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The Suitability of Fatha Clay Deposits for Clay Bricks Industry in Zurbatiya Area, Eastern Iraq

Yasmin Ibraheem Al- Fraji*, Sattar Jabbar Al-Khafaji
Department of Geology, College of Science, University of Basrah, Iraq

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Abstract

This research aims to study the suitability of the Fatha Formation clay deposits for the brick industry in the Zurbatiya area, Wasit Government. Two sites (Al-Salam police station and Al-Taff station) were selected. The clay deposits were subjected to particle size analysis, atterberg limits, chemical and mineralogical analyses. The samples have 31.45% clay, 52.91% silt, and 15.64% sand. Chemical analyses revealed that SiO_2 and CaO are the clay deposits' main components, indicating the high content of quartz and calcium carbonate. The mineralogical analysis by XRD techniques indicated that quartz, calcite, feldspar, gypsum, and dolomite are the non-clay minerals; Kaolinite, illite, palygorskite and chlorite are the most clay minerals, followed by the mixed layer (montmorillonite-chloride). Clay brick samples were formed, dried and then fired using a particular firing program. The produced bricks have good water absorption (20-24.06%), compressive strength (36.23-41.63 N/mm^2), and efflorescence (moderate – slight to nill). The properties of the produced clay bricks agree with the requirements of class A and B of the Iraqi Standard Specifications No.25,1993, British (BS 3921, 1985), and American Standard (ASTM C10, 2010).

Keywords: Fatha Formation, Clay bricks, Zurbatiya, Suitability, Firning program, Plasticity.

صلاحية رواسب الفتحة الطينية لصناعة الطابوق الطيني في منطقة زرباطية ، شرق العراق

ياسمين ابراهيم الفريجي*، ستار جبار الخفاجي
قسم علم الارض ، كلية العلوم ، جامعة البصرة ، العراق

الخلاصة

يهدف البحث إلى دراسة مدى صلاحية الرواسب الطينية لتكوين الفتحة لصناعة الطابوق في منطقة زرباطية ، محافظة واسط ، تم اختيار محطتين هما ؛ مخفر السلام ومركز الطف. خضعت الررواسب الطينية للتحليل الحجمي الحبيبي ، وحدود أتيربيرج ، والتحليلات الكيميائية والمعدنية. أظهرت النتائج أن العينات تحتوي على 31.45٪ طين ، 52.91٪ غرين ، 15.64٪ رمل. أظهرت التحليلات الكيميائية أن SiO_2 و CaOهما المكونان الرئيسيان للرواسب الطينية ، مما يدل على ارتفاع نسبة الكوارتز وكربونات الكالسيوم. أشار التحليل المعدني باستخدام تقنية الاشعة السينية الحائدة إلى أن الكوارتز والكالسيت والفلسبار والجبس والدولوميت هي المعادن غير الطينية. الكاولينايت ، الإيلايت ، الباليجورسكايت والكلوريت هي المعادن

*Email: Khafaji52000@gmail.com

الطينية الاكثر شيوعا تليها االمعادن الطينية المختلطة (مونتموريللونايت –كلورايت). تم تشكيل عينات الطابوق الطيني وتجفيفها ثم حرقها باستخدام برنامج حرق خاص. الطابوق المنتج يتمتع بامتصاصية جيدة للماء (20–24.06٪) ، مقاومة انضغاط (36.23–41.63 نيوتن / مم^2) ، وتزهر يتراوح بين متوسط الى خفيف او معدوم). خواص الطابوق الطيني المنتج تتفق مع متطلبات الصنفين A و B من المواصفة القياسية العراقية رقم 25 لسنة 1993 و متطلبات المواصفة البريطانية رقم 3921، لسنة 1985، والمواصفة القياسية الأمريكية ,ASTM– C10 لسنة 2010 .

1. Introduction

Clay is the main raw material for many ceramic industries, especially bricks and other construction industries [1]. Clay deposits are widespread and abundant in many geological formations of different ages in north, west and southern Iraq. The Fatha Formation bears massive red clay deposits is widely distributed in Iraq, especially in the north and east of Iraq. The Formation is well exposed, especially in the Zurbatiya area of eastern Iraq and has a good potential reserve of clay [2]. Clay bricks are considered one of the building materials known by humans for more than a thousand years due to their availability in nature and ease of manufacture. The quality of produced clay bricks depends on several factors like; types of clay materials, impurities, and the technological processes starting from designing, mixing, drying, and firing temperature to achieve high specifications of bricks.

Some researchers were carried out on the same purpose, such as [3], who evaluated some clay deposits of the Neogene age for brick manufacturing. [4] evaluated some clay deposits of the upper part of Gercus Formation (Middle-Miocene), North East Iraq, for brick manufacturing. [5] used the recent deposits around the Aliawa village south of Sulaimania city for the production of glazed ceramic tiles through mixing recent deposits and Sirwan river deposits and gorge. She found some raw materials suitable for manufacturing ceramic tiles covering the walls of kitchens, public building balconies and baths. [6] used fourteen types of clay selected from different locations in the Kurdistan region and found that some of these raw materials are suitable for manufacturing solid and perforated bricks. [7] Studied the possibility of manufacturing new types of pottery blocks from marl deposits within the Fatha Formation (Middle Miocene) and determining their engineering, geochemical and mineralogical characteristics. [8] dealt with the evaluation of the physical, chemical and mineralogical properties of mudstone of the Neogene age (Injana and Bai Hassan Formations) and their suitability to use as a raw material in the manufacturing of building bricks. [9] evaluated the physical, chemical and mineralogical properties of claystone of Fatha Formation in Kurdistan, and they prepared a clay brick of class A (first class) according to the requirements of Iraqi Standard Specification [10]. [11] Studied the reality of mineral resources in Iraq, Zurbatiya area as a case study and mentioned that good extensions and thicknesses characterize red clay deposits and can be invested for brick industries.

The aim of this research is the study of physio-chemical and mineralogical properties of clay deposits in Zurbatiya area, and evaluate their suitability to produce clay bricks.

