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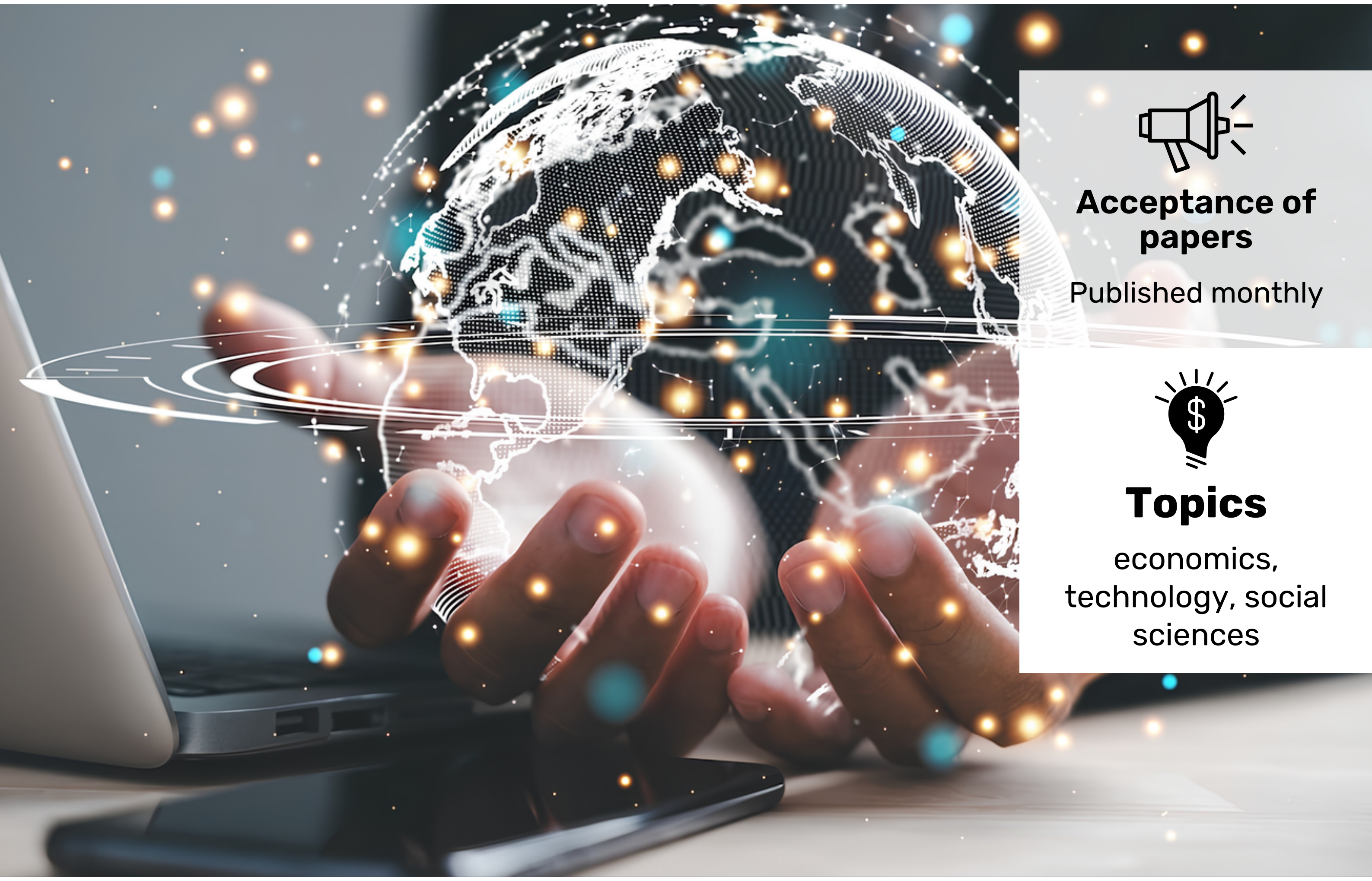

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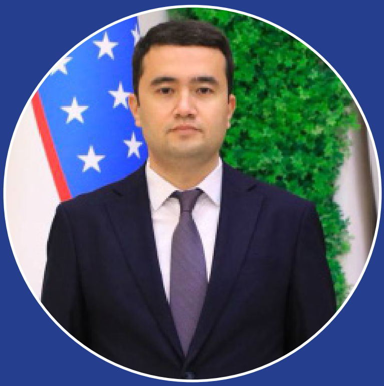

