African Journal of Advanced Pure and Applied Sciences (AJAPAS)
Online ISSN: 2957-644X
Volume 4, Issue 4, 2025
Page No: 275-286
Website: https://aaasjournals.com/index.php/ajapas/index
ISI 2025: 1.126 SJIFactor 2024: 6.752 معامل التأثير العربي: 1.62

Evaluation of the Suitability of Yafran Clays for the Manufacture of Building Bricks

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تقييم مدى صلاحية أطيان يفرن لصناعة طوب البناء

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Received: August 13, 2025	Accepted: October 16, 2025	Published: October 26, 2025

Abstract:
This study aims to assess the suitability of clay from the Yefren area in the Nafusa Mountains, Libya, for the production of fired bricks by evaluating its physical, chemical, and mineralogical properties. The methodology involved collecting field samples and conducting laboratory tests to determine moisture content, specific gravity, liquid and plastic limits, compressive strength, and water absorption rate. Additionally, X-ray diffraction (XRD) analysis was performed before and after thermal treatment at 900°C.

The results indicated that the clay exhibits favorable physical characteristics, with a moisture content of 36.8%, specific gravity of 2.6, and good plasticity reflected by a plasticity index of 45%. The produced bricks showed a compressive strength of 9 MPa and a water absorption rate of 11.6%, which falls within acceptable limits. Chemically, the clay contains adequate proportions of silica (70.63%), alumina (9.12%), as well as suitable levels of iron and calcium oxides, supporting its potential for industrial application.

Mineralogical analysis revealed the presence of clay minerals such as kaolinite and illite, with thermal stability maintained after firing—enhancing the clay's suitability for high-quality brick manufacturing. The study recommends further mineralogical analysis of additional samples and testing under various firing temperatures to optimize the final product quality.

Keywords: Yefren clay, Nafusa Mountains, brick manufacturing, physical properties, chemical analysis, XRD, compressive strength, water absorption.

الملخص
تركز هذه الدراسة على تحليل مدى صلاحية الطين المستخرج من منطقة يفرن بجبل نفوسة في ليبيا لاستخدامه في إنتاج طوب الأجر، من خلال فحص خصائصه الطبيعية والكيميائية والمعدنية. شملت منهجية البحث جمع عينات من الموقع وإجراء اختبارات مخبرية لتحديد معايير مثل نسبة الرطوبة، الكثافة النوعية، حدود السيولة واللدونة، مقاومة الضغط، ونسبة امتصاص الماء. كما تم تطبيق تحليل الأشعة السينية (XRD) قبل وبعد المعالجة الحرارية عند درجة حرارة 900 مئوية.
أشارت النتائج إلى أن الطين يمتلك خصائص فيزيائية ملائمة، حيث بلغت نسبة الرطوبة 36.8%، والكثافة النوعية 2.6، مع قدرة لدونة جيدة تعكسها قيمة مؤشر اللدونة البالغة 45%. كما سجل الطوب المصنوع مقاومة للضغط تصل إلى 9 ميجا باسكال، وامتصاصًا للماء بنسبة 11.6%، وهي ضمن الحدود المقبولة. على الصعيد الكيميائي، تبين احتواء العينات على نسب مناسبة من السيليكا (70.63%)، الألومينا (9.12%)، بالإضافة إلى أكاسيد الحديد والكالسيوم، بما يعزز جدوى استخدامها صناعيًا.

أما التحليل المعدني، فقد كشف عن وجود معادن طينية مثل الكاولينيت والإيليت، مع الحفاظ على استقرارها بعد الحرق، مما يعزز من إمكانية اعتماد هذه الأطيان في إنتاج طوب عالي الجودة. توصي الدراسة بتوسيع نطاق التحاليل لتشمل عينات أكثر واختبار تأثير درجات حرق مختلفة على جودة المنتج النهائي.

الكلمات المفتاحية: طين يفرن، جبل نفوسة، صناعة الأجر، خصائص فيزيائية، تحليل كيميائي، حيود الأشعة السينية (XRD)، مقاومة الضغط، امتصاص الماء.