2. Study area and geological setting

The study area is located in Zurbatiya area, about 80 Km east of Wasit Governorate, near the Iraq-Iran international borders, bounded by latitudes (33°14'05.55" -33°22'23.1"N) and longitudes (46°07'20.0"- 45°58'00.4"E) as in Figure 1, and Table 1. The study area is located in the Low folded Zone, Hemrin anticline fold, with a relative height (115m) above sea level. The southwestern limbs are steeper than the northeast limb [12]. The Fatha Formation in the study area comprises more than 20 cycles of red claystone, green marl, limestone, and blocky gypsum [2] (Figure 2). The cyclicity phenomenon of the the Fatah Formation may be due to tectonic factors, glacioeustatic sea-level changes, and the autocyclic processes of sabkha [13]. The depositional environment of the Fatha Formation was a semi-closed basin (lagoon) due to alternated influx of seawater [14]. Fatha Formation has a high thickness (> 60m) and extensions (> 50 km) of red clay deposits.

Table 1: The name, Location, Formation and number of clay samples of studied sections.

Station No.	Station name	Coordinate	Number of Sample
1	**Al-Salam**	N 33°14'05.55" E 46°07'20.0"	**10**
2	**AL- Taff**	N 33°22'23.1" E 45°58'00.4"	**13**

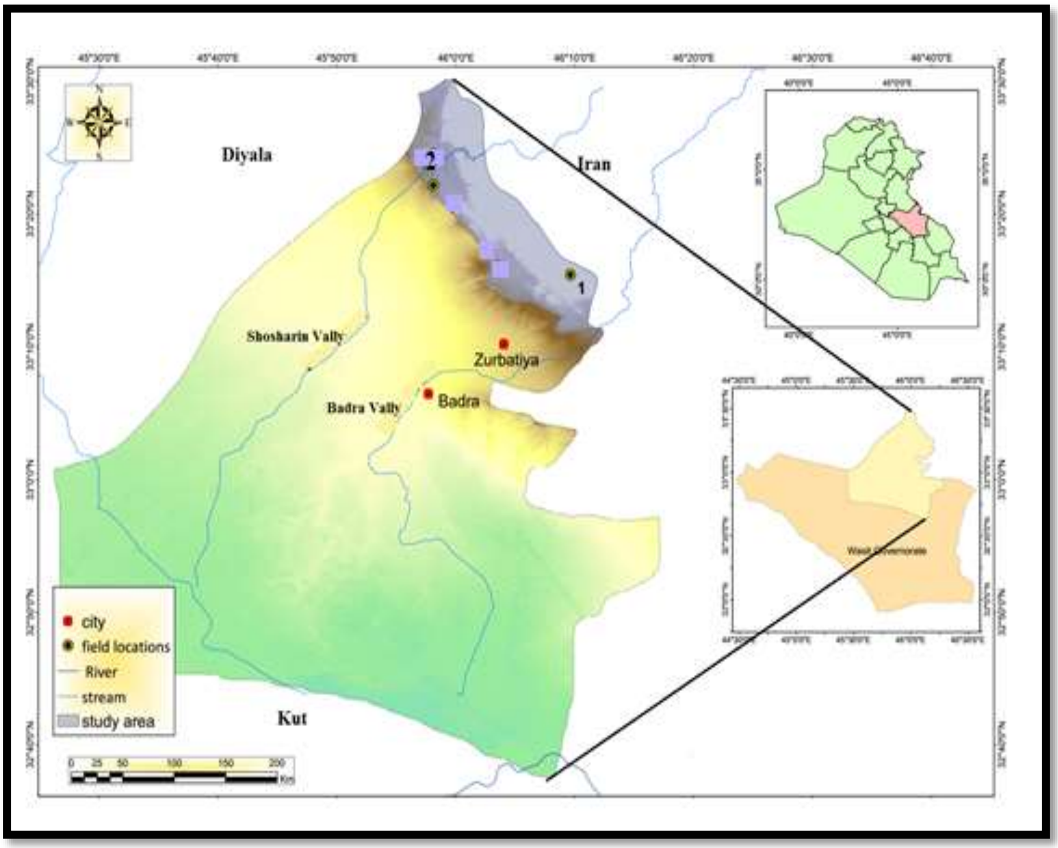

Figure 1: Location map of the study area

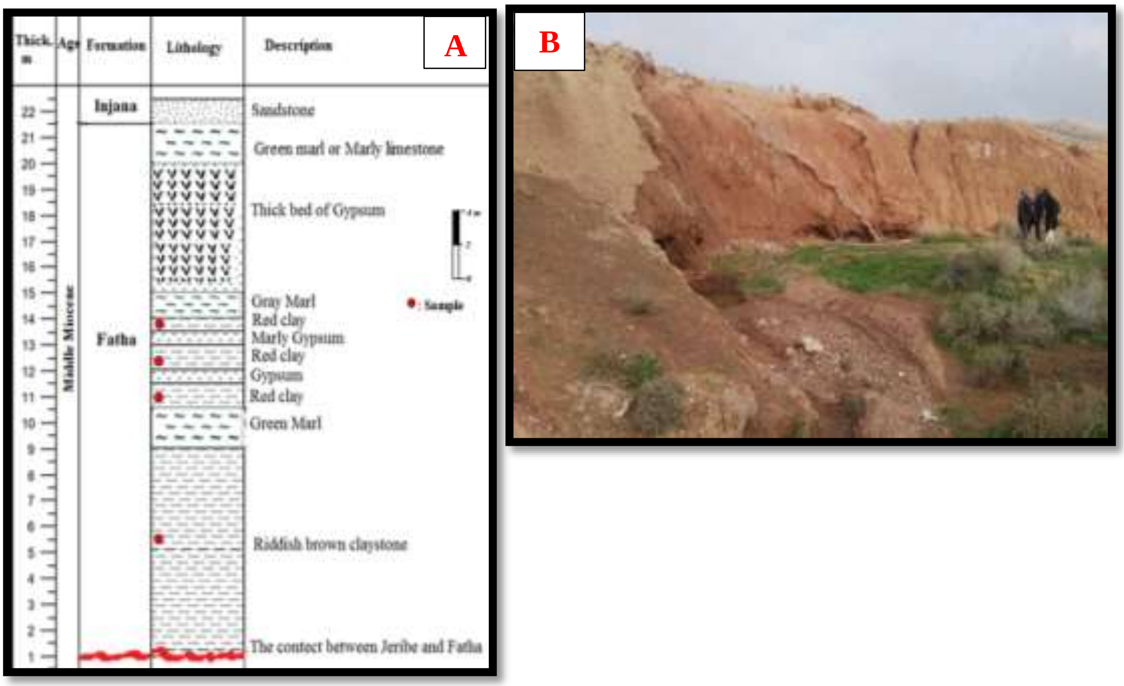

Figure 3: A- Stratigraphic succession in Al-Salam station of Fatha Formation in Zurbatiya Area, **B-** Extension of red clay in Fatha Formation