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Editorial board:

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QUALITY ASSURANCE OF NON-AUTOCLAVED AERATED CONCRETE WITH THE ADDITION OF CMC (CARBOXYMETHYL CELLULOSE)

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Abstract. This study examines cellular aerated concretes based on polymer compositions and their standardization as lightweight construction materials for the construction industry of Uzbekistan. The results of large-scale research and analysis indicate that adding a 3% aqueous solution of CMC (carboxymethyl cellulose) to the composition of cellular aerated concrete improves product quality and increases the strength grade of lightweight non-autoclaved cellular concrete. The efficiency of non-autoclaved aerated concrete was enhanced by controlling the formation of the polymer structure in a dispersed system with a composite binder. As a result, the optimal ratio of CMC to composite binding materials for the production of lightweight cellular concrete was determined. The role of a 3% aqueous CMC solution in forming the porous structure of non-autoclaved aerated concrete based on composite binders was substantiated. In addition, the moisture resistance, frost resistance, and thermal conductivity stability of cellular aerated concrete with optimized highly porous composite structures were evaluated. The role of ingredients in the composite binder containing different proportions of CMC was identified, and principles for producing aerated concrete with improved properties were developed. A methodology for producing lightweight cellular aerated concrete compositions containing a 3% aqueous CMC solution was proposed, and the optimal proportions of primary and auxiliary raw materials were determined. A technological guideline for producing lightweight non-autoclaved cellular aerated concrete based on a 3% aqueous CMC solution was also developed.

Keywords: standardization, CMC, carboxymethyl cellulose, non-autoclaved aerated concrete, concrete grade, lightweight cellular concrete, GOST 25845-89.

Annotatsiya. Ushbu tadqiqotda polimer kompozitsiyalar asosidagi g‘ovakli gazobetonlar hamda ularni O‘zbekiston qurilish materiallari sanoati uchun yengil qurilish materiali sifatida standartlashtirish masalalari o‘rganilgan. Keng ko‘lamli tadqiqot va tahlillar natijasida g‘ovakli gazobeton tarkibiga CMC (karboksimetilsellyuloza)ning 3% li suvli eritmasini qo‘shish mahsulot sifatini yaxshilashi hamda yengil noavtoklav g‘ovakli betonlarning mustahkamlik markasini oshirishi aniqlangan. Noavtoklav gazobeton samaradorligi kompozitsion bog‘lovchi ishtirokidagi dispers tizimda polimer strukturasining shakllanish jarayonlarini boshqarish orqali oshirilgan. Natijada yengil g‘ovakli beton ishlab chiqarish uchun CMC va kompozitsion bog‘lovchi materiallarning optimal nisbati aniqlangan. Kompozitsion bog‘lovchilar asosidagi noavtoklav gazobetonning g‘ovakli tuzilmasini shakllantirishda 3% li CMC suvli eritmasining roli asoslangan. Shuningdek, optimallashtirilgan yuqori g‘ovakli kompozit tuzilmaga ega gazobetonning namlikka chidamliligi, sovuqqa chidamliligi va issiqlik o‘tkazuvchanligi barqarorligi baholangan. CMC ning turli nisbatlari ishtirokidagi kompozitsion bog‘lovchi tarkibidagi komponentlarning vazifasi aniqlanib, yaxshilangan xususiyatlarga ega gazobeton olish tamoyillari ishlab chiqilgan. CMC ning 3% li suvli eritmasi asosida yengil g‘ovakli gazobeton kompozitsiyalarini tayyorlash metodikasi ishlab chiqilgan hamda asosiy va yordamchi xomashyolarning optimal nisbatlari belgilangan. Shuningdek, CMC ning 3% li suvli eritmasi asosida yengil noavtoklav g‘ovakli gazobeton ishlab chiqarish bo‘yicha texnologik yo‘riqnoma ishlab chiqilgan.

Kalit so‘zlar: standartlashtirish, CMC, karboksimetilsellyuloza, noavtoklav gazobeton, beton markasi, yengil g‘ovakli beton, GOST 25845-89.

