IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

Concrete: Previous and Future Technologies

To cite this article: A I Gabitov *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1079** 022036

Concrete: Previous and Future Technologies

A I Gabitov[1], R R Muhamedzjanov[1], A S Salov[1], V A Rjazanova[1]

[1]Ufa State Petroleum Technological University, Mendeleeva St. 195, 450000, Ufa, Russia

E-mail: gabitov.azat@mail.ru

Abstract: The analysis for development of both theoretical and applied research summarizing all the previous experience for application of the concrete as a construction material through the ages is presented herein. Current construction practice with application of high-efficient concretes as well as some new widely applied efficient binding substances, modifiers for binding substances and fillers, active mineral additives and fillers, as well as new technological techniques and methods for making construction composites of hydration hardening are considered in details. Low power-consuming processes, making of mixed and specialty cements and nanomodified concretes are demonstrated to be the main trends in development of the researches almost around the world. Therewith, the concrete properties are likely to be predicted with durability and operational reliability thereof being increased, and the outlook for improving concrete quality and technological advances, application of various technological wastes in the concrete making, in particular, for the Republic of Bashkortostan as the developed petrochemical cluster, of wastes, end products and by-products of different petrochemical industries. Some engineering concepts with application of high strength concrete grades in the Republic of Bashkortostan are given. The research results are applied in engineering and construction of reinforced concrete tall buildings both in Ufa and in the Republic of Bashkortostan.

1. Introduction

The concrete was the principal construction material under the Roman Empire, however, wide application thereof was started in the 20th century only. In the Middle Ages the concrete was used for making foundations, but it was of low strength properties as compared with the Roman concrete [1]. Interest in concrete was regenerated in the Renaissance period, but full rebirth thereof as a construction material was slowed down because of failure to understand chemical properties of the Roman concrete.

The first successful lot of the lime cement was patented by James Parker in 1796. He grounded the lime to a fine powder that was named the Roman cement. In the same year of 1796 the French military engineer Lesage prepared the natural cement made from raw materials found in Boulogne. Later, the cement production was soon spread across Europe. In 1818 the first lot of the natural cement was manufactured in the USA [1, 2].

The “artificial stones” were more widely applied in some West-European countries where the construction of pise buildings was the long-standing tradition thereof. Pise stones were manufactured by dense laying of unburnt green clay or chalk into the form. After hardening thereof the form was removed. The first examples of such laying into the concrete mass form were known since 1830, however, the new material was discovered in France and England after 1850 only [3].

There is a tendency in the current construction practice to widely apply chemical admixtures to concrete. The chemical admixtures are efficient and universal simple-to-use means for fundamental alteration of the concrete mix and concrete [4]. Application of ready-mixed concrete is increasing due to intensive construction of both residential and municipal buildings with reinforced concrete frames. Choosing of chemical admixtures is to be specially approached to according to requirements of new architectural engineering, high rates of construction in warm and cold seasons, and reducing the resource- and labor intensity in erecting reinforced structures made from concrete (high performance concrete including) [4, 5]. The concrete density is found by the structure and filler type thereof. Heavy concretes are made from large gravel and compact stone rocks, as well as smelter slag. Light concretes – from large gravel and porous natural and artificial rocks (tuff, pumice, expanded clay and granulated slag). Hollow concretes are made by making artificial pores in the mixture of binding substances, silica components and water by gas-forming agent (aerated concrete, gas silicate) or foaming agent (foam concrete, foam silicate) [6].

Fine ground concrete waste is also applied as a mineral admixture for making mixed binding substance. The concrete waste may be used in different ways: repeated use of certain parts of buildings (footing, walls) or separate parts thereof (beams, slabs, columns) as intended, for the new construction; concrete waste disposal (recycling) for application thereof as secondary (recycled) materials [6, 7].

