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An Industrial Evaluation and Chemical and Physical Properties of the Clay from the Taq Taq Area in Northern Iraq for some Ceramic Applications

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ABSTRACT

Claystone beds exposed in the Mukdadiyah (Lower Bakhtiyary) and Injana (Upper Fars) Formations at Taq Taq in the Kurdistan Region-North of Iraq will be used in this study for Ceramic Industry. The estimation of qualitative variation of Clay beds is dependent on the chemical, physical, and mechanical properties of the ceramics industry. The claystone is sandy mud composed of 49-58% clay, 22.6 – 31.6% silt, and 10.4-31.4% sand. Linear shrinkage was seen in the Fired claystone specimens between - 0.23 to 4.32 %. bulk density 1.02 – 1.42 gm/cm3, and the efflorescence is varied from nil to Heavy. The main constituents of the investigated clays are SiO_2, CaO, and Al_2O_3 ranging between (39.4 -43.3%,11.6-16.32%, and 8.52-10.17%) respectively. A significant amount of Fe_2O_3 is recorded in the samples, ranging from 4.87 – 6.02%. As per Iraqi Standard Standards No. 25, the claystone of the studied area is an appropriate content for the construction of pierced and conventional bricks in classes B and A for the wall tiles are class B3, Grade 2 and 3 for Roofing tiles.

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تقييم صناعي وخصائص الفيزيوكيميائية للطين من منطقة طاق طاق في شمال العراق لبعض تطبيقات السيراميك

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الملخص

سيتم استخدام طبقات الحجر الطيني المكشوفة في تكوينات المقدادية (بختياري السفلي) وإنجانا (فارس العليا) في طق طق في إقليم كردستان في هذه الدراسة (شمال العراق). يجب تقييم جودة الصلصال بناءً على الخصائص الكيميائية والفيزيائية والميكانيكية من أجل تصنيع السيراميك. أحجار الطين عبارة عن طين رملي مكون من 49–58٪ طين، 22.6 – 31.6٪ طمي و10.4–31.4٪ رمل. شوهد انكماش خطي في عينات الحجر الطيني المقتولةبمقدار 0.23– إلى 4.32٪، الكثافة الظاهرية 1.02–1.42 غم / سم^3، ويتنوع التزهر من صفر إلى ثقيل. المكونات الرئيسية للطين التي تم فحصها هي SiO_2 وCaO وAl_2O_3 وتتراوح بين (39.4–43.3٪، 11.6–16.32٪ و 8.52–10.17٪) على التوالي. تم تسجيل كمية كبيرة من Fe2O3 في العينات تتراوح من 4.87–6.02٪. وفقًا للمواصفة القياسية العراقية رقم 25، تعتبر الأحجار الطينية في المنطقة المدروسة محتوى مناسبًا لبناء الطوب التقليدي المثقوب في الصنفين B وA، لبلاط الجدران من الفئة B3، والدرجة 2 و3 للقرميد.

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Introduction

Clay is the primary raw material used in the production of a wide range of ceramic products, including bricks, tiles, abrasives, pottery, porcelain refractory, and so on. The chemical and physical qualities of the clays employed in the samples do not have the same results. However, which is one aspect they should all have in similar. The availability of a deposit may be just as important in a particular region as its ability to satisfy physical and chemical requirements. According to Fakolujo et al. (2012), deposits considered for use in ceramic goods face few constraints. The clay's ability to form is probably the most crucial feature. The characteristics that comprise the majority of structural clay raw materials substances are listed below in decreasing order of significance. 1-Plastic that can be molded 2- Excessive cracking and warping are avoided by drying. 3- The vitrification range is short and broad. 4- barely little carbonate 5- a variation in particle diameter 6- contain ingredients other than clay (Mirza and Faraj, 2017), It is ideal to have a small and broad vitrification limit. For two reasons, a low carbonate concentration is preferred: Carbonates' fluxing activity often reduces the effective firing variety or produces isolated flux spots, for starters. Second, Cao and MgO produced by firing typical carbonate-bearing clays will hydrate quickly, causing damage to the burnt product. A clay with such a wide variety of grain diameters often supports a better texture and also has a broader variety of vitrification than just a narrow variety of grain diameters. If the burnt color is a factor in the salability of the goods, high iron oxides in the clay are dangerous. Contact brick and, to a smaller extent, face tiles (Mohsen and Elmaghraby, 2010). Brickmaking clays must have a Minimal overall linear shrinkage after curing and combustion, as well as low susceptibility to dryness Smectite clays, are saturated with divalent cations, which results in the ejection of intermediate water and a decrease in smectite expansion. As a result, linear shrinkage and drying sensitivity will be reduced, and ceramic characteristics will be enhanced. The majority of the clays from the chosen sites were found to be acceptable for making various types of tiles and construction bricks. Surdashy and Aqrawi, (2021) In Bestana Village, Erbil City, examined the Quaternary sediments as well as the formations of the Injana, Mukdadiyah, and Bai Hassan. the evaluation of geochemistry and mineralogical information tested specimens' plasticity index indicated that they were between somewhat and completely plastic. The primary ingredients in the mud are silicate and aluminum, the latter of which serves as refractory elements during the procedure. according to the geochemical analysis of the samples. which was determined as a proven reserve (Surdashy and Aqrawi, 2021). The researchers decided that injana claystone is useful for such applications in the center of Iraq, Awad and Awadh (2021) and Awad and Awadh (2021) built both pierced and regular brickwork utilizing injana mudstone. Najim and Yousif (2021) utilized XRD to measure the optimal mixture for preparing cordierite ceramics for Commercial Ceramics (Cordierite) Production in the West Sahara Using Iraqi Basic Sources and Solid-State Densification.

The main objectives of this study are to find out the validity of the Injana and Mukdadiyah deposits for the ceramic industries, through the evaluation of the potential uses of their clays in some ceramic industries using mineralogical and physiochemical properties.

Geological Setting of the studied Area

The Taq Taq is located 60 Km NE of Kirkuk, 80 km SE of Hawler, and 120 Km NW of Sulaymaniyah in Iraq's Kurdistan Region located in X: 462067, Y: 3972850. Geologically According to Jassim and Goff (2006), It is tectonically situated in the northeaster foothill region's Butmah-Chemchemal Subzone, with such a tendency that runs alongside the Zagros provincial regions of Kirkuk, Bai Hassan, Khabaz, and Chamchamal (Fig.1). A distinct dual plunging, asymmetric anticline formation may be found in Taq Taq Field. The structure's 11 kilometers wide by 27-kilometer-long surface manifestation has a broad NW-SE axis. Strata that are highly vulnerable and have an overall elevation of about 600 m, which superior comprehension of the underlying geological structure and lithologic variations of the projecting rocks, are a positive element of the geography. The structure can easily be discerned (Jassim et al., 1984). The following formations are part of the research are

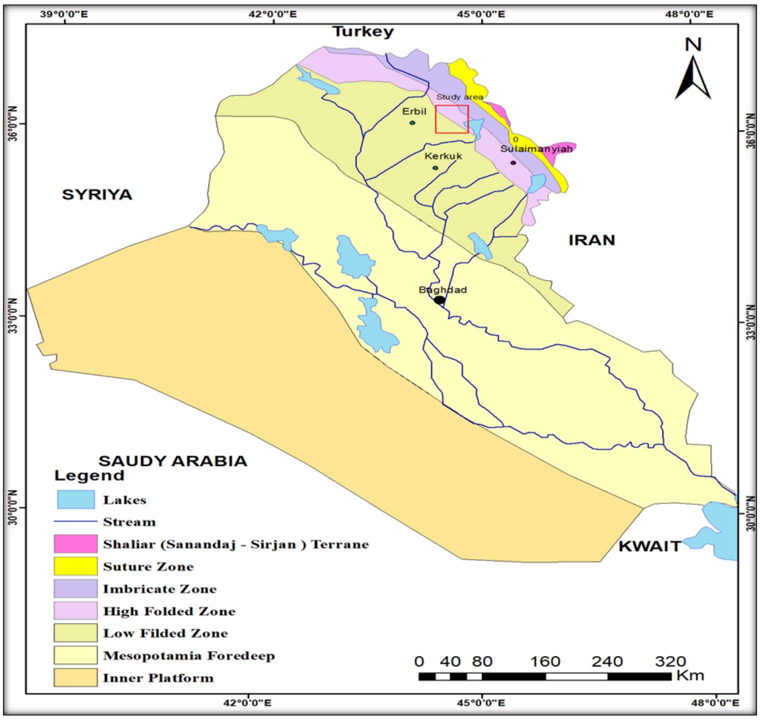

Fig.1.Tectonic Map of Iraq (Modified after Fouad, 2008)

Injana Formation:

The Injana (Upper Fars) Formation is made up of fine-grained sediments that were initially formed in coastal regions and subsequently in a fluviolacustrine environment. (Which includes the Middle Fars). it was dubbed the Injana Formation (Jassim et al., 1984). The study section was measured. It has a thickness of 620 meters. Reddish and greenish mudstones, a thin (20 cm thick) gypsum layer, a purple siltstone horizon containing glass shards, and narrow calcareous sandstone make up the base layer. (Fig. 2).