3. Materials and Methods

Fieldwork included recording a set of field notes, such as lithology, extensions and thicknesses of clay deposits, and describing the geology of the study area. Two stations were selected, namely Al-Salam and Aم-Taff in Fatha Formation. Eleven clay samples were chosen for physical, chemical, and mineralogical analyses for several laboratory tests, including:

3.1 Grain size analysis

The samples were tested to measure the grain size of clay deposits by a shaker machine which was used to separate the sand size of samples by using a set of standard sieves intervals (2, 1, 0.5, 0.250, 0.125, and 0.063 mm). The remaining parts on each sieve were collected and weighed. The passing part size (0.063) mm represents both silt and clay(Mud). Mud was used to separate clay fractions by Pipette method according to [15] method, which was conducted at the Department of Geology /College of Science - University of Basrah.

3.2 Atterberg's limits

Atterberg limit tests conducted the liquid limit (LL) and plastic limit (PL). The difference between liquidity and plasticity limits is called the plasticity index (P.I) [16]. The limits of plasticity and liquidity were examined by the Gassagrandi method according to international standards [17, 18] in the National Center for Construction laboratories (NCCL) /Basrah.

3.3 X-Ray Diffraction Analysis (XRD)

X-ray diffraction technique type PW3830 comprehensive X-ray generator was used to identify the clay and non-clay minerals in the samples according to [19] reported in [20]. The examination was conducted at the Ministry of Science and Technology, Materials Research Department, Center for Advanced Materials, X-ray Laboratory, Baghdad.

3.4 Chemical analysis

All samples were analyzed for SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, K_2O, SO_3, and TiO_2 contents using X-Ray Florescence spectrometry (XRF) at Amirkabir University and Technology laboratories/ Iran Horiba-model MESA-50.

4. Bricks forming and firing processes

Fifty grams were mixed and homogenized after adding 7-8 % water. The mixture was passed through a 200 Micron sieve size. The bricks were formed using cylindrical steel with a diameter of 4cm x 4cm by using a semi-dry method under 200 Kg/cm^2 as forming pressure. Fine sand was used as additives in different percentages of 10% and 15% to improve the properties of the produced bricks (Table 2). The mixtures were air dried for several days and then dried at 110°C for 24 hours to avoid cracks in the bodies of bricks. These cracks may appear before or after the firing to ensure water formation exited [21]. The dried bricks were fired by using a firing program at 850, 950, and 1050°C, respectively, in a muffle furnace at one and half hours as soaking time in the Geochemistry laboratory at the Department of Geology, University of Basrah.

Table 2: Suggested Mixtures of prepared bricks

Mixture number	Clay raw material% by weight	Sand %
1	**100**	**-**
2	**90**	**10**
3	**85**	**15**

5. Bricks evaluation tests

5.1 Apparent Porosity

Apparent porosity is defined as the percentage of the size of open voids or pores to the total volume in the ceramic body mass. The apparent porosity was calculated according to the Iraqi and American Standards [22, 23].

5.2 Bulk density

The bulk density is defined as the ratio of the sample weight to the total volume represented by the solid size and voids. It is measured in units of (gm/cm^3) [24]. The bulk density of the fired samples was carried out according to Iraqi and American standards [10, 23].

5.3 Water Absorption

It is defined as the percentage of absorbed water occupying the pores of the ceramic body. This test is carried out according to the Iraqi and American standards [10,23] in the Geochemistry Laboratory, Department of Geology in the College of Science, University of Basrah.

5.4 Compressive strength

Compressive strength is defined as the ability of the ceramic body to withstand the external pressure applied to it, measured in units (kg/cm^2) [25]. This test is carried out according to the Iraqi and American standards [10,26] in the concrete laboratory / College of Engineering/ University of Basrah, using a Turkey-made (BESNAC) hydraulic piston with a maximum bearing capacity of (25 tons).

5.5 Efflorescence

The efflorescence is defined as the phenomenon of crystallization of dissolved salts on the external surface of bricks after exposure to water and atmosphere and then dehydration [27, 28]. This test was carried out according to the Iraqi and British Standards [10, 29] by placing the sample on its small base in a shallow container. So it was immersed with distilled water to a depth of 1cm and maintained the water level for seven days. Then the samples were dried in the same container without moving, recording the degree of efflorescence.

6. Results and Discussion

6.1 Grain Size Analysis

The results of the grain size analysis are listed in Table 3. Clay deposits have silt ranging between 43% and 66 %, clay between 24 and 40 %, and sand between 4% and 25 % in all the studied samples. According to [15], the deposits are classified as sandy mud to mud. The results indicate that the clay deposits are of good quality to prepare clay bricks according to the requirements of Iraqi Standard [10]. Also, all studied samples J1, J4, J5, J7, J10, S1, S2, S3, S6, S8, and S9 fell into the dispersed class (60-20 µ**)**, according to [30]. It indicates that the deposits are suitable for use in the ceramic industries.

6.2 Atterberg's limits

Plasticity is an important property of clay because it gives the ceramic durability and strength when it is dried and fired [31]. Table 4 shows Atterberg's limits of Fatha clay deposits. The studied samples were classified, according to the plasticity chart, which represents the relationship between the plasticity index and Liquid limit [32], as low to high plasticity, due to their clay, silt and sand content. The high plasticity is due to the high clay content, and the low plasticity is due to the high silt content. That is a direct relationship between fine particle size and plasticity [33] (Figure 4). The result (PI) indicated that the studied samples are considered suitable for the clay brick industry, according to the Iraqi standard [10]. The studied samples were classified as plastic to moderately plastic according to [30], as in Table 5. The plasticity index is mainly affected by types of clay, grain size, type and percentage of non-clay minerals and organic matter [34].