2. Current technologies in concrete making

The design level of strength and operational properties of new concretes is achieved by proper portioning, technology of making, concrete curing and bringing of concrete items quality to the required technical layer at the operational stage [8]. Directed formation of the structure is to be considered in making high-technology concrete. Together with the traditional methods of new concretes making, the modification thereof by silica nanoparticles is the promising one, with inclusion thereof into the mineral matrix of the binding substance thereby making patterning thereof. As a result, nanomodified materials are obtained with absolutely new properties. Main problem in making nanomodified concretes is the uniform distribution of nanomaterial in the volume of the cement matrix which is of special importance when adding trace amount of the modifier. Additional environment forming continuous phase in the composite is to be applied to solve this problem. Either liquid or dispersed phase may be used for this purpose [9, 10].

Inclusion of up to 20% of fine ground concrete waste to the mixed binding substance was proven under the research to reduce the concrete strength. Therewith, depending on the concrete waste composition, grinding fineness and water requirement to be defined by the compound composition and fracturing of particles, this strength reduction may vary within 28 days under normally moist curing within the wide range and reaching 22.1%. Adding of S-3 superplasticizer to the binding-based composition containing 20% of concrete waste on the mixed binding weight enables (by reducing moisture content of the concrete mix keeping the same flowability of the test cement-based compositions) to significantly increase the strength of fine grained concrete thereby reaching the strength equal to the one of the test compositions with no concrete waste added. The research made opens up wide possibilities in concrete waste usage under manufacturing of the construction materials [11].

Now there is also an acoustic technology in concrete making providing separate preparation of the concrete mix, i.e. mixing of aggregates with cement paste pretreated in an activator. Therewith maximum homogenization of the mixture is achieved; flowability thereof is increased, other things being equal, with concrete density, strength and waterproofing being also increased [12, 13]. Activation is more efficient to sticky cement and concrete of expanded aggregates.

When combining acoustic activation of cement with hot formation of the concrete mixture (thermoacoustic activation), the duration of steam curing of concrete is reduced more than twice. Under further maturation of the cured concrete items under natural conditions within 28 days, strength

IOP Conf. Series: Materials Science and Engineering 1079 (2021) 022036 doi:10.1088/1757-899X/1079/2/022036

thereof is almost increased by times as compared with strength of concrete samples matured under normal conditions [13].

Acoustic activation of reactivity properties of cements has no limitations typical to vibration treatment as there are no adverse health effects of the sound field, stable repeatability of physical and mechanical properties of concrete is provided, and the process is significantly simplified. Activators are simple to make and endurable.

Therefore, acoustic as well as thermoacoustic activation of the concrete curing may be used as a way to increase strength thereof under the given cement consumption, or as a means to reduce consumption of the binding substance (actually up to 20%) at the given concrete strength. The most technical-and-economic efficiency of the activation process is achieved due to reducing the heat-moisture curing period thereby resulting in increase in efficiency of concrete mixing stations and precast plants. Application of acoustic activators enables to increase concrete strength by 15-20%, and to reduce cement consumption by 10-15%, or value for the construction materials or items [14].

Development of the construction and demand for the construction products is accompanied by increase of pollutant emission. Therefore, upgrading of the construction materials manufacturing process is being thoroughly analyzed [15].

Carbon Cure Technologies from Canada manufactured an innovative technology that introduces recycled carbon dioxide into fresh concrete. By the carbon dioxide fixation, application of this technology enables reduction of emissions and making of new construction materials of better quality.

Under the standard concrete making the cement is heated in special furnaces, thereby resulting in carbon dioxide emissions. However, according to the technology of the Carbon Cure the reverse reducing reaction is taking place: CO_2 from cement or other plants is used.

Upgrading such current concrete plants like Brampton Brick (Brampton, Canada) applying Carbon Cure^{TM} technology, carbon-dioxide gas is added in controlled dosage to the mixer supplying the block machine. Here the mixer acts as a reaction vessel where CO_2 is integrated in the traditional process and positive properties of carbonation of fresh concrete are used on an industrial scale [15, 16].