Mikdadiyah and Bai Hasan Formations:

The Injana Formation is composed of fine-grained deposits that were initially formed in coastal regions and subsequently in a fluviolacustrine Environment. While in Iraq, it was dubbed the Injana Formation (Jassim et al., 1984). the studied section is measured. It has a thickness of 620 meters. The basal unit consists of red and green mudstones and a purple siltstone horizon with glass fragments, as well as thin-bedded calcareous sandstone.

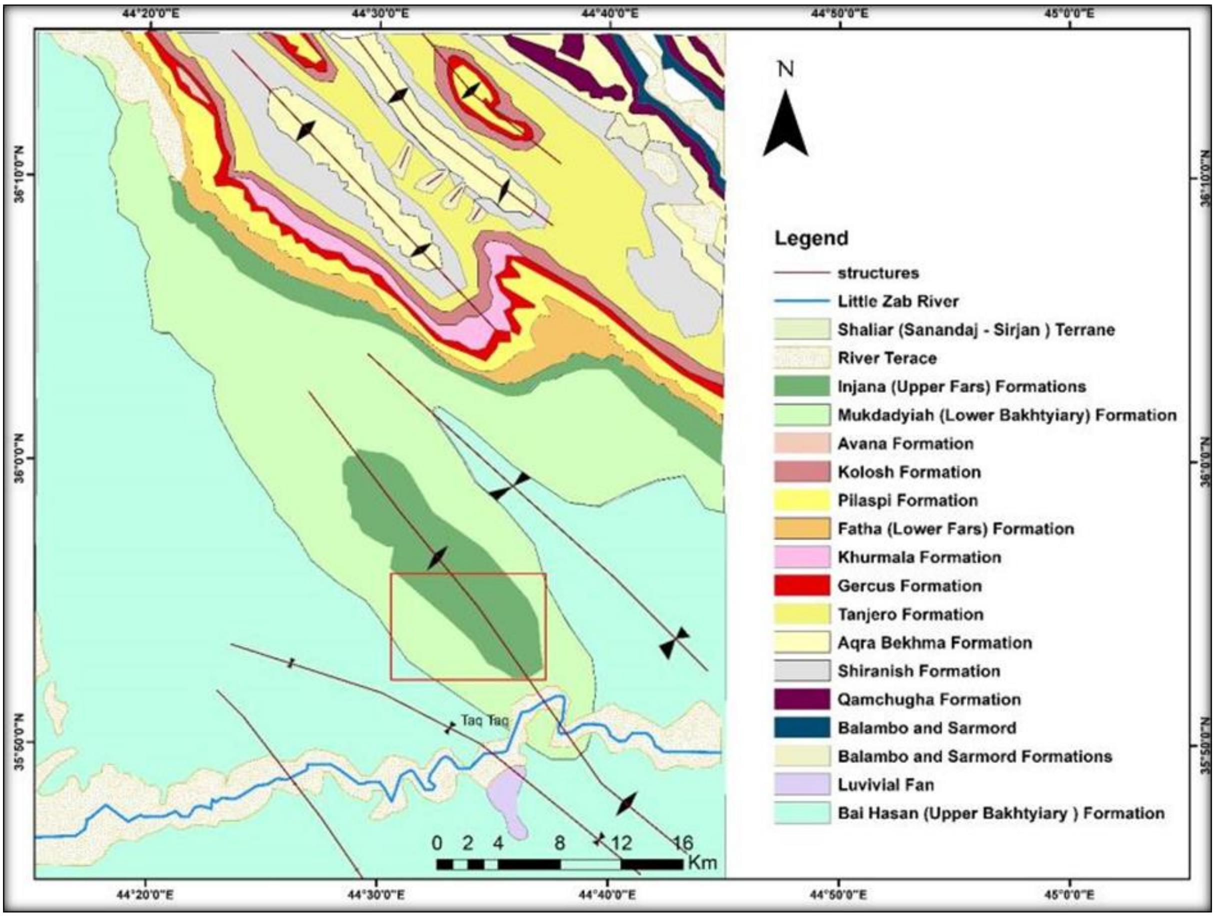

Fig.2.Geologic Maps of the Researched Area (Modified after Sissakian, 2001)

Materials and Methods

Five clay samples were chosen for the study of the ceramic forming method of F1, F2, and F3 samples from the Injana Formation, and B1 and B2 samples from the Mukdadiyah Formation. The specimens then were crushed into mud particles, and for greater homogenization, they were subsequently soaked with eight to thirteen percent of water based on the (DSI) dry sensitivity index. The material was blended by pushing it through sieves with 2 mm apertures, and for improved uniformity of the humidity in the specimen, the specimen was retained within nylon sacks and maintained in the refrigerator for more than 24 hours. Two distinct kinds of castings were created from the examined materials using the semi-dry method (Najim and Yousif, 2020). For the assessment tests, the color was involved, and a square mold with the measurements of 1×4×8 cm was employed along with 80 grams of weight of the specimen for the first pellet type. (L.Sh.) linear shrinkage, (A. P.) apparent porosity, (W. A.) water absorption, (B. D.) bulk density, (Ef) efflorescence, and (M.O.R.) rupture of modulus (following dried and then after the fire). For the next kind of pellet, 125 grams of every specimen were used, and they were crushed at a rate of 250 kg/cm3to create 12 cylindrical shapes with a height and diameter of 4 cm (Fig. 3), for the assessment of (C. S.) compressive strength employing a uni-axial press technique. Before getting burnt in conventional electrochemical with such a special burning schedule and temperatures (800, 900, 1000, and 1080 °C) that escalated at a speed of 100 °C every hour, compressed specimens were dry in ovens at 105 °C for 24 hours. The University of Salahaddin's College of Science-Department of Earth Sciences and Petroleum conducted the dryness and fire procedures.

Performed Experiments:

The basic components in this study underwent a variety of physical testing, including:

1- the amount of sand, silt, and clay in a particular specimen is represented by grain size analysis; both (Sieve and Hydrometer) at Salahaddin's College of Science-Department of Earth Sciences and Petroleum. according to British standards (BS1377, 1967).

2-In KANSARAN DENA, Asfahan, Iran, chemistry analyses were performed on all specimens using X-Ray Fluorescence (XRF) and (Loss on Ignition) (L.O.I). After firing to 1000 °C, L.O.I is determined in the same Lab.

Several experiments were conducted on the porcelain briquettes under study including:

1- Color determined by Munsell Color Chart.

2- linear firing shrinkage according to (ASTM, 1982).

3- visible porosity, specimen's surface porosity is the amount of exposed permeability divided by the sample's total external area, represented as a percentage.

4- Water content, which depends on particle sizes, particle dispersion, molding technique, and press force, indicates the proportion of water absorbed by the ceramic's pores (Kingery, 1967).

5- bulk density is the proportion of sample mass to overall volume is known as bulk density (ASTM, 1986).

