



Research article


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The clay rocks properties for the production of the ceramic bricks

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Abstract. This paper aimed to study the properties of clay rocks in terms of chemical, mineralogical, and granulometric compositions during the pre- and post-firing processes as compared to regulatory documents. Moreover, the electrochemical interactions between the clay rocks elements have been evaluated due to the electrophoresis of its core. The results revealed that the properties of the investigated clay rocks agreed well with the requirements of regulatory documents and it is suitable to produce the ceramic bricks by plastic and dry methods. However, the calculated energy charges of clay oxides prove that the chemical composition of clay rocks will provide an unstable and irritable brick system due to the negative charges being 1.6 times greater than the positive charges. To modify the composition, it is suggested to insert feedstock or additives containing 2.3 times more positive charge selected on the basis of the structure of s-, p- and d-electrons. Further studies are recommended to take into account the thermodynamic characteristics of the feedstock to monitor the firing process, reduce energy costs and improve the quality of bricks.

1. Introduction

Most of the countries spend almost half of the annual income on construction. For centuries, the industry of producing artificial ceramic occupied an important place in Material science and production; its quality was determined by an ancient technology – clay science [1, 2]. According to the principle “what you sow, you reap” the quality of quarry clay rock determines the quality of the final ceramic product, particularly bricks. Clay soils are unique in terms of the inhomogeneity of their properties. Note that, when their solid ingredients are converted into a viscous fluid, in certain circumstances, they change their compositions and properties [3, 4]. Clay rocks can be rock-like, dry or wet, depending on the region, soil strata conditions and groundwater levels. They have different moisture, as well as different particle size distribution, they are lean, medium or high ductility, different formability, furthermore they have different attitude to temperature interactions (drying, firing).

The chemical compositions of clay rocks vary widely: SiO_2 – 45–80 %, CaO – 0.5–25 %, that is 1.7–50 times [5, 6]. Atoms and molecules are in free and bound states, the ratio between them is different in energies. They are energetically charged either positively or negatively. However, when raw materials and technology are selected, the electrical core of atoms and their energetics are not taken into consideration [7–9]. Excessive amounts of salt in the original materials cause fading and destruction in the surface layer of products [10, 11]. The granulometric composition of clay rocks is closely related to the mineralogical composition; furthermore, it is very diverse [12–14]. For example, grains of less than 5 μm are attributed to clay rock, their amount is in the range of 8–60 %, while grains of 50–350 μm are attributed

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to sand, their amount is in the range of 1–22 %, i.e., their fluctuations are 7.5–22 times. Such a specific inhomogeneity and the variety of composition, structure and properties greatly change used technology and efficiency as well as affect the quality of the product [15].

Clay rocks used to produce bricks should exhibit good formability with no thermic cracks or deformations during the processes of drying or firing, and provide the required physical and mechanical properties as well as durability of the bricks. Therefore, in a newly developed quarry, clay rocks should not only be subjected to a thorough study of their primer properties but they should be periodically monitored and compared with the requirements of regulatory documents throughout the whole process. The regulatory documents, in the age of nanotechnology, must take into account all the properties of atoms, including the electrochemistry ones. In this research, the properties of clay rocks have been studied and compared with the requirements of regulatory documents to evaluate their compatibility to produce ceramic brick:

- State Standards of Ukraine DSTU BV 2.7-60-97. Clay raw materials for the production of ceramic building materials. Classification [16].
- Government Standard of Russia GOST 21-2116.1-81. Clay raw materials: Methods for determining plasticity [17].
- Industry standard of Russia OST 21-78-88. Clay raw materials for the production of ceramic bricks and stones. Technical requirements. Test method p:59 [18].

This research aimed to study the quality indicators of clay rocks: pre-firing, during firing and post-firing as compared with the above regulatory documents. Moreover, attention was drawn to the electrochemistry properties of clay rocks due to the lack information about these properties, whereas the mismatching between the energy charges of clay rock oxides could have a noticeable effect on the values of the maximum temperature and duration of firing.