Table 3: Grain size analysis percentage (%) for clay samples of study area

Station	Sample	Grain size analysis			Texture classification
		Sand	Silt	Clay	
AL-Salam	JD1	25	43	32	Sandy Mud
	JD4	24	45	31	Sandy Mud
	JD5	18	56	26	Sandy Mud
	JD7	20	50	30	Sandy Mud
	JD10	21	53	26	Sandy Mud
AL-Taff	SB1	4	56	40	Mud
	SB2	5	60	35	Mud
	SB3	10	66	24	Mud
	SB5	18	46	36	Sandy Mud
	SB8	15	55	30	Mud
	SB9	12	52	36	Mud
	Range	4-25	43-66	24-40	
	Average	15.64	52.91		31.45

Table 4: The results of Atterberg's limits for the studied samples

Formation	Section	Samples	Liquid limit	Plastic limit	Plasticity Index	Sticky limit	Reike Index
Fatha Formation	**AL-Salam Station**	**J1**	46	32	14	38	6
		J4	50	33	17	26	7
		J5	52	46	6	47	1
		J7	44	30	14	35	5
		J10	51	40	11	46	6
	AL-Taff Station	**S1**	56	36	20	46	10
		S2	44	33	11	36	3
		S3	55	45	10	48	3
		S6	40	27	13	33	6
		S8	52	26	26	36	10
		S9	49	27	22	35	8

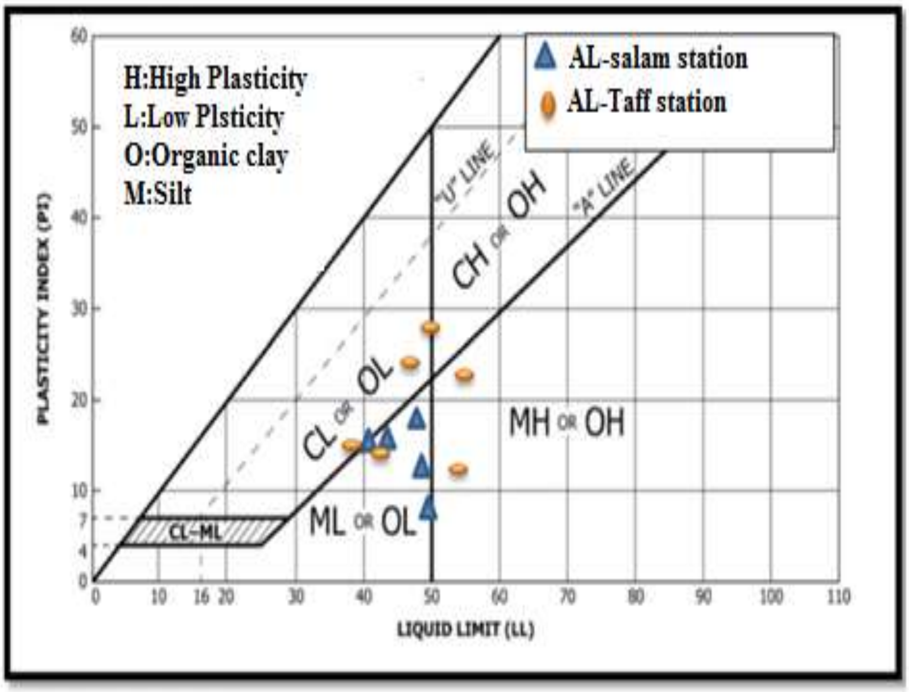

Figure 4: Plasticity chart of the studied samples [32]

Table 5: Classification of studied sample according to the plasticity Index [30]

Plasticity Index (P.I)	Plasticity (P.)	Samples
>25	Super Plastic	
15-25	Plastic	J4, S1, S9
7-15	Moderately Plastic	J1, J7, J10, S2, S3, S6, S8
<7	Poorly Plastic	J5
Non forming plastic mass	Non- Plastic	-

6.3 Mineralogical analysis

XRD charts (Figures 5 and 6) show that the studied samples are composed of quartz as the dominant non- clay mineral in all samples. Calcite is a second non-clay mineral in all samples, which behaves as a fusion oxide to help accelerate reactions during the firing and reduce the degree of melting. At the same time, the decomposition of carbonate minerals during the firing increases the porosity ratio and water absorption and decreases the density. Thus, that may cause cracks in the bricks [34]. Dolomite, gypsum and feldspar are found in small amounts. Gypsum disintegrates and gives SO_3 during firing. The clay minerals are represented by kaolinite illite, chlorite, palygorskite, and montmorillonite-chlorite mixed layer. Kaolinite is an important mineral in the mixture prepared for manufacturing bricks. It has a high drying strength and plasticity during the drying and forming process because it has a high content of Al_2O_3 in its structure [35]. Illite is one of the non-swelling minerals, so the interspaces between the layers contain potassium. Furthermore, these interfacial bonds are very strong [36]. Palygorskite has the ability ionic to exchange, as they carry ions of the elements in an unstable crystal position, and thus liberation of these elements may lead to a weak of the approved standard specifications and poor quality of bricks [37].

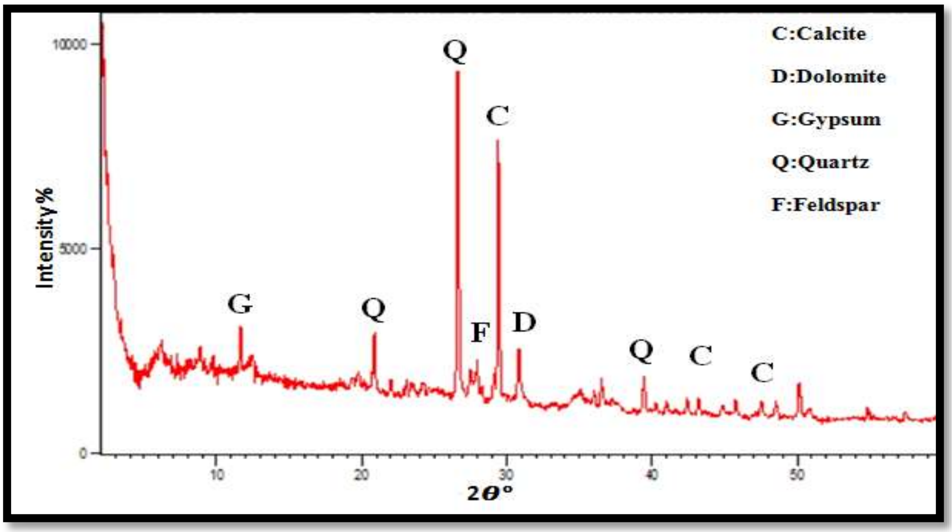

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Figure 5: X- ray diffraction of bulk sample **J1** of Fatha Clay