6-The rupture modulus the modulus of rupture is a measure of the tensile stresses that can withstand before rupturing (MOR).

formula:

MOR=(3*L*f)/ (2*b*h2)

MOR is the Modulus of Rupture (kg/cm^2) in this case. L is the separation of two lower rollers (cm) F is the force exerted on the test specimens (kg) the specimen width is b. (cm) the sample height, where h (cm)

7- compressive strength as measured by (ASTM, 1969). A cylinder sample's compressive strength is just the highest strain or loads this can endure while being evaluated for toughness using an axially directed pressure. For the compressive strength test, cylinder bricks 4 cm tall and wide were formed of each of the samples analyzed and burnt at temperatures of 800, 900, 1000, and 1080 °C. The compressive strength was estimated using the formula below:

S=W/A

S is compressive strength (kg/cm2) in this case. W = collapse-related pressure value (kg) A is the pottery specimen's transverse area in cm2.

8- Efflorescence When contaminated water passes through mudstones and produces a white or gray granule just on the ceramics surface of the material, this is known as (Kingery, 1967). According to I.C.O.S.Q.C. number 25

9- Ceramics' chemical resistance relates to their skill to tolerate the harmful impact of aggregate media brick made of 800˚C, 900˚C, 1000˚C and 1080˚C immersed in Hydrochloric acid (HCl) (3 percent and 18 percent) and Potassium hydroxide (KOH) (30 g/l and 100 g/l) for two weeks. This was done by semi-dry compressing it at a force of 250 kg/cm2. The reduced weight had been determined once the alterations had been seen.

Results and Discussion

Grain-size Analysis

Grain size analysis represents the percentage of sand, silt, and clay in a given sample, it is known that finer particle size of clay means greater plasticity and greater capability reaction (Rayn, 1978).

The findings of particle size analyses of the Five raw materials presence primarily consisted of a small amount of sand mixed with clay and silt. (Tables 1 and 2).

There are minor discrepancies between the two approaches, with the clay proportion in the hydrometer method being larger than the pipette method which has a maximum of 58 %, a minimum is 42 % at a mean of 50 %, in contrast, the maximum, minimum and mean of sand proportion is 28 %, 10 %, and 19 % respectively. While in the Pipette Method max., min., and mean of clay is 76.8 %,51 %, and 63.74% respectively. In contrast, the sand has 25 % as the maximum, 1029% as a minimum, and a mean of 17.67 % (Tables 1 and 2). The finer particles increase the silica melt which binds these crystals together and then becomes more coherent (Kingery, 1967; Rado, 1969). But higher sand content causes lower plasticity with a small surface area has fewer points of contact that require a high amount of water. These properties of clay affect the ceramic body during drying (green strength) and the firing process (shrinkage after drying, compressive strength, and vitrification) (Rayn, 1978; Khalfaoui and Hajjaji, 2010).

These specimens by using the pipette and hydrometer techniques which are placed on Sandy mud field (Fig.s 2 and 3), F3 in the hydrometer method placed in sandy clay, were plotted using Folk's (1980) categorization triangle. It is common knowledge that mud with smaller sizes has superior plasticity and elasticity (Ryan, 1978), More silicate melts are created with granular materials, that bond the crystalline and together increase their coherence. (Rado, 1969; Kingery, 1967).

Table 1. Analyzing grain size using the hydrometer technique

Samples	Sand %	Silt %	clay %
F1	28.4	27.6	44
F2	15.4	26.6	58
F3	10.4	31.6	58
B1	35.4	22.6	42
B2	26.4	24.6	49
MAX	28.4	31.6	58
MIN	10.4	22.6	42
MEAN	19.4	27.6	50

Table 2. Pipette-based examination of particle size

Samples	Sand %	Silt %	clay %
F1	25	21.82	53.18
F2	22.22	24	53.78
F3	10.29	13.24	76.48
B1	22	27	51
B2	19	27	54
MAX	25	27	76.48
MIN	10.29	13.24	51
MEAN	17.64	20.12	63.74

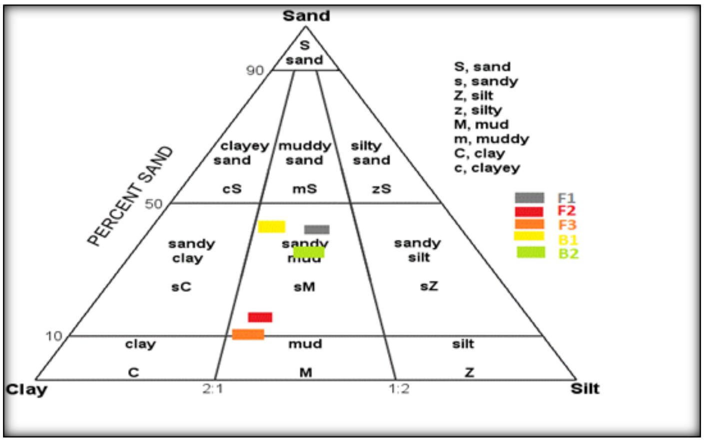

Fig. 3. Grain size analysis by hydrometer method (Folk, 1980)

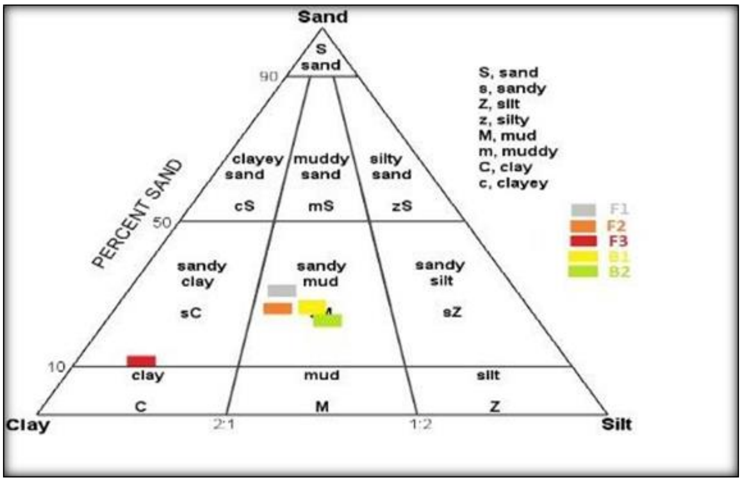

Fig. 4. Grain size analysis by Pipette method (Folk, 1980)

Mineralogical Composition

The clay mineral identification by XRD within all of the studied raw materials is represented by a major proportion of kaolinite and a minor proportion of illite, smectite, and illite-smectite mixed layer with few proportions of chlorite (Fig. 5). Each clay particle has an important influence on the ceramic properties, while in ceramic industries they have appropriate properties which make them suitable for giving plasticity, moldable when wet, hard when dried, and vitrified when fired (Kingery, 1967). Montmorillonite mineral is found as a common mineral in (F1) Injana and (B1) Mukdadyia formation samples (Fig. 5). Illite is found as a less common mineral in both samples. Kaolinite was found as a rare mineral within the B1 sample and mixed layer with chlorite in all two samples. Chlorite is found in rare mineral samples.

In the studied samples, the irregular mixed layer between Mica and Illite was found within all two samples.

Quartz and calcium carbonate minerals are present in the clay samples as common non-clay minerals. Quartz content leads to vitrification and quartz phase transformation causes shrinkage decrease at higher temperatures, which acts as a refractory material. Quartz was found to be of less proportion than calcite in F1 and B1 samples (Fig. 5). Calcite is found as a common mineral in all studied samples, the decomposition of the carbonate minerals during firing will also increase the porosity and decrease the bulk density of the ceramic body. clays will become unsuitable for ceramic industries if the carbonate percentage exceeds 30 % according to Thanoon (2013) exceeds 35% according to Al-Dwaf (1969). In the studied samples, Albite and feldspar were found as minor minerals in the B1 and F1 samples (Fig. 5) Dolomite was also found in both samples.