Аннотация. В данном исследовании изучены ячеистые газобетоны на основе полимерных композиций, а также вопросы их стандартизации как лёгких строительных материалов для строительной индустрии Узбекистана. Результаты масштабных исследований и анализа показали, что добавление 3% водного раствора CMC (карбоксиметилцеллюлозы) в состав ячеистого газобетона способствует повышению качества продукции и увеличению марки прочности лёгких ячеистых бетонов неавтоклавного твердения. Эффективность неавтоклавного газобетона была повышена за счёт управления процессами формирования полимерной структуры в дисперсной системе с композиционным вяжущим. В результате было определено оптимальное соотношение CMC и композиционных вяжущих материалов для производства лёгкого ячеистого бетона. Обоснована роль 3% водного раствора CMC в формировании пористой структуры неавтоклавного газобетона на основе композиционных вяжущих. Кроме того, были оценены влагостойкость, морозостойкость и стабильность теплопроводности ячеистого газобетона с оптимизированной высокопористой композитной структурой. Определена роль компонентов в составе композиционного вяжущего с различными соотношениями CMC, а также разработаны принципы получения газобетона с улучшенными характеристиками. Разработана методика получения лёгких ячеистых газобетонных композиций с использованием 3% водного раствора CMC и определены оптимальные соотношения основного и вспомогательного сырья. Также разработана технологическая инструкция по производству лёгкого ячеистого газобетона неавтоклавного твердения на основе 3% водного раствора CMC.

Ключевые слова: стандартизация, CMC, карбоксиметилцеллюлоза, неавтоклавный газобетон, марка бетона, лёгкий ячеистый бетон, GOST 25845-89.

INTRODUCTION

It is widely recognized that high-quality, affordable, and modern construction materials are essential for providing accessible housing, social facilities, and residential and non-residential buildings. Considering that 55–60% of construction costs are associated with building materials, modern architecture requires new, high-quality, cost-effective, lightweight, earthquake-resistant, and innovative construction materials. Therefore, the importance of the building materials industry is significant. In particular, large-scale construction and development projects currently being implemented in the country require the accelerated development of the construction materials industry.

In order to develop the production of construction materials in the Republic of Uzbekistan and implement the above-mentioned objectives, Resolution No. RP-4198 of the President of the Republic of Uzbekistan, dated February 20, 2019, “On Radical Improvement and Comprehensive Development of the Building Materials Industry”[1] and Resolution No. RP-4335, dated May 23, 2019, “On Additional Measures for the Accelerated Development of the Building Materials Industry” were adopted[2]. These resolutions provide for the development of the construction materials industry, as well as the modernization, technological renewal, and technical re-equipment of the sector. The Association “Uzpromstroy-materialy” was established to attract investment, increase export potential, and introduce modern corporate governance methods in accordance with international requirements and standards.

Standardization of construction materials in the building industry is the process of establishing and complying with mandatory requirements for quality, safety, and other technical parameters of materials used in the construction of buildings and structures. Standardization plays an important role in the construction industry, as it ensures the unification and consistency of materials, increases the reliability and durability of buildings, and guarantees the safety of human life and health. The standardization process includes the approval and application of quality certificates for construction materials, certification procedures, and testing for compliance with established requirements. Standards are defined at the governmental, international, or industry level and are mandatory for all manufacturers and suppliers of construction materials.

LITERATURE REVIEW

The quality improvement of non-autoclaved aerated concrete has been widely studied in relation to pore structure, density, moisture resistance, and mechanical strength. Rouquerol, Rouquerol, Sing, Llewellyn, and Maurin emphasized that the properties of porous materials depend mainly on surface area, pore distribution, and adsorption behavior. Their scientific approach is important for understanding how the internal porous structure influences the durability and performance of aerated concrete. Thommes, Kaneko, Neimark, Olivier, Rodríguez-Reinoso, Rouquerol, and Sing further developed methods for evaluating pore size distribution and surface characteristics of porous solids. Their findings are relevant to aerated concrete because pore stability directly affects compressive strength, water absorption, and thermal conductivity. In this context, the use of carboxymethyl cellulose (CMC) as a polymer additive can be considered an effective technological solution. CMC improves water retention, stabilizes gas formation, reduces segregation, and supports the formation of a uniform porous matrix. Therefore, previous studies provide a strong theoretical basis for investigating 3% CMC solution in non-autoclaved aerated concrete.

RESEARCH METHODOLOGY

1 Resolution of the President of the Republic of Uzbekistan dated February 20, 2019 No. RP-4198. https://www.lex.uz/ru/docs/4207838.
2 Resolution of the President of the Republic of Uzbekistan, dated May 23, 2019 No. RP-4335 https://lex.uz/ru/docs/7571918.