2. Materials and Methods

In this study, clay rocks of a quarry under development have been adopted with the aim of producing ceramic bricks. Methods of studying the technological parameters of clay rock (in the quarry) and clay raw materials (in the factory) are stipulated in regulatory documents and implemented in the processes of our laboratory research. Depending on the samples, pre-calcining properties were studied and the clay rock composition was characterized: macroscopic description, chemical and mineralogical composition as well as the particle size distribution. Characteristics of clay raw materials by moisture and cohesion of clay were determined in the quarry: molding, moisture, ductility and cohesion. The drying properties of clay puddle were determined: shrinkage and sensitivity of drying. Methods of studying the properties of clay rocks are described in regulatory documents and in the process of our laboratory research. The methodological analysis of this research was carried out in the technological sequence of brick production: clay rocks characteristics, particle size distribution of clay raw materials, clay moisture and cohesion, drying and firing properties of clay.

2.1. Clay Rocks Properties

2.1.1. Sampling

For mineralogical and physical-mechanical tests, representatives of the customer and the contractor took an average clay sample. We chose it from a developed quarry located 2 km north of the village of Hulyaivka and 8 km southeast of an urban-type settlement in Beryozovsky District, Odessa region. The quarry depth was 6 m at the sampling site, and three samples were selected at different positions. The first sample was chosen at a depth of 1 m from the lower layer of overburden, while the second sample was selected at depth 5 m and the last sample was chosen at the middle depth between the above mentioned samples. The weight of the sample was 50 kg and the clay rock of the selected three samples was scattered with a thin layer on an area of 1 m². The clay was thoroughly mixed and divided by two diagonals into four triangles and the large blocks were smashed with a wooden mallet, and this process was repeated four times, after which it was used for laboratory research.

2.1.2 Macroscopic Description

A macroscopic description was carried out with a microscope MPB-2 to study clay rocks, which made it possible to determine that the fraction of less than 0.001 mm consists of particles with clearly expressed morphological features.

2.1.3 Chemical Composition

The chemical composition (%) of clays of the study area according to State Project Development & Research Institute "CHORNOMORNDIPROEKT" is shown in Table 1.

Table 1. Chemical composition of clays rocks.

Oxides	Value
SiO ₂	57.4 – 62.7
CaO	3.3 – 4.7
MgO	2.4 – 2.8
Al ₂ O ₃	14 – 15.4
Fe ₂ O ₃ +FeO	5.4 – 6.3
TiO ₂	0.6 – 0.8
K ₂ O+Na ₂ O	3.3 – 3.7
SO ₃	0.04 – 0.07
MnO	0.08 – 0.14

2.1.4 Moisture Content

Quarry moisture content of averaged clay rocks is determined by the amount of moisture lost during drying as shown in Table 2.

Table 2. Quarry moisture of clay.

Sample number	Sample weight, g	Weight of dry sample, g	Moisture of clay, %
1	1000	910	10.4
2	1120	980	14.3
3	1150	1020	12.7
Average	1135	970	12.5

2.1.5 Granular Distribution of Clay Raw Materials

The content of finely divided fractions, i.e. clay, dust and sand particles were determined according to the recommendations of "State Standards of Ukraine DSTU and State Standard GOST" as shown in Table 3.

Table 3. Quantity determination of clay dust and sand fractions.

Quarry height tier	The content of clay particle size (mm)					
	Size of less than 0.005				0.05 – 0.005	0.05 – 1
	V cm ³	V1 cm ³	K	Clayey %	Dusty %	Sandy %
Upper	10	12.0	0.29	6.6	20.4	73.0
		13.1	0.31	7.0	25.4	68.0
		12.4	0.24	5.4	22.6	70.5
Medium	10	11.7	0.17	3.9	33.1	63.0
		14.0	0.40	9.1	26.0	65.0
		13.1	0.31	7.0	40.0	58.0
Lower	10	11.5	0.15	3.4	19.6	77.0
		11.3	0.13	3.0	21.0	76.0
		11.2	0.12	2.7	20.3	79.0
The average sample				3.0 – 6.7	20 – 33	64 – 77

After the volume of clay in a beaker with water seized to increase, the volume of clay suspension V_1 was determined. In addition, the rate of increment K was calculated, per cm³ of the initial volume V_o by the formula:

$$K = (V_1 - V_o) / V_o \quad (1)$$

The percentage of clay fractions was determined by the formula:

$$G = 22.7 * K \quad (2)$$

After elutriation of the contents in the beaker, the amount of sand fractions deposited on the bottom was determined. The content of coarse inclusions was determined by screening on sieves according to "Industry standard OST" as shown in Table 4.