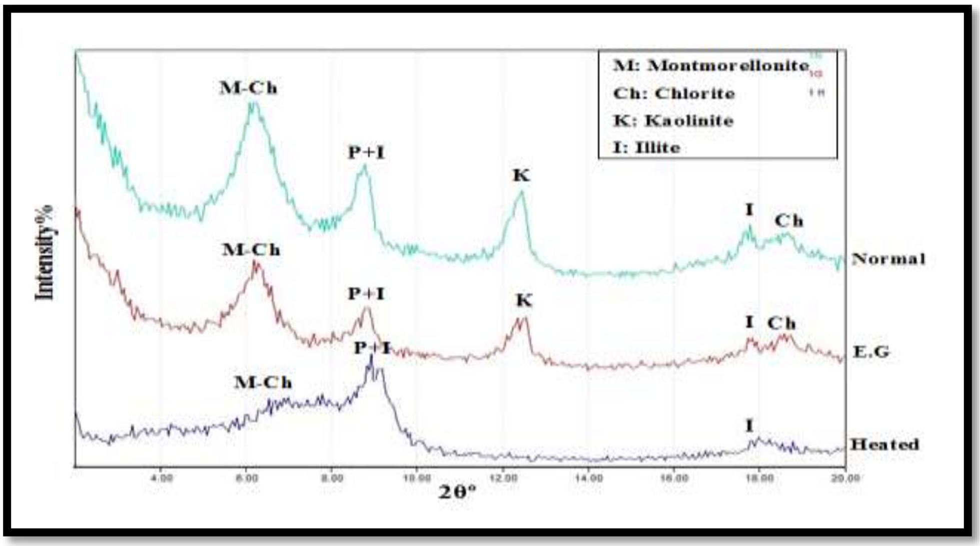

Figure 6: X- ray diffraction of Orientated sample **J1** of Fatha Clay

6. 4 Chemical analysis

The chemical analysis results of the major oxides, loss on ignition (LOI), total organic carbon, and the amount of total dissolved salts are listed in Table 6. Silica has the highest percentages of the major oxides in all studied samples, ranging between 50.3% and 53.91%, with an average of 51.30 % clay deposits. Silica plays an important role in the ceramic industry in preserving the body from deformation by reducing its plasticity and the rate of shrinkage resulting from firing [38]. It keeps the body from deformation and increases its chemical resistance to acids and bases [38]. The AL_2O_3 ranges from 6.05% to 9.59 %, averaging 7.93%. These constituents of aluminium oxide are direct, proportional to clay mineral composition and considered melting resistance oxides that raise the necessary melting temperature to reach the glass phase in samples containing a high percentage of it [39].

Fe_2O_3 ranges between 3.08% and 5.34%, with an average of 4.03%. This oxide is considered a red coloring agent for ceramic products when it has a percentage between 5% to 6 %, and not greater than 7% [40]. TiO_2 ranges between 0.21%, and 1.09%, with an average of 0.92%. The increase in TiO_2 oxide is due to the substitution of titanium ions Ti^{+4} in the place of aluminum Al^{+3} in the crystal structure of clay minerals according to their similarity in the ionic radiis. Also, Ti^{+} can replace Fe^{+3} and Mg^{+2} in the octahedral layer of palygorskite [41]. Calcium oxide ranges between 9.18%, and 22.32%, with an average of 17.92%. The carbonate content in the studied samples is a significant factor in the brick industry and must not exceed 35% because of the expansion of the bricks as a result of the effect of carbon dioxide, according to the Iraqi Standard [10]. The percentage of MgO range is between 2.03% and 3%, with an average of 2.27%. This oxide is one of the flux oxides, and its release in the form of MgO accompanied by CaO leads to an increase in the release of CO_2 during the firing process. Then the inside pressure of the brick body increases, and thus cracks appear on its surface, especially when it is not controlled slowly, increasing the ceramic product porosity [42, 43]. The Na_2O ranges between 0.25% and 1.5%, with an average of 0.77%, while the concentration of K_2O ranges between 1.24% and 2.1%, with an average of 1.48%. The flux oxides represented by Fe_2O_3, CaO, MgO, Na_2O and K_2O help to flux some brick components in a narrow thermal range, especially after the temperature of 900°C. When firing between 900 and 1100°C, these oxides presence will help form a bonding glass material and new minerals phases in the produced bricks which help to increase their strength and hardness [44,45]. Sulfates range between 0.22% and 2.55%, with an average of 1.15%. The low percentage of sulfur dioxide indicates the presence of calcium oxide in the form of carbonates and not in the form of sulfates. The XRD results indicate the presence of a tiny percentage of gypsum mineral (Figure 5).

Table 6: Major Oxides concentrations (%) in the studied area

Stations	Samples	Major Oxides %											
		SiO_2	**AL_2O_3**	**Fe_2O_3**	**TiO_2**	**CaO**	**Na_2O**	**K_2O**	**SO_3**	**MgO**	**L.O.I %**	**T.O.C %**	**TDS %**
AL-Salam	**J1**	50.3	7.06	5.34	1.16	17.86	1.5	2.1	2.34	3	17.8	1.61	2.19
	J4	50.29	8.22	5.12	1.12	12.45	1.45	1.6	2.12	2.33	17.96	1.54	1.98
	J5	50.6	7.09	4.7	1.08	9.18	0.96	1.36	1.94	2.05	18.9	1.43	0.97
	J7	50.28	8.34	4.6	1.19	17.45	1.4	1.26	1.16	2.15	18.34	1.65	1.87
	J10	51.78	8.47	4.5	1.06	14.74	1.14	1.43	2.55	2.27	17.38	1.58	1.84