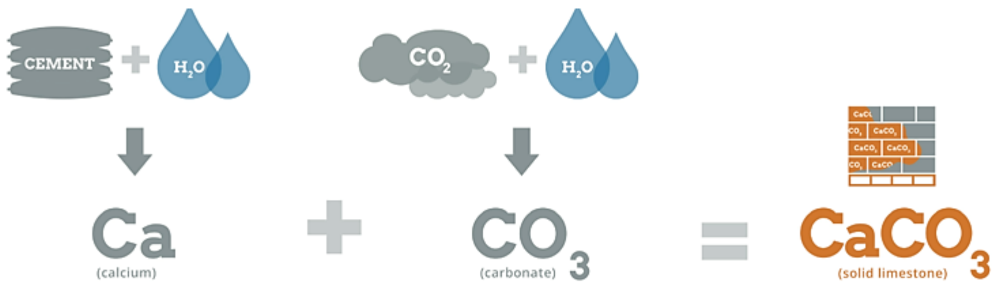

Figure 1. Carbon dioxide to solid limestone conversion.

When CO_2 is added to concrete during mixing, CO_2 reacts with water with carbonate ion formation. Then the carbonate enters into rapid reaction with calcium ions released from the cement thereby resulting in formation of nanosized calcium carbonate (limestone) minerals (Fig.1).

Carbon dioxide to solid limestone conversion means that CO_2 is permanently fixed in the concrete and never be released back.

Test cylinders were tested by three principles:

No changes of water quantity were found in the concrete mix combined with carbon dioxide;

A batch of concrete was prepared for the second test, with the operator visually adding extra water after CO_2 supply.

Chemical admixture was applied in the final test [17].

Currently there is the so-called self-healing concrete. It is the general name of different current developments and innovative solutions intended to change the structure of the material making it capable for recovering and resistant to various effects. As the concrete is the most popular material used in the construction industry, new manufacturing methods are being actively developed [18].

IOP Conf. Series: Materials Science and Engineering 1079 (2021) 022036 doi:10.1088/1757-899X/1079/2/022036

Up to 10 bln tons of concrete mix is manufactured annually. Although the concrete has some weak points it cannot be substituted for some other material with similar advantages and technical features yet. Therefore, the scientists of all over the world are keeping in making research and experiments trying to correct such defects of concrete as contraction, crack and deformation proliferation, failure in weather stability, etc.

Main direction of current developments is elaboration of self-healing flexible concrete able to withstand against deformations and recover under any effects [17, 19].

There are three kinds of self-healing concretes:

1. Polymer patches are special coating consisting of polymer capsules to be applied to concrete items. They are developed by South Korean scientists (Yonsei University) and having the following operating principle: the concrete surface is covered with a substance containing polymer microcapsules and when the cracks appear, the capsules open up filling the cavities with liquid polymers, the polymer being hardened under UV exposure, the concrete strength being fully restored. The work is still in process, the results are amazing, but the polymer surface maintains its properties within one year only.
2. Bacteria-based healing agents are self-healing elastic concrete developed by the Netherlands scientists (Henk M. Jonkers and Erik Schlangen). Bacillus bacteria act as follows: biodegradable plastic capsules containing calcium lactate and bacteria spores (thereby converting thereof) were added to the concrete. For many years the spores (yet in capsules) can remain in dormant state without changing the concrete properties, upon crack formation with the water ingress thereto the capsules break and the bacteria convert the calcium lactate and fills the open crack by precipitating calcium carbonate (limestone) and fixing the crack edges. In the laboratory conditions the bacteria heal cracks for up to 0.5mm, they will be further tested in real time and methods for reducing costs of the material will be sought (on the average its cost is 50% higher than that of the conventional cement).
3. Flexible concrete ConFlexPave was developed in Singapore with strength similar to steel rebar and flexibility two times higher than that of the conventional material. Flexible concrete contains polymer microfiber which allows the slabs to bend under pressure and increases the adhesion thereof to the surface to be covered. Composite material is stronger and lighter that is very important in road constructions and erection of tall buildings. The first types of flexible concretes were developed several decades ago, they work for sliding property of the material (whereas the conventional mixture provides for hardening of the components and loss of elasticity) therefore, there are no destructive deformations. But the cost of this material is three times higher than that of the conventional one [18].