Fig. 5. The minerals content of samples by XRD

Chemical Composition

Geochemical properties play a significant role in the ceramics industry. Determining the primary oxide fraction of raw materials aids in showing how ceramics bodies behave. after the fire through estimating flux and refractory oxides and also melting point. Additionally, various oxides affect the mechanical and physical characteristics of briquette materials (Shreve and Brink, 1977). In sintered samples, flux produces a restricted and regulated proportion of glasses, that functions to join crystalline elements. Because they minimize the overall melting temperature, fluxes are crucial in the vitrification of clay materials. Flux creates a limited and controlled amount of glass in ceramic bodies, which works to connect crystalline components. Fluxes play a key role in the vitrification of clay bodies by reducing the overall melting point. Common fluxes in clay are; K_2O, Na_2O, CaO, MgO, and Fe_2O_3 (Riley, 1951; Rattanachan and Lorprayoon, 2005; Fakhfakh et al., 2007), if the refractory minerals increased it will increase the melting temperature. Common refractory materials in clay are; Al_2O_3, SiO_2, $MgCO_3$, and Cr_2O_3 (Table 3).

Table 3. X-Ray Fluorenes tests of Samples (%)

Oxides %	F1	F2	F3	B1	B2
SiO_2	39.4	42.34	43.3	39.36	39.8
Al_2O_3	8.52	10.17	9.92	9.51	10.0
BaO	0.03	0.05	0.03	0.03	0.03
CaO	15.55	13.05	11.6	15.4	16.32
Fe_2O_3	4.87	5.83	6.02	5.35	5.22
K_2O	1.2	1.67	1.6	1.56	1.57
MgO	8.5	7.77	8.69	6.9	5.71
MnO	0.11	0.12	0.11	0.11	0.11
Na_2O	0.69	0.72	0.56	0.15	0.14
P_2O_5	0.07	0.07	0.11	0.09	0.09
SO_3	0.15	0.03	0.13	0.16	0.05
TiO_2	0.44	0.51	0.52	0.48	0.52
Sr ppm	0.07	0.02	0.07	0.05	0.03
L.O. I	20.7	17.67	17.33	20.80	20.47

Brick Color

The color of bricks is determined by specific oxides found in the production process for their production, as well as the burning temperature and organic elements. If there is indeed a rise in organic compounds, the mudstones may take on a dark grey to black tint (Worrier, et al., 1989). The specimens of brickwork started from red to yellowish red in Injana Formation. In contrast, in Mukdadiyah Formation begins from red to pale yellow at 800 ºC to 1080 ºC due to the high existence of carbonate calcium and quartz in their composition (Table 4). The light-yellow color of the brick samples is due to decolorization, particularly red and brown, which is what happens when the brickwork is burnt at 950 C. Iron oxide combines with Cao to form a light-yellow color as calcium oxide is broken down from carbonate as a function of combustion. (Worrier, et al., 1989). (Mesrar, et al., 2020) the samples included varying amounts of iron oxides which are brown and red colors at 950 °C the red and brown colors disappeared. Just after brick specimens have indeed been burnt, the color shift is primarily caused by the interaction process during the combustion of the basic constituent materials (Worrier, et al., 1989). (Fig. 6).

Table 4. Clay and briquettes color.

Sample	color of the briquettes before firing	Briquette color after firing			
		800 ºC	900 ºC	1000 ºC	1080 ºC
F1	10R 2.5/2	10R 5/6	10R 4/4	5YR 4/6	7.5YR 5/6
F2	10R 3/3	10R 5/8	10R 5/8	10R 5/6	7.5YR 4/6
F3	10R 3/4	10R 5/8	10R 5/8	10R 5/6	7.5YR 4/6
B1	10R 4/2	10R 5/6	5YR 4/4	5YR 6/6	2.5Y 8/4
B2	10R 4/3	10R 5/6	5YR 4/5	5YR 6/6	2.5Y 8/3

Fig. 6.the Fig. Shows Color Variation with Fired temperature

Water absorption, apparent porosity, and bulk density

When clay Ceramics burned at 800, 900, 1000, and 1080˚C apparent porosity study samples varied from 15.8 to 41.3 percent. Fig. 5 depicts the link between perceived porosity and rising fire temperatures. Findings of experiments on clay briquettes burnt at 800, 900, 1000, and 1080 C ranged from 13.66 to 24.7 percent in terms of water absorption. The results of water absorption were indeed shown to be inversely correlated with perceived porosity. This may be because, particularly in wide porosity situations, while perceived porosity increases, more room for water to be retained in such pores has become accessible. Fig. 7 depicts the connection between water absorption and increased firing temperatures. Findings from the bulk density test on clay briquettes burned at 800, 900, 1000, and 1080 °C ranged from 1.02 to 1.41 %. Fig. 6 depicts the association between increasing firing temperatures and bulk densities. Calcite breakdown which occurs at burning temperatures between 800 and 950°C causes the creation of pores in the ceramic body to open up and release CO_2 gas, increasing apparent porosity (%) and water absorption (%) as well as its influence reducing bulk density(gm/cm^3). At 1000 and 1080 degrees Celsius. even so, the apparent porosity and water absorption would then decline as a result of the raw particle's vitrification system, which appears to replenish pores by molten silica and quartz phase transition, while bulk density increases. Nevertheless, as innovative minerals tend to build these pores might very well shrink, and the composition of grain sizes and their distribution undouble affecting the results. (Kingery, 1967). Because the porosity increases when the calcium carbonate decomposes during firing, the apparent porosity is influenced by the concentration of organic material, calcium carbonate, and quartz phase transition (Al-Kattan, 1991). A brick's compressive strength, water absorption, and permeability are all impacted by the apparent porosity of the brick since rising apparent porosity reduces compressive strength (Table 5), (Fig. 7 and 8) (Bain, 1986).