AL-Taff	**S1**	53.27	7.67	3.54	0.5	22.31	0.25	1.54	0.22	2.32	20.23	2.12	3.97
	S2	52.26	8.44	3.16	0.49	20.67	0.37	1.4	0.32	2.21	20.56	2.67	4.07
	S3	50.34	9.59	3.71	0.21	20.02	0.33	1.32	0.38	2.14	20.8	2.58	3.89
	S6	53.91	8.3	3.29	1.12	22.32	0.27	1.45	0.98	2.37	19.76	2.15	4.78
	S8	51	6.05	3.08	1.09	20.07	0.41	1.56	0.34	2.03	20.4	4.29	4.34
	S9	50.31	8.05	3.25	1.05	20.03	0.39	1.24	0.29	2.07	19.89	3.67	4.23
Range		50.3-53.91	6.05-9.59	3.08-5.34	0.21-1.09	9.18-22.32	0.25-1.5	1.24-2.1	0.22-2.55	2.03-3	17.38-20.8	1.43-4.29	0.97-4.34
Average		**51.30**	**7.93**	**4.03**	**0.92**	**17.92**	**0.77**	**1.48**	**1.15**	**2.27**	**17.41**	**2.30**	**3.10**

6.5 Apparent porosity

The apparent porosity results ranged between 19.22-27.65%, 29.02- 34.13% , and 31.25 - 38.12%, at firing temperatures 850, 950 and 1050 ºC, respectively (Table 7). The apparent porosity values increased with the increase of firing temperature. That is mainly due to the high percentage of carbonates in samples, which disintegrate between 900 and1000 ºC and release CO_2, leaving voids [43]. Porosity values decreased when sand was added, and when the proportion of sand was increased. Mix.3 causes a decrease in the porosity values compared to Mix.2 or without sand additive as in Mix.1 for most of the site samples and firing temperatures.

6.6 Bulk density

The bulk density results ranged from 1.675 to 1.993 gm/cm^3, as 1.67-1.98 gm/cm^3 and 1.66-1.92gm/cm^3 at 850, 950 and 1050 ºC, respectively, (Table 7). The results show a decrease in bulk density with increased firing temperatures. The density value is affected by each of the properties of the raw material, additives, and their grain size distribution. Also, the formation pressure affects the density value directly. The effect of firing temperature and soaking time increases the percentage of shrinkage and decreases the porosity. Therefore, the density values increase [34]. The density values recorded at the firing temperature of 950°C are lower than those at 850°C. This is due to the low shrinkage rate at the firing temperature of 950°C compared to 850°C, and the gas release that pushes the sample components and increases their volume on the other hand [46].

6.7 Water Absorption

The water absorption results ranged from 17.21% to 21.89%, restricted between 18.37% - 22,06 %, and 19.23% - 25.13 % at 850,950 and 1050 ºC, respectively, (Table 7, and Figure 7). Water absorption is directly related to the porosity values, expressing the percentage of connected open pores [44]. Brick samples (SB5) have the lowest water absorption (17.21%) at 850°C but have higher water absorption at 1050°C. When the temperature increased, the water absorption and porosity increased. This is due to the calcite disintegration and release of CO_2, which may cause cracks in the brick body [47]. The absorbance values were decreased for all the fired samples when adding sand of fine granular sizes, which tend to fill the voids on the one hand, and speed up the interaction between the components of the mixture and silica, on the other hand [6].

6.8 Compressive Strength

The compressive strength test is one of the basic requirements tests of all standard specifications depending on classifying ceramics. The compressive values ranged between (35.22-41.87N/mm^2),(34.22-41.87N/mm^2),(40.05-45.57N/mm^2) for brick samples at 850,950 and 1050 ºC respectively. Table 7 and Figure 8 show the relationship between compressive strength and the firing temperature. The increase in compressive strength values with the increase of firing temperature indicates the development and growth of new mineral phases due to the increased temperatures, such as; wollastonite, Anorthite and diopside, which gain hardness for the fired samples [48]. The decrease in porosity increases brick samples' density, compressive strength, and mechanical strength [49]. The addition of sand increases the sintering products and binds the components of the sample with each other and thus increasing the compressive strength [28].

Table 7: The results of physical, mechanical, and chemical tests of ordinary building bricks at the firing temperature 850, 950, and 1050 ºC.

Formation	Station	Sample	Mix. No.	Temp.	App. Porosity%	Bulk Density gm /cm^2	Water Abs.%	Comp. Strength N/mm^2	Efflores.
Fatha	Al-Salam Station	JD1	1	850	21.34	1.758	18.17	41.12	M
				950	33.12	1.742	20.63	39.26	S
				1050	34.06	1.728	21.89	42.33	N
			2	850	20.25	1.810	17.96	43.22	M-S
				950	32.17	1.801	19.56	40.76	S-N
				1050	33.24	1.793	20.12	43.79	N
			3	850	19.87	1.841	17.76	45.04	N
				950	30.56	1.821	18.37	42.21	N
				1050	31.27	1.819	19.23	46.15	N
		JD4	1	850	23.75	1.894	20.12	35.29	M-S
				950	32.92	1.879	21.75	34.30	S
				1050	34.25	1.840	23.21	40.98	N
			2	850	22.89	1.937	20.87	37.40	S
				950	32.23	1.916	21.08	35.50	S
				1050	33.00	1.895	22.33	41.11	N
			3	850	22.08	1.993	20.04	42.09	S-N
				950	31.77	1.972	20.79	40.23	S
				1050	32.08	1.941	21.54	42.56	N
		JD7	1	850	27.65	1.763	21.32	38.65	M-S
				950	31.14	1.753	22.00	35.00	S
				1050	37.06	1.739	24.16	43.32	N
			2	850	27.15	1.832	21.05	39.32	S-N
				950	30.34	1.814	21.37	37.81	S
				1050	35.11	1.790	23.09	44.22	N
			3	850	26.24	1.859	20.87	40.07	S
				950	29.98	1.848	21.11	39.96	N
				1050	34.66	1.819	22.88	41.08	N
	AL-Taff Station	SB2	1	850	25.11	1.773	21.89	37.11	M
				950	32.51	1.764	22.06	35.31	M-S
				1050	37.26	1.743	24.80	41.05	N
			2	850	24.96	1.794	21.32	37.79	S
				950	31.04	1.782	21.99	37.21	S
				1050	34.85	1.775	23.30	41.87	N
			3	850	23.75	1.816	20.54	39.23	S
				950	30.91	1.803	21.85	38.58	S
				1050	33.23	1.786	23.06	42.01	N