Thus basically the concrete is the main component for making and further erecting of foundations for any building [19]. It should be noted that this material may be applied irrespective of what the building is made from:

- bricks,
- panels,
- slag blocks.

Despite the fact that much concrete is used for erection of almost any foundation, the application thereof is not limited to the foundation making. Under application of the current construction technologies the masonry of walls is impossible without using this substance irrespective of the materials it is to be made from.

Figure 2. Yumaguzino hydraulic facilities in the Republic of Bashkortostan.

Concretes with high handling abilities and performance properties to be called as the High Performance Concretes (HPC) are known since 80s of the last century [20, 21].

Unique architectural works that cannot be erected without HPC application:

- the Burj Dubai Tower in UAE;
- the English channel tunnel;
- the Akashi Kaikyō Bridge, Japan;
- the Moscow International Business Center "Moscow city"
- Yumaguzino hydraulic facilities in Bashkortostan (Fig.2).

High performance concretes are efficiently applied in hydraulic facilities, with Yumaguzino hydraulic facilities in Bashkortostan, Idel-Tower construction in October Prospect in Ufa (Fig.3) taken as the examples thereof.

The following classification of concretes by strength is taken in the Russian reference documentation (GOST 25192-2012):

- average strength (compressive strength grade up to B60);
- high performance (compressive strength grade over B60).

The following changes are to be made to the concrete mix to get high performance concrete according to Kaprielov and Sheinfeld data:

- application of high-strength cements;
- large gravel is to be comply with GOST;
- microaggregates (silica fume, rice hulls and others)
- superplasticizers.

All these components modify the concrete mix process and result in cost increase thereof.

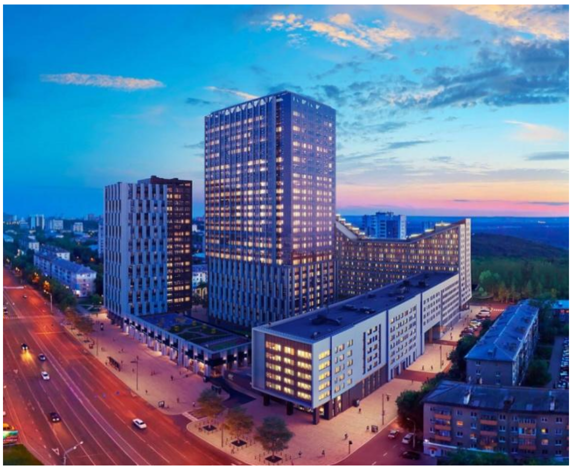

Figure 3. Idel-Tower residential complex in Ufa, the Republic of Bashkortostan.

3. Results

Nowadays due to current technologies the concrete is widely applied in the construction branch. Reliability of erected buildings and facilities is strongly achieved by application of high performance concretes in the Republic of Bashkortostan.

Under multiple numerous investigations the authors of the paper proposed design models for stress and strain behavior of reinforced concrete elements in frames of buildings with variations in slabs, thickness, actual loading, and concrete and rebar grades that enabled to specify the design values of the frame of buildings and find rational areas for application high performance and improved strength concretes and rebar. The results of the research are applied in design and construction of a number of reinforced concrete frames for tall buildings in the Republic of Bashkortostan.

The promising lines in development of technologies for the materials to be applied in industrial and civil construction in the Republic of Bashkortostan and the Russian Federation on the whole may be specified under the thorough analysis of materials on the development and history of application of effective concretes in the construction branch.

