Azerbaijan University of Architecture and Construction
ISSN 2706-7726

Engineering Mechanics
Scientific and Technical Journal

E-mail: engineeringmechanics@azmiu.edu.az

September 2026	Issue 25	Volume 12	Number 3	Pages 14-19

INVESTIGATION OF THE FIRING REGIME FOR REFRACTORY MATERIALS BASED ON QIZILCA QUARTZITE

I.N.SHİRİNZADE[1], I.H.MAMMADOVA[2], K.B.JAMALOVA[3]

[1,2,3]*Materials Science Department, Azerbaijan University of Architecture and Construction, Baku, Azerbaijan*
iradax@yandex.ru
irade.memmedova777@gmail.com
khayala.jamalova@azmiu.edu.az

Abstract. The objective of this research is to develop a technology for producing refractory materials based on natural raw material resources found within the territory of Azerbaijan. To this end, the quartzite from Qizilca, located in the Khanlar district, was selected as the primary subject of study. Initially, the chemical composition of the rock was analyzed. It was determined that the rock contained significant clay impurities; therefore, it underwent a washing and purification process (beneficiation) before being used to prepare the raw material mixture (batch). The firing regime for the refractory material was established, with the process carried out at 1350°C over a duration of 37 hours. The resulting refractory materials exhibited notably high physical and mechanical properties.
Keywords: refractory materials, Qizilja quartzite, silica brick

1. INTRODUCTION

In recent years, the expansion of the construction sector in Azerbaijan, the modernization of industrial infrastructure, the establishment of new manufacturing enterprises, and the technical reconstruction of existing industrial facilities have led to an increased demand for various types of materials including refractory products designed for use under high-temperature conditions. The reliable operation of industrial furnaces particularly those used in metallurgy, cement production, the glass industry, ceramics manufacturing, and other high-temperature technological processes depends directly on the quality of their internal linings. The refractory materials used in these linings must withstand high temperatures, thermal fluctuations, mechanical loads, and aggressive chemical environments, while retaining their structural integrity and functional properties as much as possible throughout long-term service.

Poor quality in refractory linings can necessitate frequent repairs to industrial furnaces, cause interruptions in production processes, increase energy consumption, and, ultimately, lead to a rise in the production cost of the final product. Therefore, in modern materials science, the development of refractory materials which possess high performance characteristics, are economically efficient, and can be produced based on local mineral raw materials is considered a significant scientific and practical endeavor.

2. LITERATURE REVIEW AND PROBLEM STATEMENT

In Azerbaijan, the study of mineral resources for the production of refractory products based on local raw materials is of particular importance. Siliceous rocks, clays, carbonate rocks, and other types of mineral raw materials found in various regions of the country can be utilized in the manufacture of refractory materials, depending on their chemical and mineralogical characteristics. The technological assessment of these resources creates opportunities to expand the local raw material base, reduce dependence on imported refractory products, and foster the development of national industrial production [1].

One significant type of refractory material consists of silica-based products, known as dinas (silica) refractories. These bricks are produced from raw materials with a high SiO_2 content and are primarily used in the masonry of industrial furnaces that operate under high-temperature conditions. The performance characteristics of these materials are determined not merely by the total content of silicon oxide, but also by the specific mineral phases in which it exists, the presence of additional oxides, the phase transformations that occur during firing, and the resulting microstructure. Therefore, the selection of raw materials and the precise determination of the preparation technology are of particular importance in the production of silica refractory materials.