Table 4. The content of coarse inclusions.

Sieve size (mm)	Private residues on sieves				Total sieve residues %
	Weight, g	Quantity, %	Weight, g	Quantity, %	
5	0	0	70	4	0 – 4
2	65	3	82	5	3 – 9
1	97	5	137	7	8 – 16
0.5	141	7	1095	55	15 – 71

2.1.6 Clay Moisture and Cohesion

The molding of the clay determines the amount of water needed to give the clay raw material a normal working consistency, as clay paste showing plastic and molding properties without deformation retains its shape and does not stick to hands and metal when rolling. To control the normal molding moisture of the clay paste, "Vika" device was used, which was designed to determine the normal density and setting time of the cement paste with a needle. Normal molding moisture was determined by the difference in masses between wet and dry clay; it was evaluated in percentage as shown in Table 5.

Table 5. Required molding moisture for the clay samples.

Sample number	Weight of moist sample, g	Weight of dry sample, g	Moisture, %	
			Absolute	Relative
1	20.0	17.1	14.5	16.9
2	22.4	19.6	12.5	14.2
3	23.6	20.0	13.8	17.8
Average	22	18.9	13.6	16.3

2.1.7 The Plasticity of Clay Raw Materials

The ability to change shape under pressure, i.e. the deformation without the formation of cracks or breaks, and to keep this shape after unloading. These clay properties are characterized and evaluated by the plasticity index as shown in Table 6, i.e. the difference between the clay moisture in the case of plasticity limit and the clay moisture in the case of rolling limit.

Table 6. The plasticity of clay rocks.

Container with water	Weight, g			Limit, %		Plasticity number
	Container with moist clay	Container with dry clay	Fluidity	Rolling		
50	10	37.63	32.34	20	8.10	12
50	10	48.50	44.30	20	4.22	16
50	15	30.57	24.70	30	16.30	14
50	11,5	25.15	22.87	23	14.60	8

2.1.8 The Cohesion of Clay Raw Materials

The compressive, tensile and bending strength of samples molded in a plastic way for the pastes with normal moisture that were dried at a temperature of 105–110 °C. The research results are shown in Table 7.

Table 7. Cohesion of clay raw material.

Sample No	Sample		Loading, kgf	Rcom. kgf/cm ²	Loading, kgf	Rcom. kgf/cm ²	Loading, kgf	Rcom. kgf/cm ²
	cm ²	cm ²						
1	7.07	720	102	79	17	Samples 137×50×10 mm	18.2	
2	7.07	700	99	88	19		19.1	
3	7.07	840	119	84	18		18.9	
4	7.07	900	127	Samples "Eight"				

Clay rock with a moisture content of 7–9 %, i.e. powder, was loaded into a mold cylinder with a diameter of 50 mm and pressed at a pressure of 200 kgf/cm². The molded sample was removed and immediately tested in the press. We found that the compressive strength of the freshly formed press powder was 23–28 kgf/cm².

2.2. Clay Drying Properties

2.2.1 Air Shrinkage

The mechanism of this phenomenon is an approach taken by the solid particles when the thickness of the water layer decreases between them and shrinkage of the products lasts until the moisture evaporates and the solid particles appeared. To determine that, a clay paste of normal density was prepared, tile samples were formed in the size of 100×100×10 mm and then dried to constant weight as shown in Table 8.

Table 8. Air shrinkage of clay raw material.