This study used an experimental and analytical research methodology to evaluate the quality of non-autoclaved aerated concrete with the addition of carboxymethyl cellulose (CMC). The research was based on the preparation of concrete samples using cement, sand, water, aluminum powder, sodium sulfate, caustic soda, microsilica, and a 3% aqueous CMC solution. The mixture composition was selected to improve pore stability, water retention, and mechanical properties. Laboratory tests were conducted to determine density, water absorption, flexural strength, compressive strength, and concrete grade. The obtained results were compared with standard non-autoclaved aerated concrete indicators. Through this approach, the influence of CMC on the formation of porous structure and quality improvement of lightweight concrete was assessed.

ANALYSIS AND RESULTS

The advantages of standardizing construction materials include improved construction quality, reduced risks of accidents and defects, increased labor productivity, and lower repair and maintenance costs for buildings. In addition, compliance with standards promotes innovation and attracts investment to the industry. The importance of standardizing construction materials in construction is significant, as it directly affects the quality, safety, and durability of construction projects. Standardization establishes unified requirements for the quality of construction materials and prevents the use of low-quality materials in construction. Standards define material parameters, physical and chemical properties, technical characteristics, and quality control methods. As a result, customers and developers are provided with high-quality construction outcomes, which contribute to the durability of structures and increase end-user satisfaction. Safety standards for construction materials establish requirements for operational safety and resistance to various environmental factors, including fire, moisture, and ultraviolet radiation. This helps ensure the safety of construction workers and users of completed buildings. For example, standards require the use of non-combustible materials for wall cladding, which reduces fire risks and increases the safety of building occupants. Standardization also improves cost efficiency by reducing risks in the selection of materials and structures for construction. Pre-established quality and safety requirements help determine the most suitable materials for specific projects and prevent costly mistakes. Moreover, the use of high-quality materials that comply with standards increases the durability of buildings and reduces future operation and maintenance costs. Consequently, economic efficiency is achieved both during construction and throughout the service life of the facility. In addition, standardization harmonizes the processes of production, operation, and quality control of construction materials, reduces technical risks, and ensures consistency at all stages of construction.

According to GOST 25845-89, cellular concretes are classified by their purpose, hardening conditions, pore formation method, and the types of binders and siliceous components used. By purpose, cellular concretes are divided into structural concretes, structural and thermal insulation concretes, and thermal insulation concretes. Structural concretes have a compressive strength grade not lower than B3.5, an average density grade of D700 and above, and a pore volume of 40–55%. Structural and thermal insulation concretes have a compressive strength grade not lower than B1.5 and an average density grade not higher than D700. Thermal insulation concretes have a compressive strength grade not lower than B0.35, an average density grade not higher than D400, and a total porosity of 75–85%. According to hardening conditions, cellular concretes are classified into autoclaved concretes and non-autoclaved concretes. Autoclaved concretes undergo synthetic hardening in saturated steam under pressure higher than atmospheric pressure, while non-autoclaved concretes undergo hydration hardening under natural conditions, by electric heating, or in saturated steam at atmospheric pressure. According to the pore formation method, cellular concretes are divided into aerated concretes, foam concretes, and gas-foam concretes.

The following types of products made from autoclaved aerated concrete and foam concrete are recommended for residential and public buildings: small blocks for external and internal walls according to GOST 21520-89, large blocks for external and internal walls according to GOST 19010-82, non-reinforced wall products according to GOST 31360-2007, panels for internal load-bearing walls, partitions, and floor slabs of residential and public buildings according to GOST 19570-74 and GOST 12504-80*, panels for external walls of buildings according to GOST 11118-2009, thermal insulation blocks and slabs according to GOST 5742-76, and roof panels for residential and public buildings. Non-autoclaved aerated concretes are used for the production of small blocks for external and internal walls according to GOST 21520-89 and thermal insulation products according to GOST 5742-76. They are also used for monolithic thermal insulation of basement and attic floors, roofs, and mansards; monolithic internal and external walls of residential and public buildings; insulation and strengthening of walls in reconstructed buildings; and decorative heat-resistant materials.

The bulk density of concrete is determined by testing specimens in accordance with the established requirements for equipment, including balances and drying ovens, as well as specimen preparation and testing procedures. Specimens may be prepared under natural or standardized moisture conditions. For irregularly shaped specimens, paraffin coating and underwater weighing methods are applied in accordance with GOST 12730.1-78, "Concretes. Methods for Determination of Density."