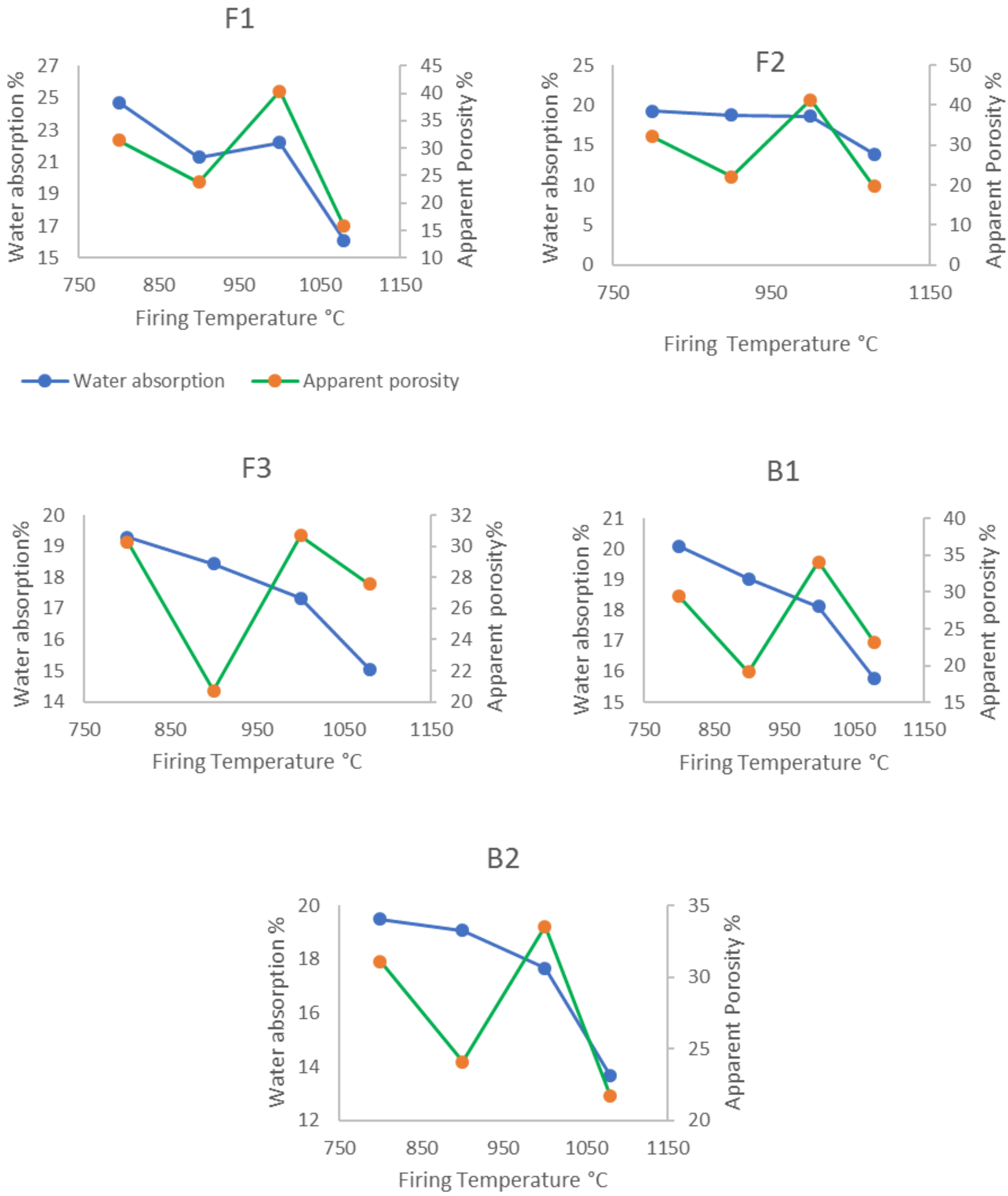

Fig. 7. The illustration exhibits correlation between apparent porosity and Water absorption

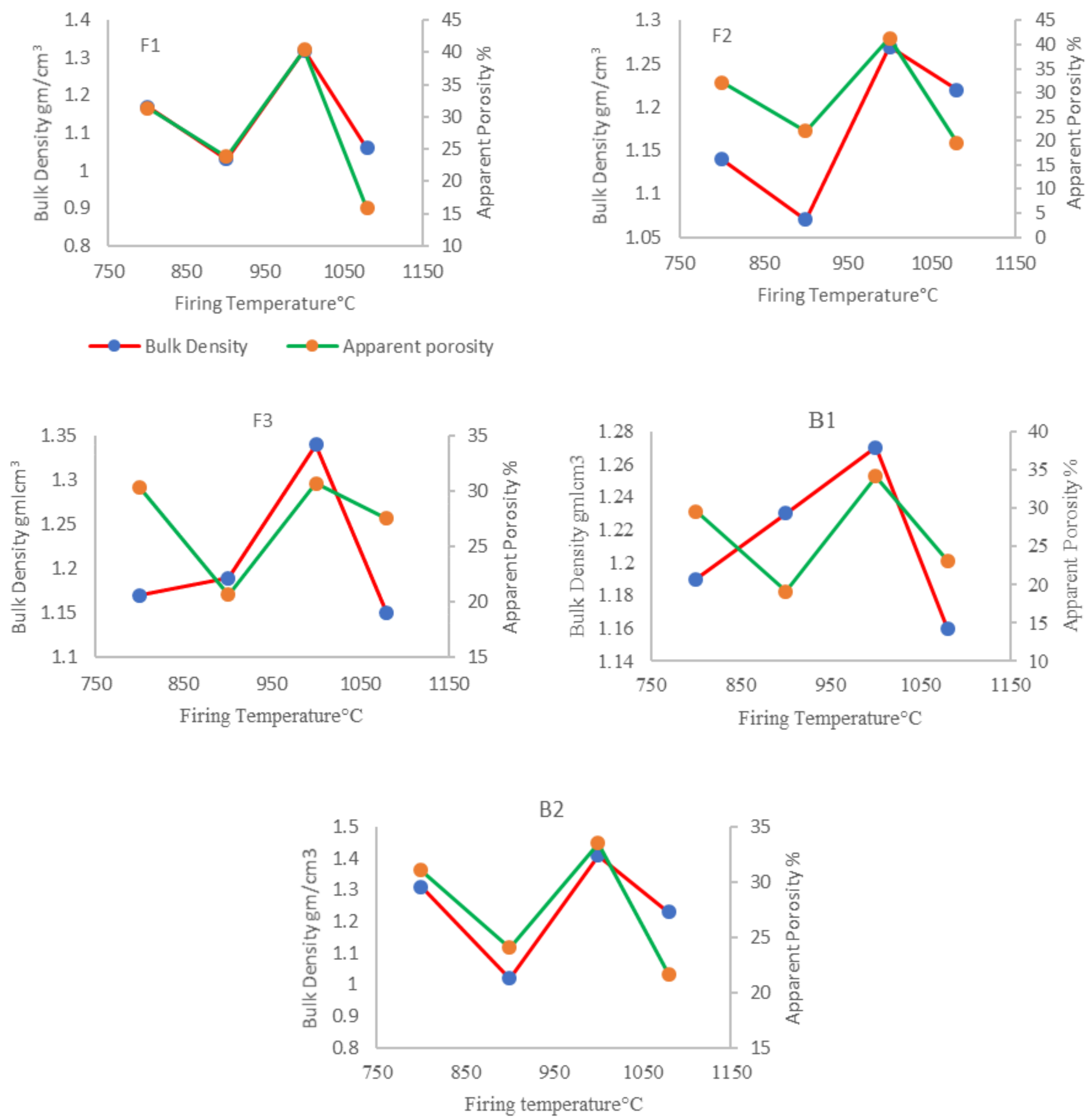

Fig. 8. The illustration exhibits a correlation between apparent porosity and Bulk density

Efflorescence (Ef)

Brick efflorescence is caused by soluble salts in the bricks. Iraqi Standard Specification No. 25 was used to conduct the Ef test (ISS, 1993). The usage of rock salt about produces deformation of the outside view of construction materials, which is the most prevalent source of efflorescence. The Ef, which is regarded as modest, was found in a rather limited region of the brick surface (less than 10%). The Ef test result for brick manufacturing under classifications A and B according to the Iraqi Specification (1993) is low and moderate which is acceptable accordingly. (Table 5). the abundant samples are nil and only at the 800 ˚C of F1 is Heavy That's because of existing of salt minerals (Fig. 9).

Fig. 9. The effect of efflorescence on the fired Bricks

Table 5. Apparent porosity %, water absorption %, bulk density/cm3, and efflorescence after firing

Sample	Properties	Firing Temperature °C			
		800	900	1000	1080
F1	apparent porosity %	31.4	23.8	40.4	15.8
	water absorption %	24.7	21.3	22.2	16.1
	Bulk density gm./cm³	1.17	1.03	1.32	1.06
	Efflorescence	Heavy	Slight	Nil	Nil
F2	apparent porosity %	32.1	22.1	41.3	19.6
	water absorption %	19.2	18.7	18.58	13.84
	Bulk density gm./cm³	1.14	1.07	1.27	1.22
	Efflorescence	Nil	Nil	Slight	Slight
F3	apparent porosity %	30.3	20.7	30.7	27.56
	water absorption %	19.3	18.4	17.34	15.05
	Bulk density gm./cm³	1.17	1.19	1.34	1.15
	Efflorescence	Slight	Slight	Nil	Nil
B1	apparent porosity %	29.5	19.1	34.1	23.1
	water absorption %	20.1	19.1	18.13	15.76
	Bulk density gm./cm³	1.19	1.23	1.27	1.16
	Efflorescence	Slight	Slight	Moderate	Nil
B2	apparent porosity %	31.1	24.1	33.53	21.7
	water absorption %	19.5	19.08	17.66	13.66
	Bulk density gm./cm³	1.31	1.02	1.41	1.23
	efflorescence	Slight	Slight	Nil	Nil

Chemical Resistant Test

Chemical sensitivity testing was done on specimens from the Mukdadiyah Formation B1 and B2 and the Injana Formation's F1, F2, and F3 formations. As per the findings of the chemical resistant experiment, the losing weight in the examined ceramic body burned at 800 ˚C, 900 ˚C, 1000 ˚C, and 1080 ˚C ranging from zero to 7.4 percent at 18% of HCL and shows more resistance when the firing temperature is increased. In contrast, 3% of HCL shows less dissolution which a median of 1.76 % at 800 ˚C to 0.005 % at 1018 ˚C.in general dissolution is low as in KOH in both 30 g/l and 100 g/l concentrations as shown in (Table 6). This is because carbonate material is present but does not completely dissolve at lower fire temperatures (800˚C and 900˚C). Because carbonate mineral is present and cannot be completely disintegrated by fire at cooler temperatures, these briquettes are affected by HCl solution (800˚C and 900˚C). In comparison to utilizing HCl 3% percent, weight loss by using HCl is 18% percent. As a result, the samples, particularly briquettes at 800 ˚C and 900 ˚C and where HCl 18% percent was employed, showed some degradation and roughness on their surfaces. (Fig. 7) Briquette specimens from Mukdadiya and Injana Formations have a strong resistance when burned at degrees of 1080 °C and beyond, as per ISO 10545-part 13.