4. References

[1] Bedov A, Salov A, Gabitov A 2018 Cad methods of structural solutions for reinforced concrete frame XXI International Scientific Conference on Advanced in Civil Engineering "Construction - The Formation of Living Environment" (FORM 2018) 25–27 April 2018 (Moscow, Russian Federation) Vol 365 pp 1-8

[2] Artamonova O V, Tchernyshov B M 2013 Concepts and Fundamentals of Technologies for Nanomodification of Construction Composite Structures *Construction Materials* **9** 82–90

[3] Nesvetaev G V 2015 Internal strain effect upon porosity and properties of the cement stone *Construction materials* **9** pp 38-42

[4] Bedov A I, Gabitov A I, Gaisin A M, Salov A S, Chernova A R 2018 CAD analysis for stress and strain behaviour of masonries made of hollow ceramic blocks IOP Conference Series: Materials Science and Engineering: Vol 465 2018 VII International Symposium Actual Problems of Computational Simulation in Civil Engineering 1–8 July 2018 (Novosibirsk, Russian Federation) pp 1-7

[5] El-mahadi A 2002 Rheological Properties, Loss of Workability and Strength Developmentof High-Strength Concrete (London: MSc.University of London) 144 p

[6] Kaprielov S S 2010 New generation modified concretes (M.: Paradise Publishers) p 258

[7] Bedov A I, Gabitov A I, Gaisin A M, Salov A S, Chernova A R 2018 CAD technologies under thermal properties analysis of wall cladding of framed buildings IOP Conference Series: Materials Science and Engineering: Vol 465 VII International Symposium Actual Problems of Computational Simulation in Civil Engineering 1–8 July 2018 (Novosibirsk, Russian Federation) pp 1-8

[8] Mayorov P M 2009 Concrete mixes: reference book for builders and manufacturers of the construction materials (Rostov-on-Don: “Fenix”) p 461

[9] Yevstifeev V G 2011 Reinforced concrete and masonry structures: in 2 Vol 1 Reinforced concrete structures (M.: “ACADEMIA”) p 432

[10] Bedov A I, Gabitov A I, Gaisin A M, Salov A S, Chernova A R 2018 CAD in interdisciplinary integration as a tool to increase specialist training quality in “Construction” education VI International Scientific Conference “Integration, Partnership and Innovation in Construction Science and Education” (IPICSE-2018) (Moscow, Russia) pp 1-7

[11] Nesvetaev G V 2011 Concretes: educational and reference book (Rostov-on-Don: “Fenix”) 381

[12] Alimov L A 2010 Technology of the construction materials and structures Concrete science (M.: “ACADEMIA”) p 432

[13] Shmit’ko Ye I 2010 Processes and equipment for technology of construction materials and items (Saint-Petersburg: “Prospekt Nauki Publ.) p 736

[14] Gabitov A I, Gaisin A M, Salov A S 2018 CAD simulation for stress and strain behaviour of

wall constructions made of hollow ceramic blocks IOP Conference Series: Materials Science and Engineering Vol 463 Issue 2 31 December 2018 No 022041 International Multi-Conference on Industrial Engineering and Modern Technologies 2018 (Vladivostok, Russian Federation) Code 144116
[15] Rybjev I A 2012 Construction materials science (M.: “Yuright) p 701
[16] Dvorkin L I 2012 Special concretes (Vologda: “Infra-engineering”) p 368
[17] Frei Hansjorg 2007 Builder’s guide Construction machinery, structures and technologies Vol 1(2) Edited by: Nestle Hans (M.:”Technosphere”) p 519
[18] Belov V V 2014 Technologies and properties of modern cements and concretes p 281
[19] Dvorkin L I 2019 Calculated prediction of properties and engineering of the concrete compositions (Vologda: “Infra-engineering”) p 385
[20] Berg O Ya 2012 High performance concrete (M.: Book upon demand) p 208
[21] Panaetov V P, Solovev D B 2019 Interaction of Tops of Domains in Metal Nano of the Film *Materials Science Forum* **945** 771-775. [Online]. Available: https://doi.org/10.4028/www.scientific.net/MSF.945.771