Introduction

Clay deposits in Libya are widely distributed, occurring within various geological formations. These clay deposits result from the weathering of mica-rich igneous and metamorphic rocks into fine particles, which are subsequently deposited through marine and continental sedimentation processes. Clay is one of the oldest building materials known to humanity and has been used extensively in construction. This material possesses numerous important properties and advantages. The applications of clay in construction have varied significantly over time, both historically and in modern use. Clay is considered one of the essential materials fulfilling basic human needs. Ancient humans utilized clay for various purposes, including constructing dwellings either as mortar or plaster. Moreover, clay has historically been used as a primary material for making cooking stoves since ancient times.

With the advancement of civilization and the passage of time, the need for improved living standards increased, prompting continuous research and practical experiments to explore diverse applications of clay. It was found that some of these applications, particularly industrial ones, have significant technical and economic value. One of the most important industrial uses of clay is in the manufacture of bricks[1]. Clay bricks represent one of the most widely used types of bricks in building walls, roofs, sloped ceilings, and partitions. This material is characterized by good construction specifications, including high compressive strength, light weight, effective insulation and moisture resistance, and low cost. The suitability of raw materials used in brick production depends largely on the type of clay and its physical and chemical properties.

It has become possible to identify and classify clay minerals through chemical analyses and X-ray diffraction (XRD). Clay primarily consists of hydrated aluminosilicates and contains impurities such as iron oxide, calcium oxide, magnesium oxide, alkalis, and some organic materials. Clay raw materials are widely available in large quantities globally, especially in Libya. The construction method requires no advanced technology, and production costs are relatively low compared to other building materials. Clay bricks can be molded into various sizes and shapes and are compatible with all types of binders. Despite the abundant presence of clay raw materials in Libya, they remain underutilized. Therefore, several studies have been conducted in the Nafusa Mountain region to assess their suitability for brick manufacturing.

Methodology

1. **Literature Review:** In this phase, theoretical data related to the research was collected through reviewing previous studies and relevant standard specifications. This phase also included consulting various sources from scientific references available in the Mining Engineering Department library and the Industrial Research Library, in addition to using the international information network to expand the knowledge base on the subject.
2. **Field Study:** This step involved collecting samples from the study area in order to perform the necessary tests on them. The site was carefully selected, and samples were collected to ensure good representation of the studied materials.
3. **Laboratory Study of Samples:**The samples were analyzed in the laboratories of Al-Sakhra Geotechnical Consulting Company and the Oil Research Center, where analyses and tests were conducted according to the available capabilities. This phase focused on analyzing the physical, chemical, and mechanical properties of the samples to evaluate their suitability for the specific purposes of the research.

Objective of Study

This study aims to focus on the clays of Yafran in the Nafusa Mountain region and analyze their suitability for brick manufacturing.

Location of Study

The Yafran area is located on the summit of Nafusa Mountain, about 120 kilometers west of Tripoli city, between the longitudes (12°29'36", 12°30'16.85" East) and the latitudes (32°03'27.85", 32°02'52.83" North) [2].

Figure 1: Location of the Study Area.

Literature Review

1. A study by Halal, Tareq, and Hatham (2019) examined the quality of three types of clay (red, green, and yellow) used in building materials in Libya. The study found that red and green clays are suitable for brick production due to their good cohesion and durability, while yellow clay was deemed unsuitable. The study highlights the importance of selecting the appropriate clay type to improve brick quality[3].
2. Ben Taher et al. (2022) conducted a study on the physical and mechanical properties of clay in the regions of Nalut, Zintan, and Khoms. The research focused on evaluating the suitability of local clay for the production of fired bricks. The results emphasized the differences in behavior between clay samples from various locations and their potential in construction applications [4].
3. Rekhibi (2024) examined kaolin clay deposits in southwest Libya and assessed their potential for producing low-alumina refractory bricks. The study confirmed the industrial significance of kaolin as a local alternative raw material for thermal insulation products used in high-temperature environments [5].