Another significant factor affecting the quality of silica refractories is the presence of additional oxides within the raw material. Oxides of aluminum, iron, calcium, magnesium, and alkali metals when present in certain quantities can influence the firing process of siliceous raw materials, the formation of a liquid phase, and the rate of mineral transformations. The impact of these components depends on their concentration and their interactions with one another. Under specific conditions, certain components can act as mineralizers, facilitating the formation of tridymite or cristobalite phases. However, an excessive formation of low-melting phases can compromise the material's refractoriness and its resistance to deformation at high temperatures. Consequently, a detailed analysis of the chemical composition of the raw materials and an assessment of its influence on the firing process are essential in the production of silica refractory materials [2]. The selection of Qizilca quartzite located in the Ganja-Qizilca region as a primary subject of this study is significant for exploring the potential use of local mineral raw materials in the production of refractory materials. The suitability of quartzites for the manufacture of silica (dinas) refractories is determined primarily by their silicon dioxide content, crystalline structure, the nature of mineral impurities, and their behavior at high temperatures. Furthermore, the presence of aluminum oxide, iron oxide, calcium and magnesium oxides, as well as alkali components within the raw material must be taken into account. While some of these oxides may have a beneficial effect on the firing process, an increase in their concentration can negatively impact the final product's refractoriness, phase composition, and mechanical properties [3].

Studying the chemical composition of Qizilca quartzite provides a preliminary assessment of its potential for use in the production of silica-type refractory materials. However, chemical analysis alone is insufficient to draw a definitive conclusion regarding the overall suitability of the raw material. To this end, it is also necessary to investigate the mineralogical composition, particle size distribution, phase transformations occurring during firing, and the physical-mechanical properties of the resulting material. In particular, the identification of quartz, tridymite, and cristobalite phases via X-ray phase analysis, combined with the assessment of physicochemical processes occurring during heating through thermal analysis methods, can strengthen the scientific substantiation of the research [4].

Raw material preparation constitutes a crucial stage in the technological process of producing silica bricks. This stage encompasses the preliminary processing of raw materials, grinding, adjustment of the grain size distribution, incorporation of additives, homogenization of the mixture, and shaping. The grain size distribution of the mixture influences its compactability, initial porosity, drying behavior, and the nature of densification during firing. Selecting appropriate particle sizes can facilitate the formation of a denser and more uniform structure. However, the primary objective in the production of silica materials is not merely to reduce porosity; it is also to ensure the necessary

mineral transformations of quartz, thereby establishing the performance properties required for the material under high-temperature conditions.

Changes in temperature during thermal processing trigger a sequence of physical and chemical processes within the material's structure. In the initial stage, free moisture present in the mixture is removed, while in subsequent stages, thermal alterations and phase transformations of the raw material's mineral components occur. As the temperature rises, the polymorphic transformations of quartz may accelerate; however, the extent to which these processes are completed depends not only on the maximum temperature reached but also on the duration for which the material is held at that temperature.

3. MAIN PART

First, the chemical and mineralogical composition of the Qizilca quartzite was studied, and it was determined that the rock from this deposit contains the following oxides: SiO_2 – 74.7; Al_2O_3 – 10.3; Fe_2O_3 – 5.4; CaO – 3.5; MgO – 1.5; R_2O – 2.6; TiO_2 – 0.6; P_2O_5 – 0.4. The mineralogical composition of the quartzite was analyzed at the Azerbaijan Institute of Petrochemical Problems. The samples were examined using an "X-Ray-TD 3500" (China) X-ray diffractometer. Based on the diffractogram, the following minerals were identified: quartz (SiO_2), kaolinite ($Al_2Si_2O_5(OH)_4$), calcite ($CaCO_3$), and small amounts of other clay minerals [4, 5].

It is well known that, although quartzite serves as the primary raw material, various mineral and chemical additives are incorporated into it to produce high-quality silica (dinas) bricks. Such additives include lime, clay, quartz sand, iron compounds, and other materials. These additives regulate the firing process, phase composition, mechanical strength, and thermal resistance of the material. Clay may be added in limited quantities to improve the shaping of the mass and the bonding of the raw material particles. Under certain conditions, iron oxides can act as mineralizers, but their quantity must be strictly controlled. Quartz sand can be used to adjust the granular and chemical composition [3].

In the production of silica refractory materials, lime is one of the most important components, second only to quartzite. Its primary function is to accelerate the transformation of quartz into other silicon dioxide modifications such as tridymite and cristobalite at lower temperatures.

The principal transformations of quartz are as follows:

α-quartz ⇌ α-tridymite (870°C) ⇌ α-cristobalite (1470°C) ⇌ melt (1728°C).