The following standards and technical specifications were used in this study: GOST 12730.1-78, "Concretes. Methods for Determination of Density"; GOST 12730.2-78, "Concretes. Method for Determination of Moisture Content"; GOST 12852.0-77, "Cellular Concrete. General Requirements for Test Methods"; GOST 13015-2012, "Concrete and Reinforced Concrete Products for Construction. General Technical Requirements. Rules for Acceptance, Marking, Transportation, and Storage"; GOST 17177-94, "Thermal Insulation Building Materials and Products. Test Methods"; GOST 18105-2010, "Concretes. Rules for Strength Control and Assessment"; GOST 21616-91, "Strain Gauges. General Technical Specifications"; GOST 21718-84, "Building Materials. Dielectric Method for Measuring Moisture Content"; GOST 22685-89, "Molds for Manufacturing Control Concrete Specimens. Technical Specifications"; GOST 23732-2011, "Water for Concrete and Mortars. Technical Specifications"; GOST 24104-2001*, "Laboratory Balances. General Technical Requirements"; GOST 24211-2008, "Additives for Concrete and Mortars. General Technical Specifications"; GOST 24452-80, "Concretes. Methods for Determining Prism Strength, Elasticity Modulus, and Poisson's Ratio"; GOST 24816-2014, "Building Materials. Method for Determination of Equilibrium Sorption Moisture"; GOST 25192-2012, "Concretes. Classification and General Technical Requirements"; GOST 25336-82, "Laboratory Glassware and Equipment. Types, Main Parameters, and Dimensions"; GOST 25898-2012, "Building Materials and Products. Methods for Determining Vapor Permeability and Resistance to Vapor Permeability"; GOST 27005-2014, "Lightweight and Cellular Concretes. Rules for Control of Average Density"; GOST 28836-90, "Strain Gauge Force Sensors. General Technical Requirements and Test Methods"; GOST 30108-94, "Building Materials and Products. Determination of Specific Effective Activity of Natural Radionuclides"; GOST 30244-94, "Building Materials. Flammability Test Methods"; GOST 30459-2008, "Additives for Concrete and Mortars. Determination and Evaluation of Efficiency"; and GOST 31108-2016, "General Construction Cements. Technical Specifications."

Thus, the standardization of construction materials plays an important role in ensuring the high quality, safety, and sustainability of construction projects. It also contributes to the development of the industry and increases competitiveness in the construction services market.

The production technology of non-autoclaved aerated concrete blocks with the addition of CMC (carboxymethyl cellulose) was applied to improve the plasticity of the mixture, enhance water retention capacity, and stabilize the porous structure. Since such aerated concrete blocks harden naturally without autoclave treatment, the composition of the mixture and curing conditions are of particular importance. In this study, a new composition for producing lightweight cellular aerated concrete with the addition of CMC was proposed in accordance with GOST 25485-2019. The raw materials used in the study included Portland cement CEM I 42.5 N according to GOST 31108-2020, produced by Kyzylkumcement JSC; CMC produced by the Fergana Chemical Plant of Furan Compounds; process water according to GOST 23732-79; construction sand according to GOST 8736-93; sodium sulfate according to GOST 6318-77; caustic soda according to GOST 2263-79; and aluminum powder according to GOST 5494-95.

In the mixing container, 795 g of cement was mixed with 23.85 g of finely ground microsilica, 780 g of sand, and 1.36 g of aluminum powder. Then, 23.85 g of CMC was dissolved in 795 g of water together with 7.5 g of caustic soda and 11.5 g of sodium sulfate. The prepared solution was thoroughly mixed with the dry components and poured into molds. After the aerated concrete mass achieved initial strength, it was cut using wires or manually (Table 1).

Table 1
Composition and Physical-Mechanical Properties of D600 Aerated Concrete[3]

Indicator	Value
Cement, g	1113
Sand, g	1092
Water, g	896
Aluminum powder, g	13150
Sodium sulfate, g	46038
Caustic soda, g	46152
Mass, g	795
Dimensions, mm	9.9 × 9.7 × 10

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% ,Water absorption	21.31
Flexural strength, MPa	22.79
Main surface area, cm²	97
Volume, cm³	960.3
Concrete grade	819.8276
Compressive strength, MPa	23.95769

The table presents the composition and physical-mechanical characteristics of D600 non-autoclaved aerated concrete. The mixture consists of cement, sand, water, aluminum powder, sodium sulfate, and caustic soda as the main components. The prepared specimen has a mass of 795 g and dimensions of 10 × 9.7 × 9.9 mm. The water absorption rate is 21.31%, while the flexural strength reaches 22.79 MPa. The concrete grade is 819.8276, and the compressive strength is 23.95769 MPa. These results indicate favorable strength properties, structural stability, and practical suitability of the material for lightweight construction applications. The following table presents the composition of cellular aerated concrete containing CMC additive at a ratio of 3% (Table 2).