These previous studies contribute to the understanding of raw clay materials in Libya and support the exploration of their broader applications in the construction and refractory materials industry.

Geology of the Study Area

The study area lies within several geological formations, including:

1. **Aziziya Formation**: This formation primarily consists of gray dolomitic limestone with thin intercalations of marl and clay, as well as lenses and nodules of chert. In its upper part, fine phosphate interlayers overlie sandstone beds, particularly observed in the Gharyan and Hazmats domes. The age of this formation dates back to the Middle to Upper Triassic period [2].
2. **Abu Sheiba Formation**: Exposed in Wadi Abu Sheiba north of Gharyan, this formation comprises continental sands and clayey sediments. It also contains irregularly distributed layers of fine conglomerates. The sandstone beds within this sequence include quartz grains [2].
3. **Abu Ghilan Formation**: Characterized by marly limestone with a light gray to light yellow color. It features distinct wave patterns and rock fracturing [2].
4. **Kikla Formation**:This formation lies unconformably above the Abu Ghilan rocks and extends westward to the Tunisian border. It is composed of three members: Khashm Al-Zarzur, Shakshuk, and Rajban. The formation consists of poorly sorted coarse quartz sandstone, along with conglomerates and intercalations of clay and limestone [2].
5. **Sidi Al-Said Formation**: It comprises two members. The lower member, Ain Tabib, consists mainly of thick, hard beds of dolomite and dolomitic limestone. The upper member, known as Yafran, consists mainly of marly limestone with minor gypsum layers [2].
6. **Nalut Formation**:Located above the Sidi Al-Said Formation (Yafran Member) with a transitional surface. It is composed of dolomitic and dolomitized limestone, yellow to occasionally gray in color[2].
7. **Qasr Taghrna Formation**: One of the youngest geological formations observed in the study area, it consists of fossiliferous limestone and forms a transitional surface separating the Taghrna Formation from the Nalut Formation. [2]

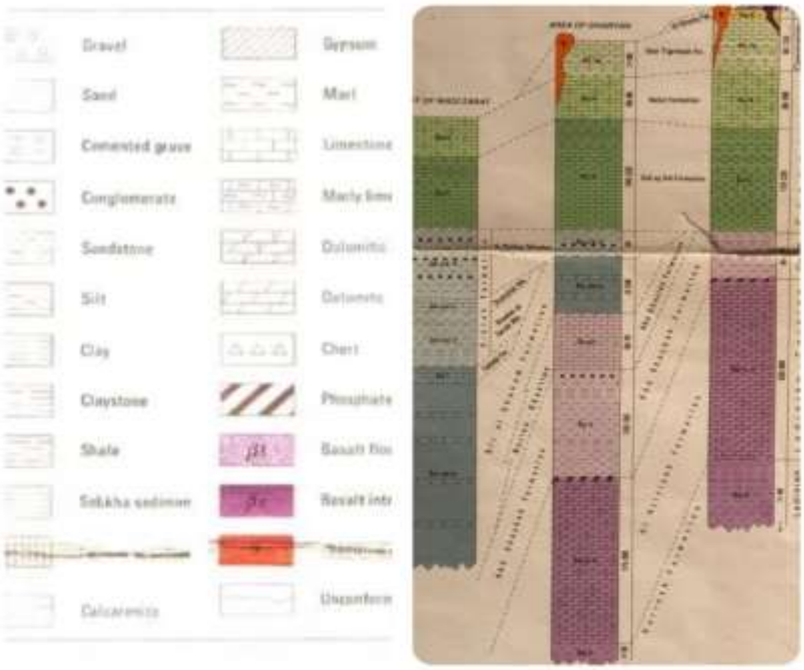

Figure 2*:* stratigraphic column of the study area.

Technical Properties of Brick

Bricks possess excellent structural properties: they are highly resistant to compression, lightweight, and provide effective insulation against heat, moisture, and sound. Additionally, they are cost-effective and aesthetically pleasing in terms of shape and color.