In these transformations, the presence of lime can accelerate the formation of a liquid phase and calcium silicates.

When lime is added, one of the following reactions may occur:

$$CaO + SiO_2 = CaSiO_3.$$

As a result of this reaction, calcium metasilicate (wollastonite) may be formed. The actual phase composition depends on the temperature, the mineralogical composition of the raw materials, and the chemical composition of the mixture.

In the production of silica refractories (dinas materials), lime is one of the most important components, second only to quartzite. Its primary function is to accelerate the transformation of quartz into silicon dioxide polymorphs such as tridymite and cristobalite at lower temperatures.

Lime can be introduced into the raw material mix for silica refractories in the form of quicklime (CaO), slaked lime [$Ca(OH)_2$], or limestone ($CaCO_3$). Among these, quicklime is the most effective. In this study, finely ground lime from the "Azərlime" plant was used.

Clay is not considered a primary raw material in the production of silica refractories. Nevertheless, in certain manufacturing processes, it may be used in small quantities to improve the moldability of the mass and the mechanical strength of the green (unfired) products. However, when adding clay, the Al_2O_3 content must be taken into account. An excessive amount of aluminum oxide can negatively affect the phase composition of silica refractories (dinas) and their high-temperature properties. For this reason, it is considered appropriate to use easily fusible clays with high plasticity, which are widely available in the country. In this research, clay from the Ashagi Guzdak deposit was utilized.

Thus, the initial study for the production of silica refractory material involves the use of the following raw materials: Ganja quartzite, quicklime from the "Azerlime" lime plant, and clay from Ashagi Guzdak.

The results of the chemical analysis of the quartzite reveal that, in addition to SiO_2, it contains significant amounts of other impurities. To remove these impurities, it is advisable to wash the rock. After washing the material until the water running off it became clear, the chemical composition of the samples was re-examined; the results are presented in Table 1.

Table 1. Chemical composition of Qizilca quartzite

No.	Material name	SiO_2, %	Al_2O_3, %	Fe_2O_3, %	CaO, %	MgO, %	R_2O, %	TiO_2, %	P_2O_5, %
1	Qizilca quartzite (unwashed)	74.7	10.3	5.4	3.5	1.5	2.6	0.6	0.4
2	Qizilca quartzite (after washing)	95.3	1.1	1.0	1.1	0.2	0.3	–	–

Thus, after being crushed, the quartzite was washed and cleaned until it became completely transparent. Once cleared of impurities, the Qizilca quartzite can be considered suitable for the production of Dinas (silica) refractory material. For this purpose, the SiO_2 content in the raw material mixture (batch) must exceed 90%. Assuming the composition of the mixture is as follows:

• Qizilca quartzite – 95%;
• Lime – 3%;
• Clay – 2%,

then the mixture contains:

$$SiO_2 = 0.95 \times 95.3 + 0.2 \times 55 = 91.4\%;$$

$$CaO = 0.95 \times 1.1 + 0.03 \times 100 + 0.02 \times 1 = 3.07\%.$$

Consequently, assuming the lime consists of pure CaO and adopting the specified nominal composition for the clay, the initial mixture contains approximately 91.04% SiO_2 and 3.07% CaO.

The lime was first slaked before being added to the mixture. The clay was ground and added to the mixture along with water to prepare the test specimens. The specimens, measuring 4 × 4 × 4 cm, were dried in a single-cavity mold, followed by an additional 5 hours of drying in a drying oven at 80–100°C, after which they were placed in a kiln for firing. The firing stages for refractory materials are carried out with particular care, and the characteristics of the firing regime stages are presented in Table 2.

