Manufacturing processes of cellular concrete products for the construction

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Abstract. Cellular concrete takes the lead in the world of construction as a structural insulation material used in the construction and reconstruction of buildings and constructions of various purposes. In this artificial stone building material, pores are distributed relatively evenly and occupy from 20 to 90% of the concrete volume, ensuring good thermal qualities, which allows cellular concrete houses to keep warmth well. For production of cellular concrete, Portland cement, "burnt lime", and fine-pulverized blast furnace slags, with a hardening activator are used as binders. As silica components, quartz sand or "fly ash" obtained by combustion of pulverized fuel in power plants as well as secondary products of different ore dressing treatments are used. The low density and high thermal insulation properties of cellular concrete enables 3 times lighter wall weight than the weight of brick walls and 1.7 times lighter than the walls of ceramsite concrete. Thermal insulation and mechanical properties of cellular concrete make possible to construct of it single-layer protecting structures with the desired thermal resistance. Cellular concrete is divided into aerated concretes and foam concretes, whose physical/mechanical and operational performance is, ceteris paribus, almost identical. By the method of hydrothermal treatment cellular concretes are divided into two groups: concrete of autoclave and non-autoclave curing.

1. Introduction

In 1919, for the first time, metal powder was proposed for gas forming in production of cellular concrete, and currently for this purpose zinc, magnesium, and aluminum powder is used [1]. A reaction of aluminum with calcium oxide hydrate occurs, resulting in a large amount of evolved gas and heat. The reaction binds water, and that accelerates thickening and setting of porous mixture. Aluminium powder forms gas pores of a uniform structure, and that is extremely important for increasing the quality of products and increasing their durability in upkeeping of buildings. Sand, binders and water are uniformly mixed with aluminum powder. The prepared solution not containing gas, so far, is poured into molds, and thereafter a chemical reaction occurs, with isolation of hydrogen. The resultant gas bubbles bloat the solution which is distributed around the bubbles and forms a uniform cellular structure of concrete. One option of production of foam concretes involves the introduction, with stirring, of a freshly prepared foam or foaming agent into the mixture.

By the close of the XX century, the world annual production of cellular concrete products ranged 43-45mln m^3. The majority of firms have annual output of 160-200 thousand m^3, and the largest enterprise built in 1987 in Hungary under a licence of the

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Hebel company, has reached a performance 560 thousand m^3 of cellular concrete/year. A number of CIS countries, Poland, China, Czech Republic, Slovakia, Denmark, Japan, and others have their own domestic developments and technology they use, along with the licensed. Technologies differ in ways of preparation, molding of porous mixture and cutting concrete blocks into products of specified sizes [2,3].

On base of cutting technology a complete set of cellular concrete products for low-rise construction houses is produced. The precision of goods manufactured is due to different technical solutions applied in cutting equipment and depends on the structural and mechanical properties of a concrete block to be cut, and the sizes of cellular concrete.

By the technology of the Ytong and the Masa-Henke companies, prior cutting the product in specified sizes, a raw cellular concrete block is turned 90° with a mold on its side, and the technology of the Wehrhahn company foresees turning over on “alien” pallet specially stitched up under the lateral surface, on which unbuttoned block is fed under cutting machines, and then to an autoclave and to a finished product warehouse.

In accordance with the technology of the companies Hebel, Durox, Aerok, and Silbet concrete block is unbuttoned and transported with a special holder from the pallet plate onto the table of a cutting machine, cut, then fed on grates into the autoclave and the finished product warehouse.

The technology of the Siporex company foresees lifting the concrete blocks cutting on its slot pallet, afterwards the mold sides lowered into its former place and the mod with a concrete block is fed into the autoclave [4]. Steam treatment is carried out in dead-end and pass-through autoclaves having 2.4-2.8 m diameter and 50 m length, at a pressure min. 1.0 MPa.

The technology of the listed and other foreign companies finished products are sent to the customer in a packaged form. Typically, the density of products manufactured is 400-700kg/m^3 and compressive strength of concrete therein is not less than 2.0-5.0MPa respectively.

When delivered to the consumer the humidity of cellular concrete products is about 20% by volume or 30-35% by weight. During the construction and maintenance of cellular concrete walling the humidity drops to equilibrium operation values and is 2-3% by volume, at an average concrete density of 600 kg/m^3.

Reinforced products are produced up to 7.2m long, up to 0.75 m wide, and up to 0.375m thick. Pitch of products in length is 5-25 mm and in thickness 25-100 mm and in width of products is usually equal to the height of the molded concrete block.

The length of reinforced products depends on their thickness and design loads. The maximum length of articles is usually equal to the length of the molded or cut concrete block [5]. Non-reinforced products are made of any size, and the block length or the width of the partitions is equal to the height of the concrete block. Dimensions of small blocks correspond to the requirements of STB 1117-98 "Wall blocks of aerated concrete", GOST 25485, DIN 4165, and others.