The bulk density of bricks ranges between 1,200 and 1,500 kg/m³ for perforated or hollow bricks, and around 1,800 kg/m³ for solid bricks. The compressive strength of standard bricks spans from 50 to 300 kg/cm², while specialized bricks manufactured using advanced techniques can reach up to 1,000 kg/cm². Bricks exhibit high strength in compression but are weak under tensile forces; hence, they are typically used in building elements subjected to compressive loads.

Thermal conductivity of bricks varies depending on their bulk density and the volume of voids, holes, and pores. The thermal conductivity coefficient falls between 0.5 and 0.7 kcal/m²·°C·hr, making bricks effective thermal insulators that contribute to comfortable interior environments in buildings. Water absorption of bricks should not be less than 8%. Bricks used for exterior facing must be resistant to weather variations and exhibit low moisture absorption to prevent cracking due to frost and other environmental factors[6].

Physical and Chemical Properties of Materials Used in Brick Making:

The suitability of materials for brick production depends on the type and natural and chemical properties of the clay. These properties can be summarized as follows:

1. Physical Properties:

a. Plasticity: This characteristic enables the clay to be shaped into bricks and retain its form for mold-making. For brick production, the clay must have intrinsic plasticity or be provided this property by adding water or blending two types of clay to achieve the desired plasticity.

b. Shrinkage: All types of clay exhibit shrinkage, and its extent varies widely depending on the clay properties and its moisture content. Excessive shrinkage causes cracking; hence, lower shrinkage is preferred. Clay shrinkage during brickmaking comprises drying shrinkage (2–8%) plus firing shrinkage (2.5–10%). The overall shrinkage depends on the clay's moisture content and firing temperature. What matters most is the **uniformity** of shrinkage, not just its total value.

c. Tensile Strength: This refers to the material's ability to maintain its shape under load, especially when dry, post-shaping. Tensile strength is crucial during brick transport and storage. It can be assessed through various tests (e.g., compressive strength, flexural strength...).

d. Fusibility: This property facilitates the gradual melting of clay at elevated temperatures, resulting in properly fired bricks that are hard, cohesive, and less prone to water absorption. Precise control of kiln temperature is essential to achieve complete sintering and partial vitrification, while avoiding viscous melting.

2. Chemical Properties:

These properties significantly influence the final color and melting behavior of the bricks. For instance, variations in iron oxide content can change the brick hue from light red to deep red. Excess iron oxide and lime reduce the clay's melting point compared to typical conditions. For good brick-making clay, chemical analysis should include elements outlined in Table 5.

Results and Discussion

1. Water Content Measurement:

Objective of the Test: To determine the percentage of moisture present in the raw material (clay).

The moisture content (WC) is calculated using the following formula:

$$WC = \frac{W1 - W2}{W1} * 100$$

Table 1: Results of the Moisture Content Test**.**

Region	Color	(g)W1	(g)W2	(%)Wc
Yefren	Red	293.11	158.13	%36.83

Figure 3: Moisture Content Measurement **.**

2. Determination of Specific Gravity

Objective of the test: To determine the specific gravity of the raw material

$$SP.gr = \frac{w - p}{(w1 - w2) + (w - p)}$$

Table 2: Results of the Specific Gravity Test.

Weight of Dry Sample	Weight of Sample + Device Filled with Water	Weight of Device Filled with Water	SP.gr
10.308	150.727	144.398	2.591
10.198	150.665	144.398	2.594
10.211	150.715	144.398	2.662

SP.gr = 2.6

Figure 4: Specific Gravity Test.

3. Determination of Liquid Limit

Objective of the test: To determine the amount of water at which the raw material loses its internal cohesion.