Table 2
Composition of Aerated Concrete with 3% CMC Addition[4]

Indicator	Value
Cement, g	795
Sand, g	780
Water, g	640
Aluminum powder, g	1.36
Sodium sulfate, g	11.5
Caustic soda, g	7.5
CMC (carboxymethyl cellulose), g	23.85
Microsilica (silica fume), g	23.4
CMC content, %	3
Mass, g	785
Dimensions, mm	10 × 8.5 × 10
Water absorption, %	21.3197
Flexural strength, MPa	9.17
Main surface area, cm²	85
Volume, cm³	850
Concrete grade	923.5294
Compressive strength, MPa	11.00076

For non-autoclaved cellular concrete, the following compressive strength classes are established: B0.5, B0.75, B1, B1.5, B2, B2.5, B3.5, B5, B7.5, B10, and B12.5. Based on the average dry density indicators, cellular concrete is classified into the following density grades: D300, D350, D400, D500, D600, D700, D800, D900, D1000, D1100, and D1200. This classification makes it possible to evaluate the physical and mechanical properties of non-autoclaved cellular concrete more accurately and to determine its suitability for various construction applications.

CONCLUSIONS AND RECOMMENDATIONS

Carboxymethyl cellulose (CMC) is used in non-autoclaved aerated concrete as a water-retaining additive, a stabilizer of foam and gas formation, a reducer of mixture segregation, an enhancer of green body strength, and an improver of block geometry. In non-autoclaved technology, the use of CMC is particularly effective because the mixture hardens more slowly than in autoclaved processes, which requires better control of moisture

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retention and pore structure formation. The obtained results show that the addition of up to 3% CMC contributes to an increase in the concrete grade. Under optimal conditions, pore formation in the cellular concrete matrix develops into near-spherical shapes. To obtain lightweight material with improved thermal insulation properties and reduced material consumption, it is necessary to form a structure with volumetric macroporosity of more than 50% and a high density of pore distribution. During pore formation, interaction occurs between pores, and in the absence of complete coalescence, a specific porous macrostructure is formed. This macrostructure, consisting of densely packed spherical pores, is known as a "packing structure." At high total porosity, approximately 70–90%, and under specific matrix conditions, spherical pores may transform into polyhedral shapes.

The volume of cellular porosity is determined by the spatial arrangement of pores, pore size distribution, maximum and average pore size, pore shape, and the thickness of inter-pore walls. The strength of highly porous materials mainly depends on the type of pore packing. For example, in aerated concrete with identical inter-pore matrix properties but different macrostructures, strength may vary by 1.5–2 times. Table 1 presents standard aerated concrete with typical characteristics obtained in accordance with GOST 25485-2019, as well as the composition containing 3% CMC. In the preparation process, the aqueous phase is intensively mixed with CMC to obtain a homogeneous solution, which is then added to the cement mixture. As a result, the liquid phase is uniformly distributed throughout the entire volume. CMC swells actively in the aqueous phase and retains water inside the pores, which contributes to the gradual increase in the strength of aerated concrete over time.

The most effective formulation identified in this study is the 3% aqueous CMC solution, as it ensures uniform distribution of the liquid phase throughout the structure. The results show that the 3% CMC solution not only improves strength but also increases the concrete grade, enhances the density level, and contributes to economic efficiency. Table 3 presents the calculation of production cost and economic efficiency, demonstrating the high profitability of the proposed composition. The obtained results confirm that the new aerated concrete block with CMC addition has improved performance characteristics and contributes to enhancing the quality of non-autoclaved aerated concrete.

Based on the research results, it is recommended to use a 3% aqueous CMC solution in the production of non-autoclaved aerated concrete to improve pore stability, water retention, and overall concrete quality. Manufacturers should carefully control the proportions of cement, sand, water, aluminum powder, and CMC to ensure uniform structure formation. It is also advisable to conduct additional laboratory tests on frost resistance, thermal conductivity, and long-term durability. The production process should be optimized to reduce material consumption and increase economic efficiency. Furthermore, CMC-based aerated concrete technology can be more widely introduced into the construction materials industry.

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