Table 2. Firing regime for Dinas refractory material

Firing stages	Temperature, °C	Heating rate, °C/hour	Holding time at maximum temperature, hours
Stage I	20–200	20–30	1–2 hours at 200°C
Stage II	200–600	50	1 hour at 600°C
Stage III	600–900	30–50	1 hour at 900°C
Stage IV	900–1200	50	1 hour at 1200°C
Stage V	1200–1350	25–50	2 hours at 1350°C
Stage VI	Cooling	–	Slow cooling down to 573°C

In the first stage, physically and mechanically bound water is primarily removed. The samples were heated at a rate of 20–30°C/hour; rapid drying could cause the material to disintegrate. The samples reached 200°C over 7 hours and were held at this temperature for 2 hours; subsequently, the temperature was raised to 600°C over 6 hours and maintained there for 1 hour. After another 7 hours, the temperature was raised to 900°C, held for 1 hour, and then the material was fired with the

temperature increased by 50°C every 30 minutes. The total firing duration for the material was 37 hours.

It is known that densification during the firing of refractory materials occurs both during the transformation of quartz into tridymite and cristobalite, and during the formation of ceramic bonds (above 1200°C). This process leads to an improvement in the material's fundamental physical-mechanical properties.

The quality of silica (Dinas) refractories is determined not only by the proper selection of the firing regime but also by the cooling regime. This is because the following transformations can occur during cooling:

• β-quartz may transform into α-quartz (at 573°C);

• Low-temperature modifications of cristobalite and tridymite may form. The transformation temperatures of cristobalite and tridymite can vary depending on their structure, impurities, and temperature fluctuations. Therefore, applying a uniform cooling rate throughout all stages of the cooling process is not the appropriate approach. Cooling should be conducted with greater caution around the quartz transformation temperature, while keeping the risk of cracking under control.

Once the fired samples had cooled completely, their density and strength were determined, and the results are presented in Table 3.

Table 3. Physico-mechanical properties of Dinas refractory materials

No.	Quartzite, %	Lime, %	Clay, %	Average density, kg/m³	Compressive strength, MPa
1	95	5	–	2000	25
2	95	–	5	1950	24
3	95	3	2	2340	31

By using small amounts of both lime and clay, it became possible to obtain a material with a stronger and denser structure.

4.RESULT

To develop Dinas (silica) refractory materials based on Qizilca quartzite, the chemical composition of the quartzite was first analyzed, and the composition of the raw material mixture (batch) was calculated. Lime and clay were incorporated into the mixture to facilitate the bonding of the quartzite grains and to act as modifiers during the mineral formation process. It was determined that the mixture contained 91.04% SiO_2 and 3.07% CaO.

Based on this composition, the firing regime for the refractory material was established; it was determined that the firing process for the Qizilca quartzite-based refractory requires a duration of 37 hours at a temperature of 1350°C.

The material produced using this composition and firing temperature exhibits sufficiently high physical-mechanical properties.

This work was supported by the Azerbaijan Science Foundation – Grant № AEF-MGC-2025-1(54)-20/01/1-M-01

REFERENCES

1. Fataliyev S. A., Imanov E. M., Bayramov F. H. Mineral Raw Material Resources for Construction Materials in the Republic of Azerbaijan. Baku, 2000. 199 p.

2. Vladimirov V. S., Karpukhin I. A., Moyzis S. E. A New Generation of Thermal Insulation and Refractory Materials. Part II // Po Vsey Strane. 2002. No. 33.

3. Shirinzade I., Mammadova I. The State, Prospects and Current Directions of Production of Refractory Materials // Engineering Mechanics. 2025. No. 4. P. 1–7.

https://engineeringmechanics.az/uploads/2026/01/irada-shirinzade-irada-mammadova-the-state-prospects-and-current-directions-of-production-of-refractory-materials.pdf
4. Shirinzade I. N., Mammadova I. H., Aliyeva K. N. Study of the Composition of Raw Materials Used to Produce Refractory Materials in Azerbaijan // Technical Sciences: Problems and Solutions. Moscow. No. 6 (103), June 16, 2026. P. 110–115. https://www.internauka.org/conf/te
5. Shirinzade I. N. Study of the Influence of Chemical Composition on the Properties of Clay-Dolomite 11 Composite Materials Using Mathematical Modeling // Problems of Logistics, Management and Operation in the East-West Transport Corridor. Baku. 2026. P. 115–116. https://plmo.cyber.az/2026/Abstracts_PLMO2026_2026-05-12.pdf