Table 3: Results of the Liquid Limit Test**.**

N	Weight of Empty Container	Weight of Container + Wet Sample	Weight of Container + Dry Sample	Water Content (%)
18	15.014	26.827	21.582	79.856
9	15.034	26.522	21.966	65.724
17	15.729	27.067	22.712	62.365

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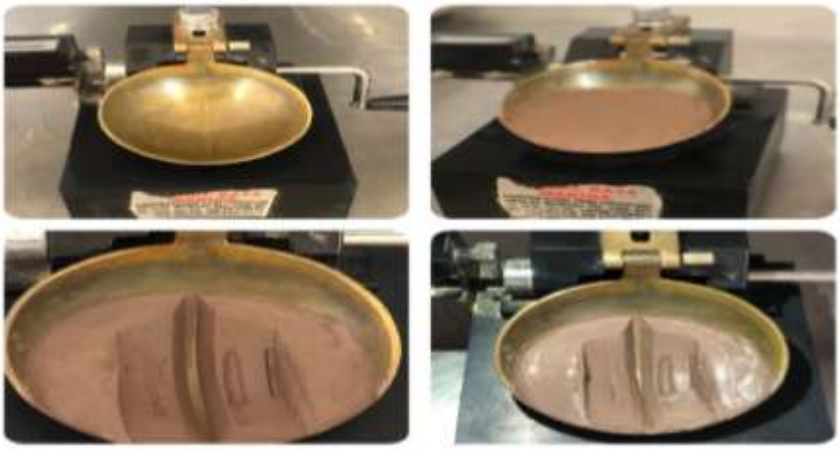

Figure 5: Liquid Limit Test**.**

4. Determination of Plastic Limit: To determine the amount of water that can be added to the raw material to achieve the desired plasticity.

$$Ip = {}_{L}W - {}_{P}W$$

Table 4: Results of the Plastic Limit Test.

Weight of Empty Container	Weight of Container + Wet Sample	Weight of Container + Dry Sample	Water Content (%)
15.832	21.050	19.790	31.83
15.835	20.971	19.754	31.05

Where: Plasticity Index (Lp) = 45%

Figure 6: Plastic Limit Determination Test.

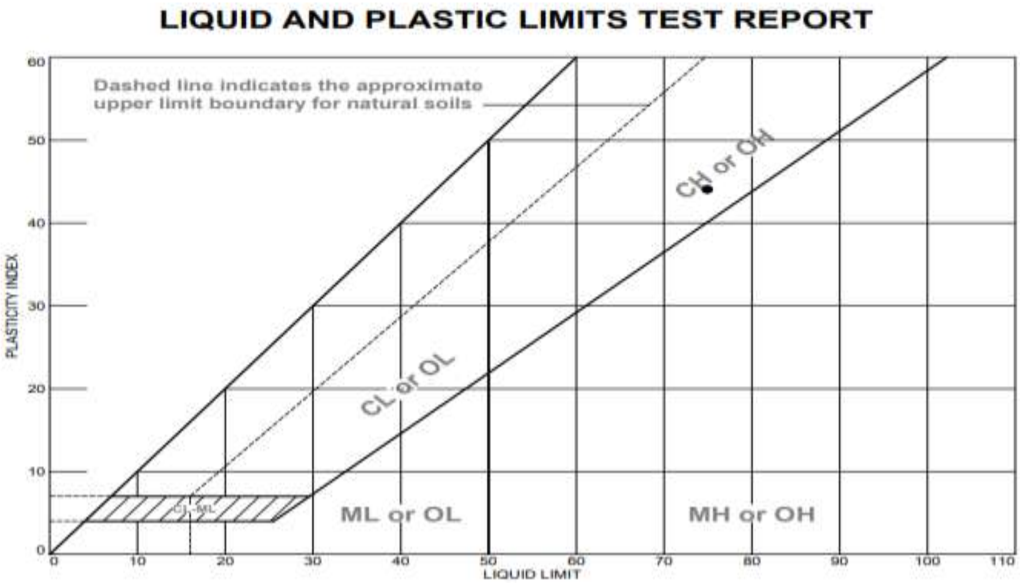

Figure 7: Liquid Limit Chart.

5. Chemical Analysis

Chemical analyses are conducted to determine the percentage of the main components of the raw materials and the proportion of accompanying impurities, due to their importance in defining the properties of the produced bricks.

Table 5: Results of the Chemical Analysis Test.