No.	Non-pressed samples			Pressed with 200 kg/cm ²		
	L_{moist} , mm	L_{dry} , mm	Shrinkage %	L_{moist} , mm	L_{dry} , mm	Shrinkage %
1	100	93.8	6.6	16.4	16.1	1,8
2	100	93.2	7.2	16	15,6	2,5
3	100	91.6	9.1	32.8	31,9	2,8

2.2.2 Drying Sensitivity of Clay

We determined it via the Chizhsky method [19] by forming three tile samples 100×100×10 mm. We found their weight and sent them for drying. It was revealed that the moisture of the samples at which the shrinkage stops is critical moisture. According to the theory of drying, critical moisture is understood as moisture at which the constant drying speed stops and the falling drying speed begins. The clay sensitivity coefficient for drying was determined by the formula:

$$K_s = \frac{V_1}{V_o \frac{m_o - m_1}{V_o - V_1}}, \quad (3)$$

where, m_o and V_o are the mass and volume of the freshly formed sample; m_1 and V_1 are the mass and volume of the sample in an air-dry state. Tests were carried out on cylindrical molds with a diameter of 13 mm and a height of 39 mm: the samples were placed in them after being cut out by a clipper from a clay paste with normal moisture. Then the prepared samples were weighed and measured by length and diameter after a day and then periodically every 3-4 hours. Then we weighed the samples at the moment of reaching constant weight to determine the clay sensitivity coefficient for drying using the parameters presented in Table 9.

Table 9. The clay sensitivity coefficient for drying.

No.	The weight of sample, g		The length of the sample, mm		The diameter of the sample, mm		Ks
	Moist	Dry	Moist	Dry	Moist	Dry	
1	10.9	9.69	41.1	39.6	12.4	12.0	0.96
2	10.93	9.72	43.8	39.1	12.5	12.1	0.89
3	10.86	9.69	39.1	38.3	12.3	11.9	0.97
Average	10.9	9.7	41	39	12.4	12.4	0.95

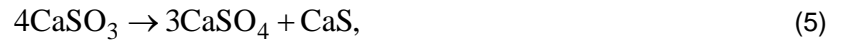
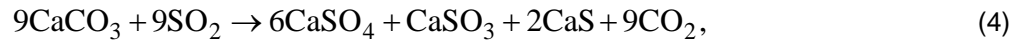
These results are confirmed by the method of Z.A. Nosova [20] who used different sample sizes: 50×50×8 mm and 50×50×15 mm. The results are shown in Table 10.

Table 10. Determination of the clay sensitivity coefficient for drying.

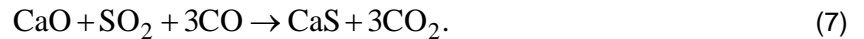
No.	Moist. sample			Dried sample			K_s	Sample size, mm
	L_o , cm	M_o , g	V_o , cm ³	L_l , cm	M_l , g	V_l , cm ³		
1	–	51.47	24.93	–	43.30	22.45	0.51	50×50×15
2	–	46.94	22.93	–	39.76	20.86	0.57	
3	5	58.61	28.52	4.70	49.42	25.38	0.51	50×50×8
4	5	50.37	25.7	4.67	42.80	25.06		
Average		54.49	27.11		46.11	24.07	0.51	

2.3. Clay Firing Properties

The thermal properties of clay rocks which included refractory materials and fire shrinkage were studied according to the requirements of State Standard of Russia GOST 21216.11-93 [21]. During the fire, the raw clay materials are burned to form the calcium sulfate (CaSO_4) in complex reactions as shown in equations below [22, 23]:



Equation 6 can be changed if insufficient oxygen is provided as follows:



Pyrometric cone samples (sometimes called pyroscope) made from a clay paste with normal molding moisture were prepared. The refractoriness was estimated via the firing temperature at which the pyroscope started softening. The fire shrinkage was determined at 900–1250 °C for 67×30×15 mm tile samples according to the formula:

$$U = 100 * (l_o - l_1) / l_o, \quad (8)$$

where l_o and l_1 represent the length of the sample before and after firing in mm as shown in Table 11. The same formula was used to calculate the air shrinkage at 105–110 °C where l_o and l_1 represent the length of the sample before and after drying.

Table 11. Determination of fire shrinkage.

