

Social and technological aspects of building materials production in the concept of a smart city

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Abstract. The concept of a smart city is based on the improvement of the quality of human life in a comfortable environment. Depending on specific goals, priority is given to certain environmental factors. Among the most important factors, the analysis allows highlighting social inequality, ecology, sustainability, the use of local conditions, resource optimization, and benefits for citizens. The creation of infrastructure that ensures and supports the development of cities is largely determined by the state of the construction sector. In the field of construction, we are talking about the choice of socio-technological aspects of the production of materials that correspond to the concept of a smart city. Therefore, the choice of building material is determined by the social significance of its availability, environmental friendliness, technological feasibility from the standpoint of durability, the possibility of using local raw materials, and the possibility of involving technogenic materials. Based on the SWOT analysis method, ceramic tiles have strong technological aspects. The article presents the results of optimization of the raw material composition of ceramic tiles, which includes anthropogenic material - cullet and local raw material - chalk, and technological parameters (pressing pressure and firing temperature). As a result of the work, the rational content of the studied floodplains (cullet and chalk) in the raw material mixture was determined - 17-25% for the production of facing ceramic tiles. It is established that press pressure is a factor in the formation of a structure that allows reducing the temperature of roasting ceramic tiles.

1. Introduction

In the process of the dynamic development of various spheres of human activity, both in the organization of the national economy of the countries of the world and in the scientific literature, the boundaries between the directions and tasks of this development are increasingly blurred. Man comes to the fore both as a global goal of development and as a basic means of achieving it. This position is fully reflected in the concept of a “smart city” whose main purpose is to change the quality of life of people in a comfortable environment [1, 2, 3].

Habitat is a multifaceted concept. The quality of the environment is determined by economic, social, environmental, technological, informational and other factors. Depending on the existing base and specific development goals, priority is given to certain factors. Accordingly, a smart city can be, for example, a city of knowledge, informational, technological, ecological city [2]. Particularly, researchers note the importance of such a characteristic of a smart city as sustainability [4, 5, 6, 7], in particular, in relation to the creation and use of technologies and building materials [7, 8], knowledge and use of local conditions [1, 9, 10].



Taking into account the importance of the noted aspects in relation to the implementation of the concept of a smart city, in this article we focus on the socio-technological aspects of creating decorative building materials. We use an example of the peculiarities of ceramic tile production from the point of view of optimizing the composition while reducing energy costs for its production, taking into account the availability, sustainability, expediency of local use and involvement in the secondary production of man-made materials. The aim is to identify rational formulations for the production of cladding ceramic tiles using local raw materials with a reduction in energy costs for its production.

2. Problem statement

The most common definition of a smart city today is related to its aims. The concept of a smart city involves the study of a holistic structure that ensures sustainable development, an increase in the quality of life and efficient use of resources for its residents. The concept is based on the idea of creating a comfortable living environment [2, 3, 4].

Essentially, the human environment in the smart system is divided into corresponding enlarged components: social, material, environmental [1]; disaster susceptibility, sustainability, security, infrastructure, ecology, social and integration elements of the system are considered separately [4]. Moreover, according to published data, in modern conditions, more than 80% of the cities in the world show signs of fragility. Social inequality is growing (social positions of 75% of cities have deteriorated over the previous 20 years). There is a need for the construction of 1 billion new medium-sized houses. Environmental problems are intensifying (about 75% of the use of natural resources goes into emissions) [11].

Accordingly, the need to solve the problems noted comes to the fore. In particular, it is noted that the philosophy of a smart city is correlated with the alliance of man and nature, based on the propaganda of an ecological approach based on knowledge of local conditions, both material and social [10]. The creation of infrastructure that ensures and supports the development of cities includes the extraction and enrichment of raw materials, the production of building materials and the utilization of technogenic materials. The results of the survey of respondents demonstrate the prioritization of sustainability components that provide the best quality of life inside buildings based on the principles of the green economy of buildings. Among the priority tasks are energy efficiency, reduction of toxic materials and reduction of indoor pollution [7]. Finally, we are talking about the use of building materials that provide psychological and physical benefits for residents in terms of affordability and sustainability in the construction of low-cost housing [8, 12], resource optimization and waste reduction in design, in particular in the ceramic materials sector [13].