Table 6. ISO 10545-part 13 chemical resistant examination for burnt bricks

Samples	Properties	Firing Temperature ºC			
		800	900	1000	1080
F1	HCl (3%)	3.5	2.1	1.8	0.01
	HCl (18%)	7.4	6.3	5.2	0.78
	KOH (30 g/l)	0.01	0.02	0	0
	KOH (100 g/l)	0.03	0.01	0	0
F2	HCl (3%)	0.36	0.22	0.18	0
	HCl (18%)	3.9	3.88	1.81	0
	KOH (30 g/l)	0.03	0.01	0	0
	KOH (100 g/l)	0.04	0.01	0	0
F3	HCl (3%)	0.02	0.2	0.12	0
	HCl (18%)	3.81	3.701	0.2	0
	KOH (30 g/l)	0.02	0.02	0	0
	KOH (100 g/l)	0.05	0.03	0	0
B1	HCl (3%)	0.25	0.15	0.08	0
	HCl (18%)	3.99	2.1	0.4	0
	KOH (30 g/l)	0.01	0	0	0
	KOH (100 g/l)	0.01	0	0	0
B2	HCl (3%)	0.16	0.41	0.21	0
	HCl (18%)	6.14	4.51	0.91	0
	KOH (30 g/l)	0.01	0	0	0
	KOH (100 g/l)	0.06	0.03	0	0
HCl (3%)	MAX	3.5	2.1	1.8	0.01
	MIN	0.02	0.15	0.08	0
	MEN	1.76	1.125	0.94	0.005
HCl (18%)	MAX	7.4	6.3	5.2	0.78
	MIN	3.18	2.1	0.4	0
	MEN	5.25	4.2	2.8	0.3
KOH (30 g/l)	MAX	0.03	0.02	0	0
	MIN	0.01	0	0	0
	MEN	0.02	0.01	0	0
KOH (100 g/l)	MAX	0.06	0.03	0	0
	MIN	0.01	0	0	0
	MEN	0.035	0.02	0	0

Compressive Strength

Results about the compressive strength of clay briquettes burned at 800, 900, 1000, and 1080 degrees Celsius vary from min. 198.1 to the max. 732.31 kg/cm^2 as median 322.65 kg/cm^2 at 800 ˚C, 296.33 kg/cm^2 at 900 ˚C, 317.8 kg/cm^2 at 1000 ˚C, 498.15 kg/cm^2 at 1080˚C.

(Table 8). The compressive strength measurements steadily rose at firing temperatures between 800- and 1080 degrees C. Boch and Leriche (2007) claim that the cohesion between basic particles brought on by glass liquid produced during smelting and vitrification processes at 1080oC is the reason for the improvement in compressive strength. According to the probability that such a carbonate is greatly influenced by temperature-caused crystallization, the F2 and F3 samples have significant percentages of silica (quartz) and fine carbonate grains, and the two will have relatively higher density concerning their apparent porosity (Table 5), Since their bulk densities (gm/cm3) are lower and their silica content is lower than that of F2 and F2 and F3 samples, they have higher compressive strengths(kg/cm2) than B2 specimen.

Modulus of Rupture

While burned at 800 ˚C, 900 ˚C, 1000 ˚C, and 1080 ˚C, the clay briquettes under investigation have a modulus of rupture that varies from 67.87 to 227.42 kg/cm2 a median 123.98 kg/cm2 at 800 ˚C, 123.74 kg/cm2 at 900 ˚C, 143.69 kg/cm2 at 1000 ˚C, 170.04 kg/cm2 at 1080˚C. (Table 8). Similar to compressive strength, the cause of it is explained either by the application of pressure or during the molding process using the semi-dry pressing process and cohesion in-between basic - materials particles produced by hardening and vitrification, particularly at 1080˚C. The analyzed samples' mineral content, apparent porosity (%), bulk density (gm/cm$^{3)}$, and water absorption (%) all play a part.

Linear Shrinkage

Linear shrinkage was utilized to gauge the strength and caliber of the brickwork by comparing their measurements before and after burning (ASTM C 326-09, 2009). The linear shrinkage was discovered to range from -0.23 to 4.32 % (Table 7). Rashed (2017) discovered that as the calcium carbonate concentration of the clay lowers, linear shrinkage increases and reduces. Because it reduces linear shrinkage, Increasing the number of silica particles is essential for reducing the shrinkage that occurs after the fire (Merza and Faraj, 2017). The tiny ratings of the linear shrinkage allow the samples to be used in the manufacturing of ceramics which are F1, F2, and F3.and case of increasing the length in F1 which is signed as a minus is due to changing of minerals, increasing pores by CO_2 and/or by vitrification of quartz (Fig. 10 and 11). Shrinkage of the ceramic substance happens once some granules dissolve, causing grain consolidation. The quantity of the liquefy stage relies on the quantity of the pollutant that behaves as a flux. It is defined as the variations in linear shrinkage that already have taken place in experiments pieces at varying degrees of temperature, from which responses would then happen here between individual components of the body, establishing new mineral deposits that are variable in size and form from the reacted mineral deposits (Aqrawi, 2000). Shrinkage percentages are higher in fine-grained materials with higher clay content than in coarse-grained materials. (Oloruntola et al., 2010).

Table 7. Table show Linear Shrinkage.%

Samples	Firing temperatures ºC			
	800	900	1000	1080
F1	0.63	-0.012	-0.23	-0.062
F2	1.04	1.43	1.453	2.3
F3	0.91	1.53	2.073	3.65
B1	3.36	2.73	3.084	4.32
B2	2.16	2.15	2.811	4.32

Table 8. Modulus of rupture and Compressive Strength of fired bricks

Sample	**Properties**	**Firing Temperature** ºC			
		800	900	1000 º	1080
F1	Compressive strength Kg/cm²	224	198.9	211	245.99
	Modulus of rupture Kg/cm²	75.579	67.87	99.14	112.66
F2	Compressive strength Kg/cm²	276.84	254.11	396.2	732.31
	Modulus of rupture Kg/cm²	125.329	142.76	120.82	225.32
F3	Compressive strength Kg/cm²	355.6	365.34	424.6	409
	Modulus of rupture Kg/cm²	121.992	141.11	140.66	174.72
B1	Compressive strength Kg/cm²	421.3	393.75	319.87	267.1
	Modulus of rupture Kg/cm²	172.386	170.74	188.24	227.42
B2	Compressive strength Kg/cm²	344.23	310.9	346.6	317.4
	Modulus of rupture Kg/cm²	138.096	179.61	157.45	193.61
Compressive strength Kg/cm²	MAX	421.3	393.75	424.6	732.31
	MIN	224	198.9	211	245.99
	MEN	322.65	296.33	317.8	498.15
Modulus of rupture Kg/cm²	MAX	172.384	179.61	188.24	227.42
	MIN	75.579	67.87	99.14	112.66
	MEN	123.98	123.74	143.69	170.04

Dry Sensitivity Index

The accompanying procedures and mathematical formulas for demonstrating the impact of temperature and duration on the moist bricks supported this finding: If the DSI is greater than 2, it has a high drying sensitivity and requires moderate drying at low temperatures. If DSI1 has a low drying sensitivity, it will require rapid drying at a high temperature. (Equip Ceramic, 2014). It is ranging from 9.5 to 12.6. Regardless of such outcomes, a conventional drying program was used in pellet drying before combustion, and it demonstrates that these specimens require low temperatures and slow curing. Another test was carried out to identify an appropriate water percent ratio to manage shrinkage during the drying process; when making briquettes, the water content will rise, which means there will be more shrinkage post-dryness; growing water content denotes more shrinkage. Based on DSI data, the amount of water content percent varies from 7.301 to 13.9 percent when calculating the used water amount for clay molding preparation. F1 specimen has the lowest water contents percentage because of existing of higher clay contents that adsorb water more than of B1 and B2 samples that have higher water content percent because of lower clay and more sand content if the clay shrinks occurred when curing, the shrinkage % test is also necessary. The drying shrinkage shown in (Tables 7, 8, 9, 10, 11, 12, and 13) ranges from 0.604 to 0.78 percent, showing a relatively high-level shrinkage. This is because making briquettes requires using an amount of moisture, which directly affects drying shrinkage.