No.	The distance between the sample marks, mm			Air shrinkage, %	Fire shrinkage, %
	Freshly molded	Dry	Fired		
Firing temperature 1000°C					
1	18.5	18.2	18.2	1.6	0.0
2	19.3	19.2	18.9	0.5	1.6
3	18.8	18.7	18.6	0.5	0.5
Firing temperature 1200°C					
1	29.1	28.9	28.7	0.7	0.7
2	27.4	27	26.5	1.4	1.9
3	32.8	31.9	31.9	2.7	0.0
4	31	30.2	30.1	2.8	0.3

We determined the degree of sintering which represented the value of the water absorption of burnt pottery. We used using tile samples with dimension of 60×30×10 mm prepared from paste with normal moisture, then dried at 105–110 °C and fired in an oven at three to four temperatures, taking into account that the temperature of each subsequent firing was 50 °C higher than the previous one. The results are shown in Table 12.

Table 12. Determination of the clay sintering temperature.

No.	Temperature, °C	The weight of sample, g		Water absorption, %		Average density, g/cm ³
		Fired	Water saturated	Individual	Average	
1	1140	44.13	49.12	11.13	11	1.95
2		43.85	48.62	10.9		1.89
3		41.52	46	10.8		1.96
4	1220	43.18	41.1	4.8	4.4	1.97
5		44.23	42.24	4.5		1.99
6		45.1	43.34	3.9		1.95

Bloating, i.e. an increase of the volume of samples during high-temperature firing, was evaluated by the average density of the samples before and after firing.

Table 13. Determination of clay bloating coefficient.

No.	Sample volume, cm ³		K bl.	Weight, g		Volume, cm ³		Loss on ignition %	K bl.
	Before firing	After firing		Before firing	After firing	Before firing	After firing		
1	22.25	22.4	1.01	4.73	4.54	2.05	1.96	4.4	1.01
2	25.10	26.26	1.05	4.75	4.3	2.01	1.95	4.1	0.99
3	24.00	25.32	1.06	4.24	4.0	2.0	1.89	3.6	1.02

Cylinder samples with a diameter of 13, 30 and 50 mm were used to evaluate the ability of burnt ceramic materials to resist the destructive action of internal stresses arising under the influence of external forces. The average density and porosity were also determined on 67×3×15 mm samples. The amount of water absorption was also obtained for each sample which should be no less than 8 %. The result of the post-fired physic-mechanical properties of the fired samples was also obtained.

Table 14. Physical and mechanical properties of fired ceramics.

Sample Area, cm ²	Load of press, kg	Rcom, kgf/cm ²	Average density, g/cm ³	Porosity, %			Water absorption %	LOI %
				True	Accessible	Sealed		
1.33	200	150	1.89					
	260	195	1.89					
	300	225	1.95					
7.07	920	130	1.89	28	11.3	6.6	11.3	4.4
	950	134	1.95	26	19.6	5.4	10.8	3.9
	1000	141	1.96	25	11.4	13.6	10.9	3.6
19.625	4400	224	1.95					
	3945	201	1.9					
	3830	195	1.89					

3. Results and Discussions

3.1. Macroscopic Results

The color of clay in the dry case is light yellow and in the wet case is dark yellow and its texture is formed as lumpy, dense, messy and disoriented. The clay grains are located without any noticeable orientation and they have different sizes: from dusty to several centimeters. The viscosity of clay is weak in the wet case so that the clay rocks and clay pieces are easily crumbled when pressed on with fingers; in the dry case, they are firmly dense and adhering grains. In addition, we think that it is worth noting the presence of impurities and inclusions observed under the microscope:

- Light gray granular porous inclusions of both fine-dispersed and coarse-dispersed carbonates;
- Rounded, colorless grains of quartz, in the vast majority up to 0.05 mm in size;
- Dark-colored grains of pyrite up to 0.1 mm in size.

3.2. Compared with Ukraine DSTU BV Standard

The properties of the investigated clay rocks were compared with State Standards of Ukraine DSTU BV 2.7-60-97. The results proved that these rocks are suitable for production of ceramic bricks by plastic and dry methods.