Chemical Element	Result After Firing	tandard Specifications	Notes
(SiO_2)	70.63	40 - 60 %	
(Al_2O_3)	9.12	10 - 25 %	
(Fe_2O_3)	5.56	4 - 8 %	
(CaO)	3.35	1 - 15 %	Mostly fluxing agents, total > 20%
(MgO)	0.99	1 - 4 %	
(SO_3)	0.58		Very small amounts
(CL)	0.06		
(Na_2O)	0.59		
(K_2O)	2.54		
(L . O .I)	6.3		

Tests Conducted on Bricks After Firing

Figure 8: The Firing Apparatus and the Fired Sample .

Water Absorption Percentage Test for Bricks (Test of Absorption):

Objective of the test: To determine the percentage of water absorption by the bricks.

$$A_b = \frac{W2 - W1}{W2} * 100$$

Table 6: Results of the Water Absorption Test After Firing

W1	W After 30 Minutes of Drying	W2 After 24 hours	W
184.4	162.3	165.2	11.6

Water Absorption Percentage = 11.6%

Compressive Strength Test of Bricks

Objective of the test: To determine the compressive strength of the bricks.

$$p = F / A$$

Figure 9: Compression Test.

Mineral Analysis

This test is conducted to verify the quality of the raw materials and their associated substances using X-ray diffraction (XRD) equipment.

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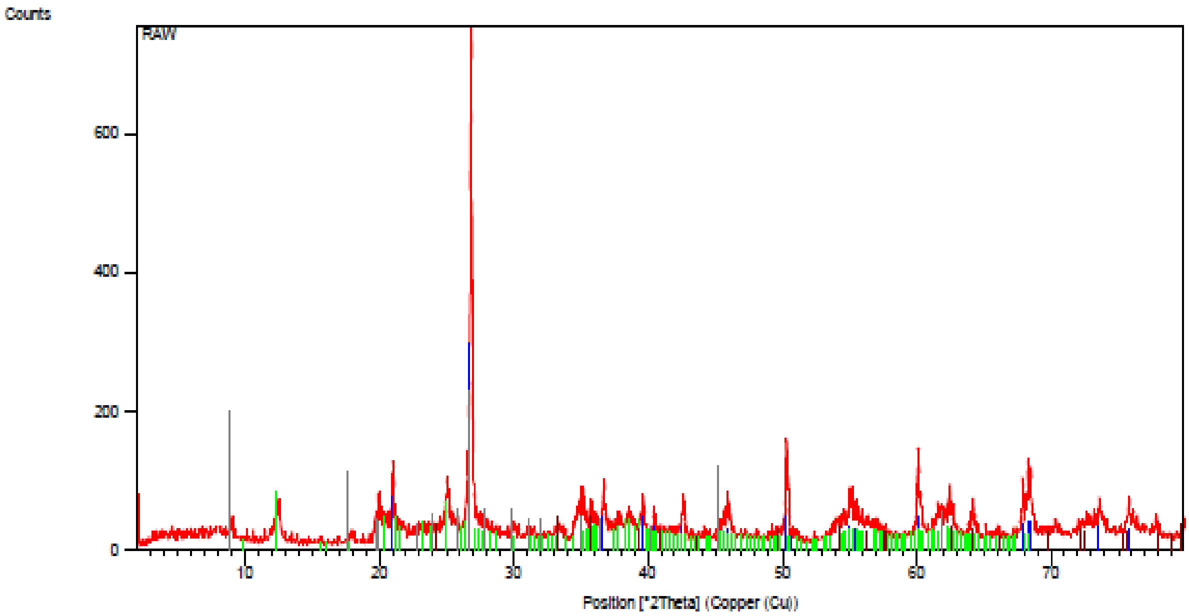

Figure 10: Mineral Analysis of Clay Before Firing

Pattern List & Sime Quantitative of the -1-

Table 7: Clay Minerals Before Firing.