In the 50s of the last century reinforced products of heat insulating concrete had density 800-1,000 kg/m^3, and by 1996 for mass production it dropped to 650-750kg/m^3.

For a comprehensive test technology of production of small cellular concrete blocks with a 2 m diameter autoclave, of forming 1.2 m high concrete blocks, and cutting them into products of specified sizes on mold pallets, without moving the block (as it is carried out on the "Universal-60" line), the construction of four plants of 160,000 m^3 per year was planned in Belarus (Bobruisk, Luban, Orsha, Petrikov), by two plants in Ukraine and Kazakhstan, as well as seven plants for 40- 400 thousand m^3 a year in the Russian Federation [6].

The mentioned program was based on the use of domestic experimental and the newly created equipment for the production of small cellular concrete blocks on shock cutting and vibro-cutting technologies. For the production of reinforced products and small cellular concrete blocks the equipment of the Ytong company was purchased with the option of its reproduction. On base of the domestic produced and reproduced equipment of the Ytong company, 400-450 plants for the production of industrial products from cellular concrete, with production capacity 50-200,000 m^3/year, were planned to be built in the USSR in 1989-1995, including 50 complex technological lines of new generation with the production capacity 100-200 thousand m^3/year, in 1990.

It was planned to launch in cement plants the manufacture of low water-need binders (VNV) and process equipment for the production of non-autoclave wall blocks of cellular concrete on base of VNV, with output 50,000 m^3/year, including - by 40 production lines in 1989-1990.

To coordinate these plans, a program was designed to 1989-1995 "Creating highly effective types of cellular concrete with desired properties based on new binders, the development of a new generation of building structures, technology, equipment, the creation of highly automated manufacturing equipment."

The program not only included the creation of highly automated manufacturing equipment, but, since 1995, intended the development of highly automated pilot production line for the manufacture of cellular concrete products, with the density of 500-550kg/m^3 and 600-650kg/m^3.

After the collapse of the Soviet Union, in which the USSR Gosstroi (State Committee for Construction) was the sole head of all the works on the development of the production of cellular concrete products, all CIS-wide programs were practically stopped, and the USSR Gosstroi was dissolved.

In some cities of the CIS and Baltic countries (Ekaterinburg, St. Petersburg, Saratov, Tallinn, and others), cellular concrete buildings up to 25 floors were built.

The plants in the CIS country usually release the whole range of reinforced products providing the use of a large number of individual shapes of different sizes. The number of standard sizes of panels for the construction of a series of a residential or public building is up to 100, and the outfit weight is 750-800 t of metal. The filling factor of the autoclave in the manufacture in individual forms of reinforced products equals 0.25-0.30, and by cutting technology it is 0.40-0.45. Steam consumption for the manufacture of concrete with the density 500-600kg/m^3, in individual forms, equals to 250-280kg/m^3 and by cutting technology - 165-190kg/m^3.

The production-line technology of manufacturing reinforced cellular concrete products in individual forms was borrowed from the experience of the manufacture of concrete products in the early days of the production of autoclave materials and plants and it has been used in the CIS by now so far. From volume production of 1.6 mln.m^3 reinforced products, in the CIS, only 130,000 m^3/year are produced by cutting technology.

The main drawback of the manufacture of reinforced products in individual forms consists in dependence of product manufacture quality upon the outfit quality. High deformability and low strength of cellular raw concrete require the use of hard tooling technology to prevent cracks in the steps of pre-autoclave curing and hydrothermal treatment. It increases the material consumption of production, reduces the volume of the output of finished products from the autoclave. The outfit, under constant mechanical, cyclic and thermal effect, requires frequent preventive and major repairs. Otherwise, the quality of products has steadily decreased over time. The disadvantage of the considered technologies is the need of complete replacement of the forms in the transition to a new product. Horizontal position of forms when the preparatory operations, molding and cropping or stitching "crusts" require large production areas, additional amounts of manual labor and a significant increase in the number of means of mechanization and transportation.

These drawbacks are not evident at the cutting manufacturing technology when in the form with defined and fixed reinforced frames the block is shaped with dimensions 6.0 × (1.2-1.5) × (0.6-0.9)m or 6.0 × 0.9 × 0.9m, and then its cutting is carried out by means of special machines, for products of specified sizes, and that allows to obtain different forms of the same type in the length, thickness and width of the product with profiles, grooves, chamfers and keys. After autoclaving additional mechanical processing can be made: further calibration of products, "groove - comb" cutting and "pockets" to capture with masonry and others.