In the dry places in the quarry on the sharp corners of the large dry pieces, white efflorescence was visible signaling presence of salts [24]. The amount of silica in the clay rocks is inversely proportional to the strength of the resulting ceramic, as the amount of silica determines the amount of sand fractures present in the clay rocks, which cause an increase in the porosity that negatively affect the strength of the resulting ceramic. The high content of alumina requires a high firing temperature, and a low content reduces the strength of the products and lengthens the preparation time of the paste. Iron oxides reduce the temperature range of clay sintering, give color to the products from light cream to cherry-red. Calcium and magnesium oxides make firing difficult, lowering the melting point, increase porosity, and reduce the strength of the

ceramics [25]. The alkaline components, K_2O and Na_2O , lower the melting point, condense and increase the strength of the ceramics.

The swelling index (3–6.7) is very weak which means that the water holding capacity is low, and according to the standard documents, this allows us to classify the studied clays as “kaolinite-hydromicaceous” that is the average content of clay particles is 3.0–6.7 %, i.e. less than 15 %. In addition, with regard to the dust, the percentage is 20–33 %, i.e. almost up to 30 %; therefore, the studied clay rocks belong to the “coarse” group. In addition, with regard to the content of sand fractions: $100\% - (6.6 + 20.4) = 73\%$, the research data on the granulometric composition of clay rocks indicate that clay rocks belong to the “dusty sandy loam” group [26].

The number of the coarse inclusions larger than 0.5 mm is 0.15–0.71 %, which is less than 1 % according to the standard requirements, therefore the clays under study were assigned to the group “with low content of inclusions” and “with small inclusions” as shown in Table 4 above. The type of predominant inclusions when examined under an MPB-2 microscope and exposed to 1% HCl solution, showed presence (more than 50 %) of calcite, dolomite and similar substances. In addition, according to our data, the carbonate inclusions were 0.15–0.53 % corresponding to the group of clay rocks “with carbonate inclusions”. Molding moisture means the amount of water needed to make the clay paste, that exhibits its forming and plastic properties, keeping its shape without deformation and does not stick to the arms and metal of the equipment when rolling in order to give the ceramic mass a normal working consistency [27]. To control the normal molding moisture of the clay paste, a “Vika device” TMM-2450A was used as given in Table 5.

In this research, the sensitivity coefficient of the tested clay rocks K_s is in the range 0.82–0.97 as shown in Table 9, which is less than the value recommended by the standard documents. Thus, these clays belong to the “insensitive to drying” group as well as the tested samples in Table 10 because the obtained coefficient of clay sensitivity to drying K_s was within “0.51–0.57” [28]. The sensitivity coefficient of clay to drying becomes higher if the dust content is greater. With regard to plasticity, when the plasticity index fluctuates within 8–16, this means that the clay rocks belong to the “moderately plastic” group [29, 30].

3.3. Electrochemical Interactions

From the studied pre-firing properties of clay rocks, it is worth paying attention to their chemical composition. The properties of clay rocks are determined by the degree of particles dispersion and their energy [31]. Hence, the degree of particles dispersion and the energy consumption of clay oxides was calculated according to Putz et al.[32] as shown in Table 15.

Table 15. The electric charge of clay oxides.

Oxides		The value of atomic charges in each oxide, eV		The value of the effective charges of oxides, $\pm q$, eV
Type	Amount, %	Positive, +q	Negative, -q	
SO_3	≤ 1	5.2	12.9	-7.7
Al_2O_3	7 – 23	6.8	12.9	-6.1
SiO_2	53 – 81	4	8.6	-4.6
Fe_2O_3	1,5 – 4	8.6	12.9	-4.3
MgO	0.5 – 2	2.8	4.3	-1.5
CaO	0.7 – 14	2.8	4.3	-1.5
Na_2O	≤ 4.5	4.4	4.3	+0.1
K_2O		4.4	4.3	+0.1
FeO	1 – 4	4.3	4.3	0
Total charge, eV		+43.5	-68.8	

The majority of oxides are characterized by the presence of excessive negative charges. Therefore, it should be equalizing for each other due to the greater quantity of similar charges, which may lead to greater repulsion. Up to 4.5 % of positively charged alkaline oxides Na_2O and K_2O will be neutralized by reacting with negatively charged and electrically neutral 4 % FeO, which can react with charges of any sign and create a solid. However, the problem is only that there are over 1.6 times more negatively charged oxides compared with similar positive charges. Moreover, the synthesis of positively charged atoms with negatively charged atoms gives the electronic structure of “the brick” as a future constructive product. The building materials with equal amounts of different positive and negative signs are always electronically stable, which gives them durability. Therefore, the result with respect to the studied clay rock as a raw

material for the production of bricks, which contains about 40 % of the excess electrical charge of negative atoms:

- First: instead of synthesis, these atoms will push each other off.
- Second: the brick system will be unstable and could reduce the durability because it may react with positively charged atoms during the operation.