Table 7: Continued, The results of physical, mechanical, and chemical tests of ordinary building bricks at the firing temperature 850, 950, and 1050 ºC

Formation	Station	Sample	Mix. No.	Temp.	App. Porosity%	Bulk Density gm /cm^2	Water Abs.%	Comp. Strength N/mm^2	Efflo.
Fatha	AL-Taff Station	SB5	1	850	20.06	1.675	21.03	40.13	S
				950	34.13	1.662	22.01	39.51	S-N
				1050	38.12	1.641	26.62	42.06	N
			2	850	19.87	1.677	17.21	41.87	S
				950	30.77	1.657	21.92	40.93	S
				1050	35.61	1.624	26.47	44.14	N
			3	850	19.22	1.687	20.54	42.93	S
				950	30.00	1.665	21.23	41.34	N
				1050	34.27	1.638	22.60	45.57	N
		SB8	1	850	25.64	1.715	18.37	37.85	M
				950	32.19	1.690	21.82	34.22	M-S
				1050	34.74	1.664	23.67	40.05	N
			2	850	24.86	1.718	17.58	35.22	S
				950	30.33	1.701	20.98	34.89	N
				1050	33.04	1.683	22.79	40.95	N
			3	850	23.93	1.728	17.21	39.63	S
				950	29.02	1.709	19.81	36.12	N
				1050	31.25	1.685	21.04	42.37	N
	Range			850	19.22 - 27.65	1.675 - 1.993	17.21 - 21.89	1.675 - 1.993	
				950	29.02 - 34.13	1.657 - 1.916	18.37 - 22.06	1.657 - 1.916	
				1050	31.25 - 38.12	1.624 - 1.941	19.23 - 26.62	1.624 - 1.941	
	Mean			850	23.26	1.79	19.86	1.79	
				950	31.40	1.78	19.91	1.78	
				1050	34.28	1.76	22.68	42.53	

- Values is the average of three

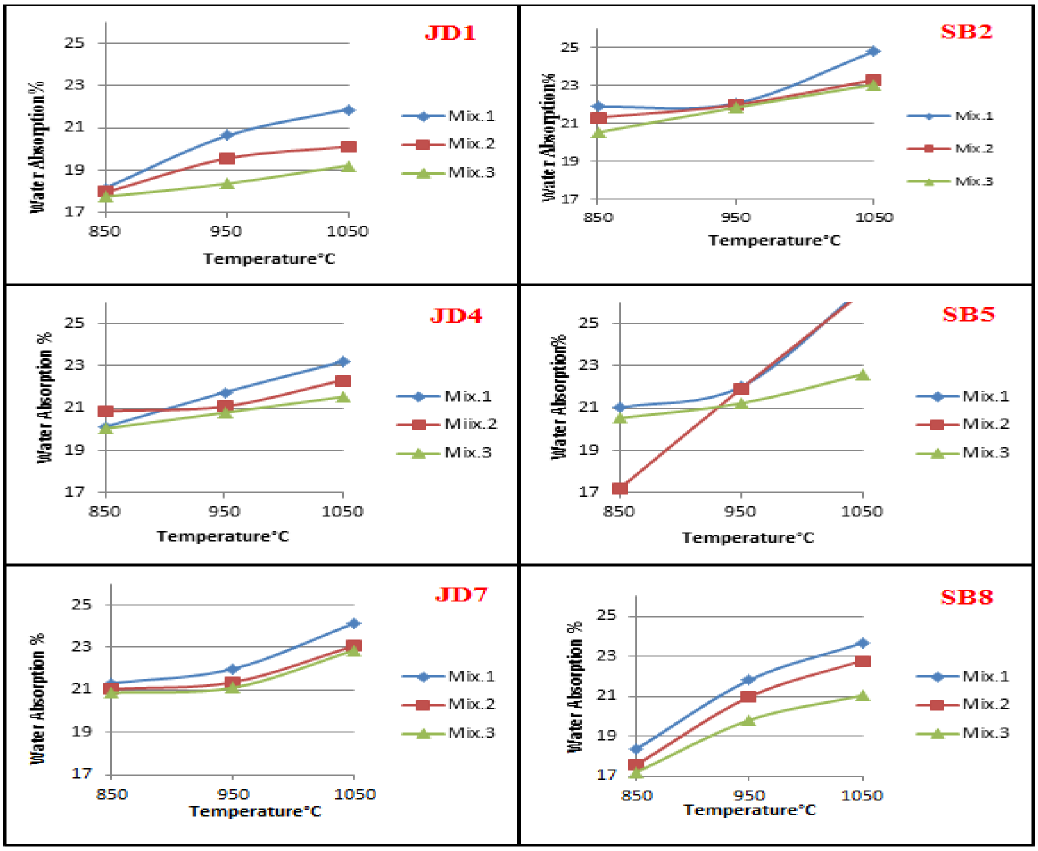

Figure 7: The relationship between the water absorption and firing temperatures for ordinary bricks.