Technical and economic analysis of the production of reinforced cellular concrete products by cutting technology shows that in comparison with the production in individual forms it is possible to:

— *lower:* metal consumption of forms per 1m^3 of finished product, 3 times; specific heat consumption for autoclaving, by 18%; relative capital investments for the production of products, by 16%;
— *improve performance of:* autoclave unit, by 1.5; molding span beam**,** by 4.7 times; labor per employee of main production, by 21%; labor across the whole enterprise**,** by 14%.

Unlike some other foreign countries, where finishing of cellular concrete products is carried out on the construction site, in the CIS countries, as a rule, the reinforced wall panels are finished at the factory. With mass standardized public construction, such an approach met the requirements of time, however, the quality and variety of the raw materials used for protective and decorative coatings and coating quality do not allow providing the necessary appearance and durability of building facades.

In recent years, Russia and Belarus began intensively re-use cellular concrete. At present, in Russia, a plant in the village of Sertolovo, Leningrad region, and two plants in Lipetsk, licensed by the Hebel company, produce cellular concrete. The plant "Sibit", in Novosibirsk, the Glavnovosibirsk, JSC, and the Plant on Manufacture of Products of Cellular Concrete, JSC, and the Cottage, JSC, Vodino town, Samara region, mastered the production of cellular concrete products by the Ytong technology. Plants with capacity of 120 thousand m^3/year produce wall blocks with density 400-600kg/m^3 and reinforced products with density 700 kg/m^3 (floor slabs, roofs and intel blocks). In the city of Naberezhnye Chelny the Plant of Cellular Concrete, JSC, has developed, produced and mastered the production line for the production of cellular concrete products, which is similar to the cutting technology of the Ytong or the Masa-Henke companies but without turning over the concrete block.

By injection-molding technology, the block is molded in a vertical snap (6.0 × 0.626 × 1.3 m) consisting of a stationary opening sides and removable tray. After getting the required plastic strength by fresh aerated raw concrete, molds and tray with a vertically standing block are opened, using a special traverse, suspended on the crane, moved under the cutting machine for cutting "crusts"**,** the lateral vertical slitting of the block, horizontal and vertical slitting cut to length.

The Corporation of Building Materials, ZAO, (Moscow), Volgotsemmash, JSC (Togliatti) and P.P. Budnikov VNIISTROM Institute (settlement Kraskovo, Moscow region) developed a conveyor line without a crane of the Vibroblok system, production capacity 30-120 thousand m^3/year. Aerated blocks, dimensions 3,000×1,300×1,270 mm, made by vibro-cutting technology. Head sample line with an annual output 100,000 m^3 (ВКА-100) is manufactured, assembled and mastered by the Volgotsemmash, JSC.

The Silbetindustriya, ZAO*,* (Moscow) has developed processing equipment for the construction of new and modernization of existing cellular concrete plants using domestic shock technology and different versions of cutting the concrete block into the products of specified sizes.

In the project, the Hebel company has laid claim to the original raw materials, especially to cement and lime that exceed the requirements of GOST and STB, i.e., in the Republic of Belarus and the CIS countries such cement and lime are not made. For example, raw materials of the deposit "Kolyadichi", used for the production of cement by Krasnoselskcement JSC, and the existing clinker production technology with short rotary kilns do not provide clinker with saturation ratio above 0.9. Building industry enterprises do not produce lime containing over 80% of calcium oxide, and lime hydration kinetics does not meet the requirements of DIN 1060.

Specialists of the technical/engineering centre of Zabudova, JSC and UPP Building Structures Plant developed a number of cellular-concrete mixture formulations for 350-700kg/m^3 concrete density on the raw materials base of the Republic of Belarus. More than 30 formulations have been introduced in the production, allowing producing aerated concrete products and structures of different density and strength. The plant produces a complete set of home materials of cellular concrete, according to the standards of the Republic of Belarus (STB): non-reinforced blocks (STB 1117-98), roof slabs and floor (STB 1034-96), trough and arched intels (STB 1332-2002), wall panels (STB 1185-99), elements of stairs (STB 1330-2002). The products obtained certificates of conformity of the Republic of Belarus, Russia, Lithuania, Latvia, and others. Production of aerated concrete is certified by the International Quality System ISO 9001. In 2002, the plant was awarded a Prize of the Government of the Republic of Belarus for achievements in the field of quality.

Cellular concrete produced by Zabudova, JSC and UPP (Unitary Production Enterprise) Building Construction Factory is used for the erection of residential, public and social buildings. For example, in Minsk, the cottages are built of aerated concrete in two microdistricts "Bolshaya Slepyanka" and in Gazeta Izvestia avenue. In Moscow - experimental districts "Kurkino", "Mitino", "Edem", etc. Cellular concrete is widely used in enclosing structures of multi-storey buildings. In Minsk, Moscow and in other regions of Russia, as well as in the Baltic countries a number of high-rise buildings were built, including in Moscow - a complex of residential houses in Mosphilmovskaya street, and the building of the British Embassy. The study and critical analysis of the global and domestic experience in the production of cellular autoclaved concrete, as well as the use of shock technology make possible the modernization of plants and increasing the cellular concrete production.