Therefore, to obtain high-quality brick in these studies, at this stage, there is a need for refinement of clay rock to eliminate this problem. There are recommendations to pay attention to the energetic aspect of the firing process and the energy of the atomic composition of bricks. It is necessary to take into account the natural essence of clay rock as it consists of atoms, and the natural essence of atoms is the electrical composition and electronic structure: a positively charged nucleus and negatively charged electrons. The moving force is the charge of electric atoms as indivisible particles since the adhesive force of these atoms with others creates new materials with an electromagnetic field (chemical bond) as electrochemistry provides unlimited possibilities in creating new materials [33, 34]. It also can be said that the atoms are primordial by nature but the molecules and minerals of clay rocks and additives sometimes are not accurate because there are certain interventions by a researcher and a human.

It is known that a positive nuclear charge determines all the properties of an atom as they depend mainly on the number of negatively charged electrons and on the number of their orbitals around the nucleus. In this case, the chemical properties of atoms are strongly determined by the number of electrons in the outer electron layer and on the distance between the nucleus and the outer layer (orbital quantum number of the electron). In the outer electron layers, the farther the electron's orbital from the nucleus, the weaker its association with the nucleus.

With regard to the science of building materials, we can distinguish electrons of s-, p- and d-molecular orbitals. Since the electrons are in essence the material itself, so the respective materials are also called: s- p- and d- substances. The greatest bonding force of the nucleus is with s-substance while the smallest is with d-substance [35, 36]. These forces do not only affect the properties of the produced brick but also determine the firing mode. Thus, it is known that with increasing temperature the interatomic chemical bonds become longer and lose their bond strength. However, as the d-bonds are basically also weak in nature, they will break at a low firing temperature and transfer to the liquid phase faster, which is economically advantageous. The properties of clay soils are determined by electric forces (charges), whereas the main substances of clay rock are: s-elements (H, K, Na, Mg, Ca, Be), p-elements (Cl, N, B, O, F, Al, Si, C, P, S) and d-elements (Fe, Cr, Cu). It is only possible to obtain a building material with desired properties, if the energy properties of the feedstock are taken into account [37]. The calculations shown in Table 16 are for the quantitative content of s-, p- and d-substances in the studied clay sample.

Table 16. The degree of charge by the removal electronic orbit from the atomic nucleus.

Oxides		The number and type of orbital substances of oxide atoms		
Type	Amount, %	S-substance	P-substance	D-substance
SO ₃	1	-	4	-
Al ₂ O ₃	15	-	5	-
SiO ₂	67	-	3	-
Fe ₂ O ₃	5	-	3	2
MgO	1	1	1	-
CaO	7	1	1	-
Na ₂ O	4	2	1	-
K ₂ O	4	2	1	-
FeO	3	-	1	1
Total types of substances %		6	20	3
		21	69	10

According to the above results, there is an extremely low 10 % d-substance; therefore, further studies should be conducted to illustrate the effect of this reduction on the maximum temperature and duration of firing during production process of ceramics bricks [38, 39].

4. Conclusion

1. Assessment of the properties of clay rocks by their chemical composition meets the requirements of regulatory documents. They are suitable for the production of ceramic bricks by plastic and dry methods.

2. The results of electrochemical interactions indicated that the chemical composition of the studied clay rocks contained 1.6 times more negatively charged atoms as compared to positively charged ones. To modify the composition, it is suggested to insert feedstock or additives containing 2.3 times more positively charged atoms with the selection based on the structure of s-, p- and d-electrons to achieve more stable and durable brick structure.

In the future, it is necessary to study the thermodynamic characteristics of clay rocks consisting of electrically charged atoms, and the possibility of refinement of the feedstock in order to reduce the maximum temperature and duration of firing.

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