Ref. Code	Compound Name	Mineral Name	Chemical Formula	Semi Quantitative %
01-086-1628	Silicon Oxide	Quartz	2SiO	.5 65
01-080-0886	Aluminum Silicate Hydroxide	Kaolinite	$Al_2(Si_2O_5)(OH)_4$	10.1
00-026-0911	Potassium Aluminum Silicate Hydroxide	illite	$(K,H_3O)\ Al_2Si_3Al\ O_{10}\ (OH)_2O$	3.22
01-089-8103	Iron Oxide	Hematite	Fe_2O_3	7.54

Main Graphics, Analyze View of the -2-

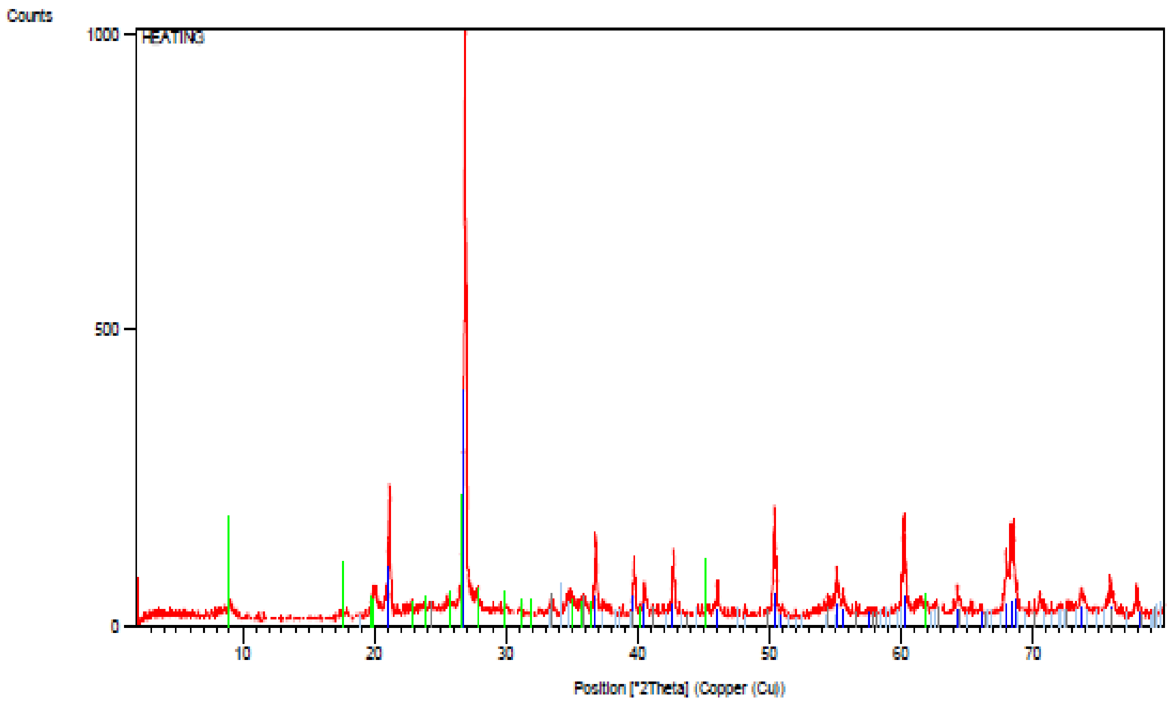

Figure 11: Mineral Analysis of Clay After Firing.

Pattern List & Sime Quantitative of the -2-

Table 8: Clay Minerals After Firing.

Ref. Code	Compound Name	Mineral Name	Chemical Formula	Semi Quantitative %
01-086-1628	Silicon Oxide	Quartz	2SiO	60.4
00-026-0911	Potassium Aluminum Silicate Hydroxid	illite	$(K,H_3O)\ Al_2Si_3Al\ O_{10}\ (OH)_2$	5.46
01-089-8103	Iron Oxide	Hematite	Fe_2O_3	8.5

Conclusions

The results of this study indicate that the clays from the Yefren region in the Nafusa Mountains possess physical, chemical, and mineralogical properties that qualify them as a suitable raw material for brick manufacturing. The chemical composition aligns well with international standard specifications, particularly in terms of silica content, plasticity, and compressive strength.