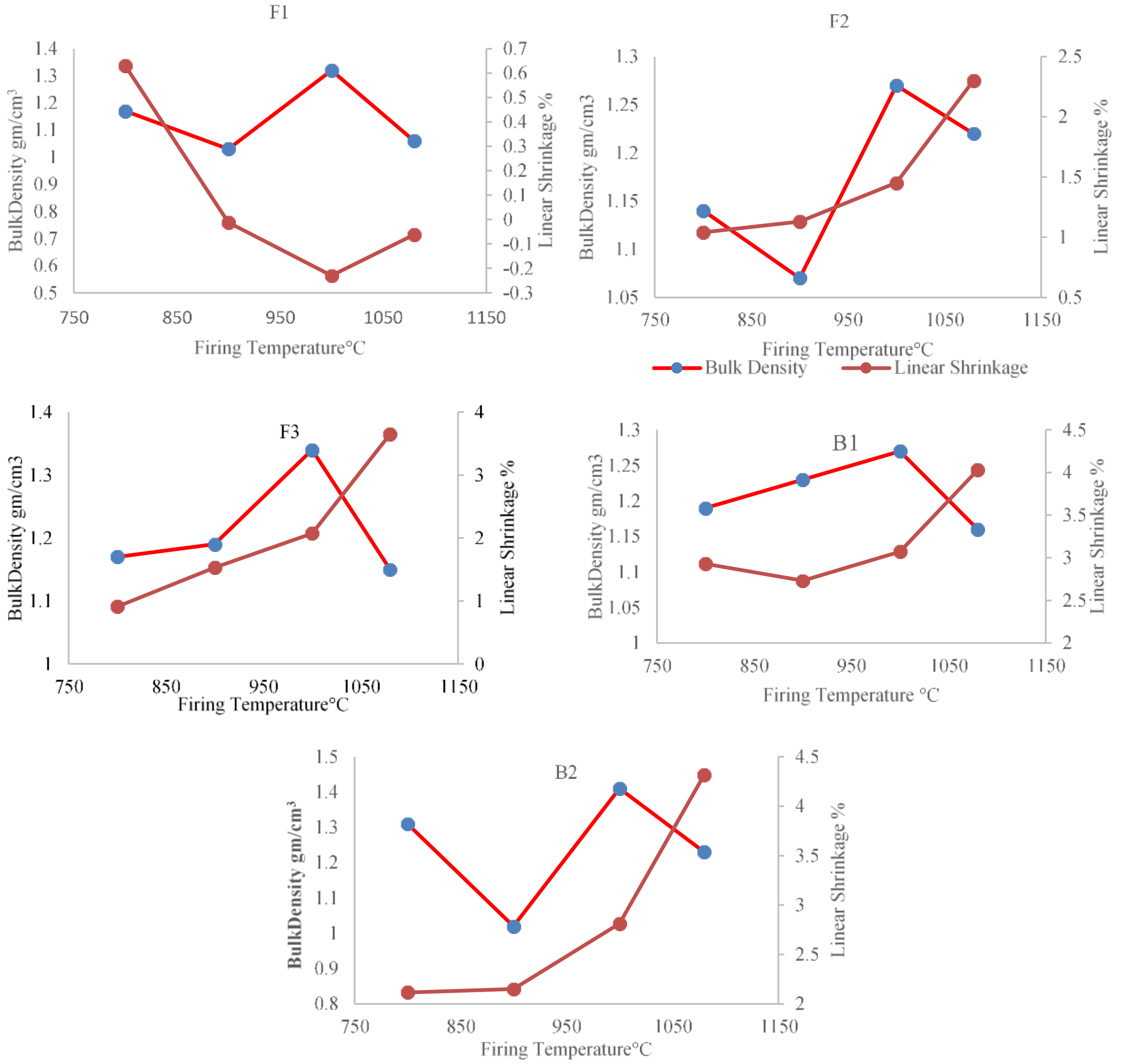

Fig. 10. Correlation between bulk density and linear shrinkage.

Table 9. Water saturation percentage, the Dry Sensitivity Index (DSI), and drying shrinkage of F1

T.°C	Time min.	L. cm	W. (gm)	DSI %	Water content%	Shrinkage %
0	0	80.94	71.9	10.5	7.301	0.605
R.T.	30	80.71	73			
30	30	80.65	72.1			
60	30	80.56	70.6			
90	30	80.37	69.09			
120	30	80.56	67.9			
150	30	80.56	67.15			
210	30	80.45	66.65			
270	30	80.45	66.65			