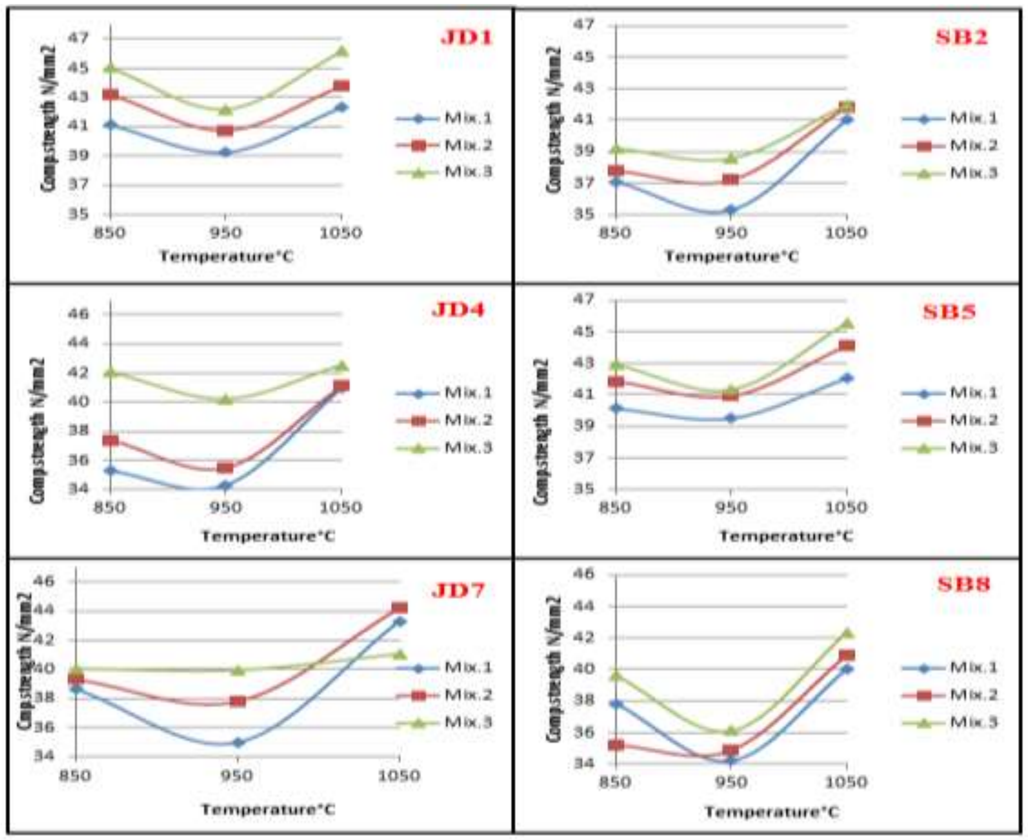

Figure 8: The relationship between the compressive strength and firing temperatures for ordinary bricks.

6.9 Efflorescence

The degree of efflorescence ranges from moderate to nill at the firing temperature (850°C), and it decreases from a slight to nill at 950°C. Most samples at 1050°C are characterized by the absence of efflorescence, some range from slight to nill (Figure 9). The decrease in the efflorescence with increased firing temperatures is due to the dissolved salts in samples. Also, it may be due to the chemical reacting with components of the mixture during the firing process and forming new mineral phases that are insoluble in water, such as gehlenite, wollastonite and diopside [50]. The results also showed the addition of sand could reduce efflorescence, especially at 15% sand. Sand provides more silica and reacts with other oxides, Fe_2O_3, Al_3O_3, MgO and CaO, to form the new stable mineral phases, especially at 1050°C [50,51].

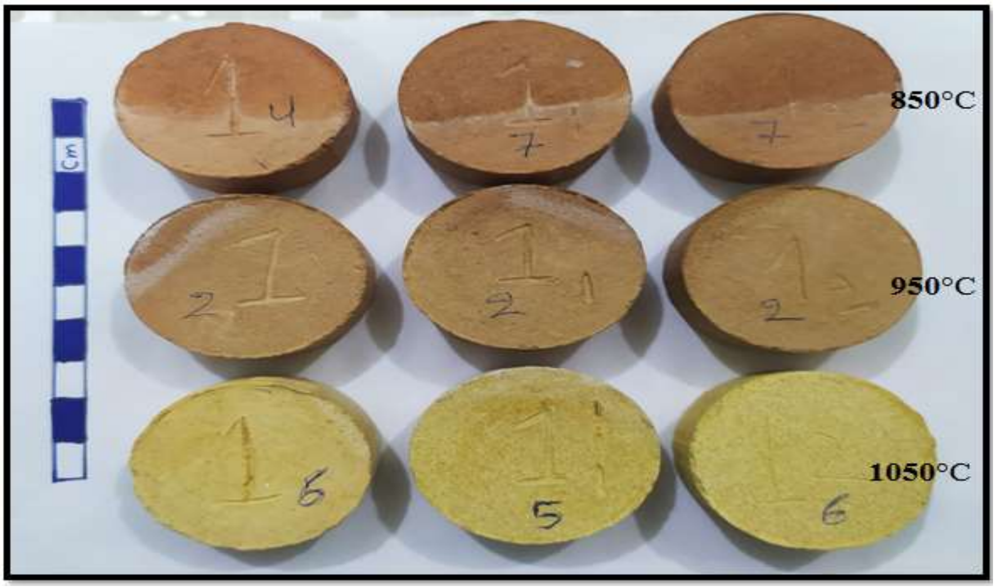

Figure 9: Variation in the degree of efflorescence in bricks samples at different firing temperatures.

7. Assessment of clay Bricks

The manufactured clay bricks were evaluated by comparing their physical, mechanical, and chemical properties with the requirements of the Iraqi British and American Standard Specifications [10,29,52] (Table 8). The firing at 850 and 950°C gave class A according to[10] compared to the fired bricks at 1050°C, which gave class B. The firing samples at 850°C gave class A according to [52] and gave class B at firing temperatures 950 and 1050°C.

Table 8: The requirements of the Iraqi, British and American Standard Specifications.

Requirements	Iraqi standards (25,1993)			American standards (C62-10, 2010)			British standards (3921, 1985)	Average of present study of Fatha formation samples		
Glasses	**A**	**B**	**C**	**A**	**B**	**C**		**850**°C	**950**°C	**1050**°C
Water absorption %	22	26	28	20	25	-	No limit	20	21.71	24.06
Compressive strength N/mm^2	16	11	7	17	15	9	> 5	38.35	36.23	41.63
Efflorescence	S	M	H	-	-	-	N-M	M-N	S	N

8. Conclusions

The results of the current study lead to the following conclusions:-

1- The Fatha Formation clay deposits in the Zurbatiya area have good extensions and thicknesses.

2- Clay deposits are classified as sandy mud to mud, characterized as plastic to moderately plastic, and can be easily formed and suitable for manufacturing clay bricks.

3- Quartz and calcite are the most common non-clay minerals in clay deposits, followed by gypsum, dolomite, and feldspar minerals in lower percentages, whereas montmorillonite-chlorite mixed clay has the highest amount, followed by Palygorskite, illite, kaolinite and Chlorite.

4- Silica, calcium, magnesium, aluminium and iron oxides were considered the main components of the clay samples and occur in acceptable percentages as important oxides in clay raw materials for the brick industry.

5- The physical, chemical, and mechanical properties agree with Iraqi Standard Specifications No.25,1993 and American Standards (ASTM C62-10, 2010) for class A and B bricks.

6- Fatha clay deposits are suitable raw materials for manufacturing ordinary clay bricks.

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