental infrastructure. Reinforced concrete is a primary material for erection of environmental facilities – sediment ponds, aeration tanks, coast-protecting structures, noise barriers and, especially, facilities for storage of radioactive, explosive and poisonous substances. As mentioned
bove, various types of waste can be used for its manufacture.

The economic benefit of using waste can be obtained by ultimately possible replacement of natural raw materials.

In the building industry on the whole the materials consumption and, hence, the withdrawal of natural resources per unit of end products is continuously growing. This is connected with improvement of comfort conditions in buildings, complication of mechanical equipment, increasing requirements to their energy efficiency, etc.

A get-out is, first of all, in essential increase of amounts of both other industries' by-products and the building industry's waste to be processed for building purposes. And the preference should be given to low-waste and high technologies. Beside the use of industrial waste for concrete manufacture there are great opportunities in building waste recycling.

A share of new construction in the total building activities is continuously diminishing, while the share of demolition and rehabilitation of old buildings is growing. So the building waste volume is growing too.

Of late the great attention is paid not only in Europe, but also worldwide, to the problem of environmentally balanced construction using bio-positive (environmentally safe) building materials.

Bio-positive materials imply those meeting the principles of bio-positivity:

- renewable resources are used for their production;
- they do not release hazardous substances during use;
- they succumb to self-decomposition after use without environment pollution;
- fully recyclable materials (partially bio-positive).

Solution of environmental protection problems by construction means has a global nature and is already a subject of wide international cooperation. The important results of this cooperation are: development of the environmental concept of building materials utilization; estimation of damage caused to environment by multi-tonne waste; implementation of environmental settlement demo-projects, etc.

A number of international organizations on construction – FIB, CIB, RILEM, AIPC, ERMCO and others have also established special technical commissions; they release various scientific and technical journals, which devote special issues to environmental problems.

In Russia an important role in solving environmental problems of concrete and reinforced concrete production and use shall be played by the Federal Law "On Technical Regulation".

In conformance with the main principles of the law the technical regulation is implemented with the purpose to apply uniform rules of establishing requirements to products, production processes, operation, storage, transportation, distribution and disposal, i.e. establishing requirements to products at all stages of their life cycle.

Technical regulation in construction is legal regulation of relations in the field of establishing, application and implementation of mandatory requirements to safety including environmental safety of building products and services, building production processes, operation of buildings and structures, storage, transportation, distribution and disposal of building materials and construction waste, i.e. establishing requirements to products at all stages of their life cycle.

The environmental protection objectives are specified in Article 6 of the Law where the question of technical regulations is set forth, and Article 11 where the issue of national standards is specified.

This Federal Law defines environment protection as an important component in ensuring human life and health safety. The program of developing general, i.e. the most significant technical regulations, comprises the technical regulation "On Environmental Safety". The requirements to environment protection will be integrated into special technical regulations dealing with safety on the sectoral level including construction.

As is known, national standards and corporate standards form a document base for the feasibility of requirements in general and special technical regulations.

Among various documents extending the rules of ensuring environmental safety a particular role is played by ISO standards of 14000 series "Environment Management Systems", the majority of which was adopted in Russia as national standards (GOST R ISO 14001-1998; GOST R ISO 14010 and 14011-1998) harmonized with international standard ISO 14000.

There are cases, though few, of certification, insomuch voluntary, due to the absence of the technical regulation, of the building industry organizations for conformity with requirements of these standards. Motivation of such certification can be raising an organization's image in the eyes of clients or inspecting bodies, cost reduction owing to more efficient use of waste, saving penalties for violation of environment protection laws, insurance premium reduction, improving competitiveness, etc.

In the nearest years such terms as "environmental management", "ecological audit" will become habitual for manufacturers of building materials including concrete and reinforced concrete.

The policy in science and technology oriented to development of construction as a governing means to solve environmental problems shall acquire priority in the nearest future.