Currently, the production of zero industrial waste is the key to maintaining global competitiveness. A new industrial model focusing on resource optimization and waste reduction is being considered. Improving the comfort of housing during the construction of a new and repair of an existing one is associated with the use of finishing materials. The primary indicators when choosing them are the combination of high decorative indicators with physical and mechanical characteristics, environmental friendliness, durability, and the possibility of recycling [12, 13, 14].

Thus, from the perspective of the socio-technological aspects of production in the concept of a smart city, there is a problem of producing affordable, environmentally friendly, aesthetic, durable, and hygienic, high-quality building materials.

The purpose of the work is to determine a competitive finishing material, identify its strengths and weaknesses, develop a composition using local and technogenic raw materials, and optimize technological parameters according to the criterion of material and energy costs.

3. Materials and methods

Compared to other finishing materials, ceramic tile has a number of key advantages: high mechanical properties, light and color resistance, hygiene, environmental friendliness, fire resistance, antistatic, radiation safety, long service life. It is used for wall decoration inside buildings, facades and

for floors. In addition, the technological capabilities of its production are constantly being improved. Innovative technologies allow the use of technogenic raw materials and reduce energy costs.

During the study, a SWOT analysis of ceramic tile production was performed, the results of which are presented in table 1. SWOT analysis showed that ceramic tile has rather strong sides and promising opportunities when using local and technogenic raw materials and using innovative technologies.

Table 1. SWOT- analysis of the competitiveness of ceramic tile production

	Opportunities	Threats
	Introduction of energy-saving technologies The use of local and industrial raw materials Market expansion	Strengthening risks, the development of new production Rising prices for necessary raw materials and equipment Increased competition
Strengths	SO field	ST field
Market demand High mechanical properties, environmental friendliness fire resistance, hygiene, durability	Application of innovative production technologies Expansion of the raw material base, with the involvement of technogenic materials and local raw materials	Measures aimed at increasing the competitiveness of products: reducing costs by reducing the cost of raw materials, reducing energy consumption in production
Weaknesses	WO field	WT field
High risks associated with the development of innovative technologies	Carrying out measures to reduce the risks of developing new raw materials and production technology	Activities aimed at improving the competitiveness of products while reducing production costs

Today, the production of ceramic tiles is based on the use of flow-conveyor technology using a high-speed firing mode, for the implementation of which multicomponent raw mixtures of kaolin clay, fills, and special additives are necessary [14]. Under such conditions, the methods of controlling the processes of forming the structure of products at the stages of preparing the raw mix and molding are of great practical importance. These processes are controlled by: mineralogical, chemical and granulometric charge compositions, the moisture state of the moldable mixture; thermal effects during drying and firing products [15].

Table 2. The chemical composition of raw materials

Type of raw material	Oxide content, %											
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	TiO ₂	PbO	BaO	Li ₂ O	p.p.p.
Kaolin clay	62.34	18.93	3.20	2.73	1.15	0.68	0.47	1.2	-	-	-	9.3
Cullet	61.07	3.65	0.15	5.32	2.27	6.33	8.06	0.32	9.45	2.88	0.50	1.1
Chalk	1.30	0.7	0.10	93	4	-	-	0.1	-	-	-	42

In order to determine the rational raw material composition of ceramic tiles, using local and technogenic raw materials, the pressure values and the firing temperature, method D was used - optimal design of experiments. The raw material composition varied the content of kaolin clay, alkali-

containing flux — cullet (technogenic raw materials), alkaline-earth flux — chalk of the Belgorod deposit (local raw materials). The chemical composition of raw materials is presented in table 2.

The mixture was prepared by joint wet grinding in a china ball mill; the samples were pressed at a moisture content of 8% and a given pressing pressure. The samples were fired at the maximum set temperature with an exposure of 30 min in an electric furnace.

As the main physic mechanical properties of the ceramic tile, the average density (ρ_m), the ultimate tensile strength in bending (R_{bend}) water absorption by mass (B_m) were determined.

The experimental conditions are presented in table 3, the planning matrix and the test results in table 4.