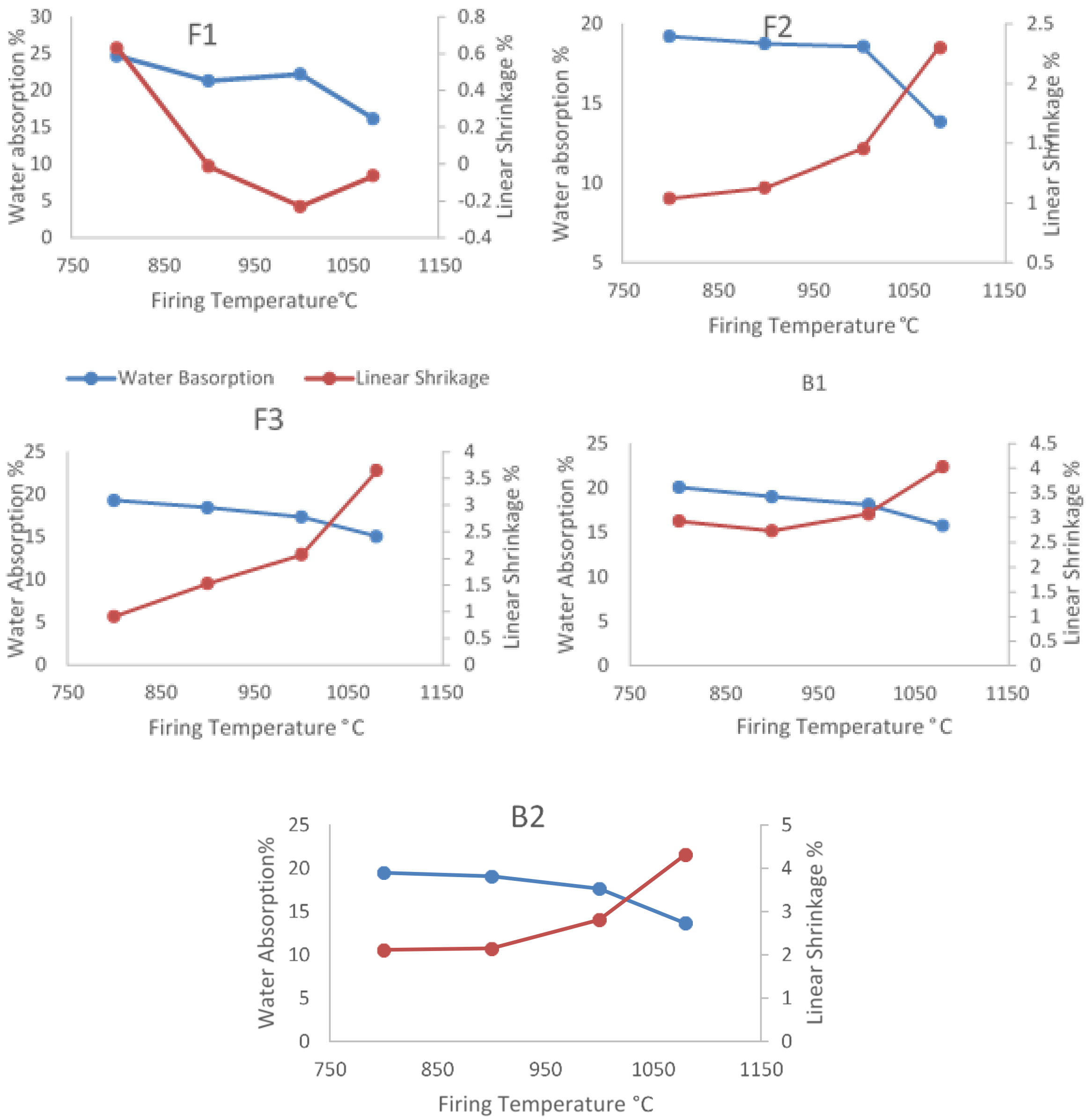

Fig. 11. Correlation between water absorption and linear shrinkage.

Table 10. Water saturation percentage, the Dry Sensitivity Index (DSI), and drying shrinkage of F2

T.°C	Time min.	L. cm	W. (gm)	DSI %	Water content%	Shrinkage %
0	0	80.98	72.3	12.6	9.405	0.765
R.T.	30	80.65	74			
30	30	80.49	72.2			
60	30	80.39	70.35			
90	30	80.1	68.95			
120	30	80.45	67.15			
150	30	80.45	66			
210	30	80.36	65.5			
270	30	80.36	65.5			

Table 11. Water saturation percentage, the Dry Sensitivity Index (DSI), and drying shrinkage of F3

T.˚C	Time min.	L. cm	W. (gm)	DSI %	Water content%	Shrinkage %
0	0	80.87	74.01	11.0	12.83	0.704
R.T.	30	80.65	73.4			
30	30	80.56	72.5			
60	30	80.5	70.58			
90	30	80.31	68.75			
120	30	80.39	67.8			
150	30	80.39	66.1			
210	30	80.3	65.4			
270	30	80.3	65.35			
300	30	80.3	65.3			
330	30	80.3	65.3			

Table 12. Water saturation percentage, the Dry Sensitivity Index (DSI), and drying shrinkage of B1

T.˚C	Time min.	L. cm	W. (gm)	DSI %	Water content%	Shrinkage %
0	0	80.7	75.5	9.5	13.9	0.72
R.T.	30	80.64	74.75			
30	30	80.33	72.7			
60	30	80.33	70.88			
90	30	80.33	69.11			
120	30	80.33	67.6			
150	30	80.33	66.4			
210	30	80.16	65.15			
270	30	80.16	65.3			
300	30	80.16	65.15			

Table 13. Water saturation percentage, the Dry Sensitivity Index (DSI), and drying shrinkage of B2

T.˚C	Time min.	L. cm	W. (gm)	DSI %	Water content%	Shrinkage %
0	0	80.74	77.4	9.89	12.66	0.78
R.T.	30	80.64	76.9			
30	30	80.42	74.5			
60	30	80.42	72.4			
90	30	80.42	71.2			
120	30	80.3	69.5			
150	30	80.3	68.5			
210	30	80.11	67.6			
270	30	80.11	67.6			

Evaluation of fired samples for bricks for ceramic tiles.

For the brick sector, see Iraqi Central Organization for Standardization and Quality Control (I.C.O.S.Q.C.) No. 25 (1988). varies significantly on the mechanical, physical, and chemical characteristics of burnt bricks. The brickwork is divided into three groups based on their modulus of rupture, compressive strength, and water absorption.

Class A: Loaded Foundation, Construction, and exposed to corrosion.

Class B: Loaded Construction and non-exposed to corrosion.

Class C: Construction of non-Loaded and non-exposed to corrosion.

Based on Compressive strength and Water absorption which that Showed in Tables (5 and 8) the fired bricks are classified into class (A) except F1 and B1 which they fitted into Class (B) at 800 ˚C (Table 14).

Moreover, because of the high-water absorption of samples, most specimens for flooring are classified as B3 by the Iraqi Central Organization for Standardization and Quality Control (I.C.O.S.Q.C.) at 800, 900, 1000, and 1080 C. (Table 15).

Table 14. Iraqi standard for clay bricks Industry No. 25 (1993), and classifying of fired bricks

Brick class	(kg/cm2)	Max. water absorption %	Briquettes are distributed to these categories.			
			800˚C	900˚C	1000˚C	1080˚C
A	180	20	F2, F3, B2	F1, F2, F3, B1, B2	F1, F2, F3, B1, B2	F1, F2, F3, B1, B2
B	130	24	F1, B1			
C	90	26				

Table 15. No. 1704/5, 6, 7/1998, and 1704/8/1997 of Iraqi standards for floor and wall tile and classifying of fired brick

Tile class	Water absorption %	Supplying ceramics to such classes			
		800˚C	900˚C	1000˚C	1080˚C
BA	≤ 3				
B 2-1	3 to 6				
B 2-2	6 to 10				
B3	> 10	F1, F2, F3, B1, B2	F1, F2, F3, B1, B2	F1, F2, F3, B1, B2	F1, F2, F3, B1, B2

For the roofing tile industry, on the base on Modulus of rupture and water absorption in (ASTM C1167-9603 (2003)), which showed in tables (5 and 8) except F2 and B2 for 1080 ˚C which are located in grade 2, all others are located in grade 3 (Table 16).

Table 16. Roof tile ASTM C1167-9603 (2003) and burned brick classification

Tile grade	Minimum of modulus of rupture (kg/cm^2)	Maximum of water absorption %	briquettes classes			
			800˚C	900˚C	1000˚C	1080˚C
1	>160	< 8				
2	115-160	8-13				F2, B2
3	115-160	13-15	F1, F2, F3, B1, B2	F1, F2, F3, B1, B2	F1, F2, F3, B1, B2	F1, F3, B1

Summary and Conclusion

depends on a laboratory experiment on clay materials that three distinct firing temperatures (800 °C, 900 °C, 1000, and 1080 °C) were chosen for firing the manufactured ceramics. The findings materials that the majority of clay samples can endure temperatures of up to 1080 °C. It is discovered that the proportions of fluxing oxides, namely the percentage of calcium oxide, and refractory oxides (silica and alumina) have a good influence on the physical characteristics of the tested ceramic briquettes (high proportion exist in some of the studied samples).

at 900˚C, 1000 ˚C, and 1080 ˚C have negative Linear shrinkage which has elongated instead of shrinking, because of the decomposition of CO_2 that causes increasing of porosity at that time the bulk density decreases. in contrast, in normal cases shrinkage happens due to the vitrification of silicates and decompressing materials. All samples have high DSI.

Manufactured clay briquettes exhibit different degrees of color including during burning. This is Because of the increased carbonates and Cao composition, the samples of Mukdadyia that dissolved the initial red hue became yellow at 1080 ˚C. Despite having the same amounts of CaO and Fe_2O_3, the color of the samples of Injana formation varies from dark red to yellowish red. Due to variations in chemical composition. briquette color varies with temperature, which has a negative influence at high-temperature firing.

With elevation silicates, refractory materials, and burning temperature, mechanical and physical tests and results from compressive strength, modulus of rupture, and bulk density rise which means they have a positive influence, and conversely.

It could be that every one of the investigated specimens is acceptable for class A, class B, floor, and wall tile type B3. Additionally, the second-grade and grade 3 roofing tile industries might use the examined specimens. The ideal firing temperature, which may be employed for chemical defenses, is 1000 ˚C.

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