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Evaluation of the Injana claystone from Central Iraq for the brick industry

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Abstract

This study aims to suggest an alternative to the use of quality agricultural soil in the brick industry (Iraq). The Late Miocene claystone bed in the Injana Formation in central Iraq was targeted through the study of 18 exposed sections that were sampled by using the trench sampling method. The claystones are characterized by quartz (36.4%) followed by calcite (32.8%), quartz (36.4%) feldspar (2.6%), gypsum (1.3%) and dolomite (0.7%), kaolinite (10.5%), illite (7.7%), chlorite (6.7%), palygorskite (6.0%) and montmorillonite (0.7%). New thermal mineral phases were formed at 950°C, including diopside (62.9%), quartz (18.4%), wollastonite (8.28%), akermanite (7.6%), Anorthite (6.25%), Nosean (4.9%), gehlenite (3.75%) and Lazurite (3.15%). The raw material's engineering tests showed that the Atterberg index for the plasticity varies from low to high, low volumetric and linear shrinkage during drying and firing with a temperature at 950°C. The raw material produced bricks with 155 kg/cm^2 uniaxial compressive strength, 23.2% water absorption, and zero to low efflorescence. The results show the potential use of the Late Miocene clays of the Injana Formation to replace the existing agricultural grade muds presently being manufactured within the A and B category based on the Iraqi standard specification No.25 in 1993.

Keywords: Bricks; compressive strength; geotechnical evaluation; Injana Formation claystone; Atterberg limit.

1. Introduction

The original raw material for brick production in ancient times was clay soil, and today there is a paucity of mineral reserves of high-quality claystone sources to satisfy the markets (Šál, 2019). Currently, bricks are made in Iraq from recent clay of the floodplains, which is fertile soil that can be invested solely for agriculture. The continuation of such activity will eventually lead to a reduction in agricultural output due to the over-exploitation of the river basins in Iraq. The rapid population growth led to increased bricks for consumption, resulting in depletion of the soil from agricultural lands. Alternatives exist. The large deposits of Injana clays provide a new potential source that will lead to better conservative actions for the alluvium clays in Iraq's river basins. The Injana Formation (Late Miocene) was targeted due to its extensive reserve of clay. In the area of interest, the Injana formation is very well exposed along a region called the Tar located in the Karbala-Najaf Plateau. The previous studies were done by Merza & Mohyaldin, 2005; Maala *et al.*, 2007; Ismail & Omar, 2014, mentioned that the Late Miocene claystones in N Iraq conform to the parameter specifications regarding the raw material of brick manufacturing. This paper is going to: 1) Assess the mineralogical, chemical, and physical properties of the Late Miocene claystone known as the Injana Formation as raw material for the bricks production, 2) Manufacture of bricks using protocols for lab procedures, and 3) Evaluation of the quality of the produced bricks.

2. Study area and geological setting

The study area is exposed on two cliffs known locally: Tar Al-Najaf and Tar Al-Sayyed, situated in Iraq's central part. The area is characterized by vertical cliffs which trend NE-SW and NW-SE, respectively (Figure 1). The exposed rocks in the study area are Injana Formation, Dibdibba Formation, and adjacent Quaternary sediments (Hassan, 2007). The Injana Formation (Late Miocene) is one of the most widespread in central, eastern, and northern Iraq (Buday, 1980), with thickness varies from 9 to 27m in the Najaf-Karbala plateau (Dawood, 2000). This formation is divided into two units, the upper cave–forming claystone unit and the lower clastic unit (Awadh & Aboud, 2013). The section TN3 is displayed below, together with an outcrop stratigraphy in Figure 2.

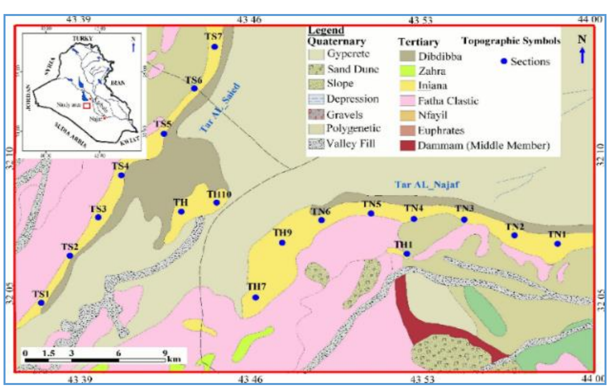

Fig. 1. Geological map shows sections and sampling sites.

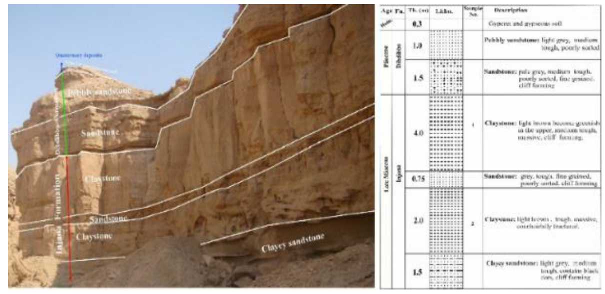

Fig. 2. Stratigraphic column and photo showing section TN3in the study area.