Table 3. Planning matrix and experimental conditions

Variable name	Units	Designation	Levels of variation		
			Lower (-1)	Main (0)	Upper (+1)
Mass fraction of cullet	%	x_1	15	30	45
Mass fraction of chalk	%	x_2	2	10	18
Firing temperature	°C	x_3	1000	1040	1080
Pressing pressure	MPa	x_4	15	20	25

Table 4. Results of determining the physic-mechanical properties of ceramic tile samples after a single firing

№ of experience	Planning matrix				PHYSICAL AND MECHANICAL PROPERTIES		
	x_1	x_2	x_3	x_4	Average density, kg/m^3	Bending strength, MPa	Water absorption by weight, %
1	+1	+1	+1	+1	1681	15.5	21.8
2	+1	+1	+1	-1	1652	13.6	22.5
3	+1	+1	-1	+1	1734	16.1	19.7
4	+1	+1	-1	-1	1635	13.1	23.5
5	+1	-1	+1	+1	2035	24.3	10.9
6	+1	-1	+1	-1	1818	11.5	16.3
7	+1	-1	-1	+1	1892	16.0	14.6
8	+1	-1	-1	-1	1754	11.4	16.8
9	-1	+1	-1	+1	1774	16.9	19.7
10	-1	+1	+1	-1	1755	18.3	21.9
11	-1	+1	-1	+1	1751	15.7	21.2
12	-1	+1	-1	-1	1723	13.5	22.6
13	-1	-1	+1	+1	2076	22.0	10.6
14	-1	-1	+1	-1	1823	16.2	17.5
15	-1	-1	-1	+1	1914	16.9	15.0
16	-1	-1	-1	-1	1745	13.4	19.9
17	+1	0	0	0	1776	19.7	17.7
18	-1	0	0	0	1821	21.9	17.4
19	0	+1	0	0	1674	17.1	22.1
20	0	-1	0	0	1834	17.8	15.5
21	0	0	+1	0	1845	20.8	17.2
22	0	0	-1	0	1734	11.0	21.0
23	0	0	0	+1	1826	16.7	17.2
24	0	0	0	-1	1711	12.6	20.2

Based on the results of the study, we calculated the regression equations of the dependence of the tensile strength in bending (1) and water absorption by weight (2) of the ceramic tile after firing, on the content of fluffs in the composition, pressing pressure and firing temperature:

$$R_{bend} = 18.586 - 0.769x_1 - 0.536x_2 + 1.803x_3 + 2.031x_4 + 2.212x_1^2 - 1.138x_2^2 - 2.888x_3^2 - 0.888x_4^2 - 0.059x_1x_2 - 0.334x_1x_3 + 0.772x_1x_4 - 0.653x_2x_3 - 1.309x_2x_4 + 0.366x_3x_4 \quad (1)$$

$$B_m = 18.683 - 0.111x_1 + 3.217x_2 - 0.917x_3 - 1.694x_4 - 1.136x_1^2 + 0.114x_2^2 + 0.714x_3^2 + 0.014x_4^2 + 0.406x_1x_2 + 0.369x_1x_3 - 0.206x_1x_4 + 0.619x_2x_3 + 0.706x_2x_4 - 0.181x_3x_4 \quad (2)$$

4. Conclusion

The concept of a smart city involves the study of a holistic structure that ensures sustainable development, an increase in the quality of life and the efficient use of resources for its residents. The concept is based on the idea of creating a comfortable living environment. In accordance with this idea, the socio-technological aspects of the production of finishing building materials are investigated. From a social perspective, taking into account consumer preferences, the existing problem of social inequality and the need to build low-cost housing, priority is given to such aspects as accessibility, aesthetics, and environmental friendliness of the material. From the point of view of its production technology, the possibility of waste disposal (cullet), the use of local materials in production, and the minimization of material and energy costs are significant.

As an example, the production of ceramic tiles in the conditions of high-speed firing conditions is considered. As a result of the SWOT analysis, it was shown that ceramic tile has rather strong sides and promising opportunities as a finishing material, while reducing raw material costs and applying innovative technologies. It has been established that the rational content of fluxes based on local and technogenic raw materials (chalk and cullet) in the charge compositions for the production of ceramic cladding tiles is $RO+R_2O=17-25\%$, while the ultimate tensile strength in bending of ceramic tiles of more than 20 MPa, water absorption less 16%, which meets the requirements of GOST (Russian State Standard).

It is shown that with increasing pressing pressure, the formation of a denser raw structure at the molding stage is expedient technologically and economically, as it allows a decrease in the maximum firing temperature by about 40 °C. The methods considered in the article suggest a multidimensional solution to the problem of increasing the competitiveness of the technology of finishing building material using ceramic tiles as an example. Practical experience in implementing the applied methods allows approaching the solution of tasks purposefully and effectively.

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