Despite the relatively high content of iron oxide, it imparts a distinctive and desirable color to the bricks for certain applications. The study recommends conducting further experiments by blending the clay with other types to adjust some thermal and color properties, and testing the clay's behavior under varying firing temperatures to achieve optimal brick quality.

Table 9: Comparison Between the Results of Local Clay and International Specifications for Clay Used in Brick Manufacturing.

Parameter	Local Clay (Study Results)	International Standard	Scientific Interpretation
Silicon Dioxide (SiO_2)	70.63%	50% – 70% (Williams et al., 2019)	The chemical analysis results show that the silica content in the clay is within international standards. Silica is a key component that imparts the desired properties for brick production.
Iron Oxide (Fe_2O_3)	5.56%	2% – 5% (Smith et al., 2018)	The iron oxide content is relatively high compared to the standard. This may result in a dark red brick color and could influence the clay's thermal resistance.
Aluminum Oxide (Al_2O_3)	9.12%	10% – 20% (Brown, 2020)	The alumina content is within the optimal range, enhancing the hardness of the clay and making it suitable for producing strong, balanced bricks.
Calcium Oxide (CaO)	3.35%	2% – 5% (Jain et al., 2017)	The calcium content is within acceptable limits and does not pose a risk to the clay's properties. It may improve clay reactivity with water during production.
Color	Red	Ranges from red to brown (Ali et al., 2019)	The high iron oxide content gives the bricks a darker red hue, which is desirable in certain architectural applications.
Moisture Content	36.83%	20% – 30% (Ghosh, 2020)	The high moisture content indicates the clay contains more water than the standard range. This must be considered during design and manufacturing, as it affects shaping, drying, and strength.
Compressive Strength	9 MPa	10 – 15 MPa (Mohan et al., 2021)	The compressive strength is within acceptable limits, indicating the produced bricks possess sufficient strength and durability.

Summary

The results of this study demonstrate that the clays from the Yefren region in the Nafusa Mountains possess physical and chemical properties that make them a suitable raw material for brick manufacturing. The silicon dioxide (SiO_2) content was found to be approximately **70.63%,** which falls within the recommended standard range of **50%–70%,** enhancing the brick's resistance to environmental factors.

Aluminum oxide (Al_2O_3) was measured at **9.12%,** which is close to the lower limit of the standard range **(10%–20%),** contributing to improved cohesion and plasticity. On the other hand, iron oxide (Fe_2O_3) was recorded at **5.56%,** slightly exceeding the upper limit of the standard **(2%–5%).** This gives the brick a distinctive dark red color, although it may affect its thermal resistance.

Calcium oxide (CaO) was measured at **3.35%,** which lies within the acceptable range (**2%–5%**) and does not pose any negative impact on the clay's behavior.

Regarding the physical properties, the moisture content was found to be **36.83%,** which is higher than the ideal range (**20%–30%**). This indicates the need to adjust forming and drying conditions to avoid cracks and shrinkage.

The compressive strength of the bricks reached **9 MPa**, which is close to the lower limit of the standard **(10–15 MPa),** indicating an acceptable level of strength in the produced bricks.

Based on these findings**, Yefren clay can be considered a promising raw material for brick production**, with potential for improving certain thermal and mechanical properties through blending or adjusting manufacturing conditions to achieve higher product quality.

Recommendations

1. Expand the scope of the study by collecting samples from various locations across the Nafusa Mountains and comparing them with the clays of Yefren.
2. Technical specifications and standard measurements should be strictly followed during all stages of brick manufacturing to ensure a high-quality final product.
3. Achieve a balanced mineral composition; since the iron oxide content in the clay was relatively high, it may be necessary to adjust its proportion to improve the color and thermal resistance of the bricks.
4. Investigate the potential for enhancing the clay properties by blending it with other clays or industrial additives that reduce water absorption and increase mechanical strength.
5. Test the behavior of the clay at different firing temperatures to determine the optimal production conditions

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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