The Republic of Belarus uses modern technology equipment sets, combining domestic and foreign technology shock cutting technologies of the leading German companies - Masa-Henke, Wehrhahn, Hebel, and others.

For the manufacture of aerated concrete binders, siliceous components and gas forming agents *binders:* portland cement; calcium burnt lime; granulated blast furnace slag; ash from the burning of oil shale and some types of brown coal; *silicon components*: quartz sand or silica-containing waste mining and processing industry; ash from the burning of lignite and coal; *gas forming agents*: aluminum powder or paste, which is applied with the addition of surfactants; plasticizing additives, regulating processes of gas forming and thickening are used.

Raw materials used for the manufacture of cellular concrete products, must meet certain requirements. The suitability of the raw materials and properties of porous concrete is determined on base of technological tests. Test scope to be specified in each case [7].

Binders:

a) Portland cement (GOST 10178). Brand M400-500 without active mineral additives. The content of tricalcium silicate - at least 50%, tricalcium aluminium - less than 6%. The specific surface of cement should be at least 3000 sm^2/g. Initial setting - not later than in 2 hours, the end setting - not later than 4 h after mixing;

b) slaked lime calcium (GOST 9179; SN 277-80). The content of active CaO and MgO - at least 70%, including MgO - less than 5%. Overburning number - less than 2%. blanking speed 5-15min;

c) granulated blast-furnace slag (basic and neutral) (GOST 3476). The content of manganese oxide is not more than 1.5%, sulphide sulfur is not more than 0.1%. Activity module of not less than 0.4, the main modules of at least 0.9;

d) ash from the incineration of oil shale and some types of brown coal. The CaO content is not less than 30% (including free CaO not less than 15%). SiO2 20 to 30%. CO3 not more than 6%. K2O + Na2O - not more than 3.5%. The specific surface of the ash 3000-3500 sm^2 /g.

Silica components [8]*:*

a) quartz sand (GOST 8736; SN 277-80). Silica content (unbound SiO2) of not less than 70%; alkali (calculated as Na2O) is not more than 2.7%; sulfuric acid and sulfur compounds (calculated as SO_3) not more than 0.5%; mica is not more than 0.5%; dust, silt and clay particles are not more than 5%. The recommended maximum size of sand grains - not more than 3 mm content of grains of 0-1mm in the range of 60-80%;

b) acidic ash from the burning of lignite and coal, captured in the electrostatic precipitators (OST 21-60; SN 277-80). Quartz SiO2 content of at least 45%; CaO is not more than 10%; sulfuric acid and sulfur compounds (calculated as SO_3) not more than 2%; the content of unburned fuel residues: not more than 7% for fossil fuels; for brown coal is not more than 5%. The specific surface area of not less than 2,500 cm^2/g.

Gas-forming agent: Aluminium powder or paste based on it (GOST 5494-71).

Industrial water: (GOST 23732; STB 1114) [9].

For the preparation of cellular concrete can be used water suitable for the preparation of conventional concrete, can be used. Maximum content in mg/l: soluble salts – 10,000; SO4 ions -2,700; C1-1 ions – 3,500; suspended solids - 300.

Chemical additives: These surfactants are specified in dependence on the type of binder and specified empirically. To control the process of structure formation, increase the plastic strength and accelerate hardening of porous mixture and its plasticizing the following is used: gypsum dihydrate; soda ash; triethanolamine; trisodium phosphate; water glass; sulfanol; superplasticizers, and other substances.

Bar steel for frames: for reinforced structures (frames and grids) bar steel is used, which meets the requirements of GOST 10922. Control tests on the strength of steel are carried out in accordance with GOST 12004. As an anticorrosion coating for the reinforcement the following is used: cold cement and bitumen mastic; polystyrene cement paste; latex-cement paste; latex-mineral paste; inhibited shale-bitumen-cement paste; metallosilicate mastic; anti-corrosion coatings for steel [10].

Anticorrosion coatings must meet the following requirements: impact strength of not less than 10 kgs/cm^2 according to GOST 4765; elasticity of not more than 20 mm in accordance with GOST 10086; layer thickness reinforcement coating after drying 0.4-0.7mm; continuous coating without cracks and through pores; coating must withstand transportation stacking and piling of rebar in a mold.

Lubricating materials: to apply the lubricant on material forms the following compositions (in weight ratio) are applied: petrolatum-kerosene mixture 1:2.5; grease or avtol with kerosene 1: 1; mixture of rocker and engine oil 1:3; different separating liquid or film coatings that prevent adhesion of raw cellular concrete with steel.

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