3. Sampling and methodology

3.1. Field and laboratory procedures

Eighteen stratigraphic sections of Injana exposed rocks were described, from which a total of 33 samples of claystone were collected along the western side of Karbala-Najaf Plateau, locally named Tar Al-Sayyed, Tar Al-Najaf, and many adjacent small hills for the chemical analysis. Twelve Samples (TS1-1, TS2-1, TS3-1, TS4-1, TS5-1, TS6-1, TS7-1, TN2-2, TN3-2, TN5-2, TN6-1, and TH7- 1) were selected for the physical tests. The physical tests (grain size analysis, liquid limit, plastic limit, compressive strength (CS) test, efflorescence (Ef) test, water absorption (WA) test, and combustion processes) were conducted in the laboratories of the General Company for Construction Industries in Baghdad. Mineralogical investigation using X-ray diffraction (XRD) for seven specimens (oriented and non-oriented) using a Bruker X-ray device, type D2 phaser. The 2Θ scan of the bulk samples ranged from 5 – 60° and between 4 - 20° for the oriented samples. The combustion process on samples was conducted at 950 ºC using a Japanese model known as LAC furnace. Twelve samples of claystone were subjected to several heating stages, which were elevated gradually to 950 °C using 5 minutes' intervals up to a maximum of 120 minutes (Duggal, 2008).

The XRD test was carried out in the Iraqi - Germany Laboratory, University of Baghdad.

All samples were analyzed for SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, K_2O, Na_2O, TiO_2, MnO, LOI, SO_3, and Cl by using X-ray fluorescence (XRF) at the ALS laboratory group in Spain using the code number ME-XRF26, and reference materials GIOP-102, NCSDC79001, SARM-5, and SY-4.

3.2. Geotechnical properties

The geotechnical properties of claystone were obtained through several laboratory tests includes:

3.2.1. Grain size analyses

Wet sieve analysis of claystone was performed by washing the samples. This procedure is capable of separating the fines from the larger grain sizes, especially those that cannot pass through a sieve of 200 mesh (less than 75 microns). Hydrometer analyses were carried out on both silt and clay according to American Standard Test Method D422-63 (2007) ASTM D422-63 (2007).

3.2.2. Atterberg limit

Two parameters were tested in order to understand the Atterberg limit. These are the liquid limit and plastic limit. The liquid limit of claystone is the moisture content, expressed as a percentage of the oven-dried claystone's weight, at the boundary between the liquid and plastic states of consistency (Grim, 1962). Water content values can be read easily from the x-axis against 25 blows on the y-axis. A liquid limit test was performed by a Casagrande device (Casagrande, 1947). It is determined according to ASTM for liquid limit, plastic limit, and plasticity index (2005). The plastic limit is the moisture content at which claystone begins to behave as a plastic material, at which water limit (plastic limit), the claystone will crumble when rolled into threads of 3.2 mm (1/8in) in diameter. This test can be done via rolling the spherical piece of claystone on a glassy plate (Ali *et al.*, 1990). According to ASTM for liquid limit, plastic limit, and plasticity index (2005), the plastic limit was carried out.

3.2.3. Water absorption test

This test is used to determine the soil's moisture content as a percentage of its dry weight. The samples are dried in an oven for a specified time at a temperature of 105 °C and, the bricks were immersed in water for 24 hours and then dried. The difference in weight between the wet and dried brick represents the WA. The WA test was conducted to determine the physical properties that influence the building materials (Shamiah *et al.*, 2018). WA is determined by using Iraqi standard specification No.25, 1993, (ISS No. 25 (1993), which defined the range 22 to 28% WA is accepted.

3.2.4. Efflorescence test

This test can be summarized by placing one end of the brick in a dish containing distilled water with a shallow level. The water should fill a dish so that the bricks are immersed in a depth of up to 2.5 cm. Since the water is completely absorbed and the brick appears to be dry, a similar amount of water is placed in the dish and allowed to evaporate for seven days. After this process, the effect of brick is examined through Ef (Table 1). The uniaxial compression strength is the maximum axial pressure that a cubic sample of claystone brick can withstand before failure (Topolinski, 2019). When the surface of the bricks is dried, each brick is tested for CS individually. The test brick is compressed between the plates of a compression-testing machine. The uniaxial compression strength was carried out using a 500 kilo Newton (K.N) C70 - Matest mechanical press, with the Cyber-Plus evolution touch-screen control unit. This test was conducted in the laboratories of the General Company for Construction Industries.

Table 1. Iraqi standard specification number 25, 1993, for clay brick manufacturing.

Class	Maximum absorption (%)	Minimum compressive strength		Efflorescence
		(Kgm/cm^2)	(KN/m^2)	
	1 brick	1 brick	1 brick	
A	22	160	16	Low
B	26	110	11	Medium
C	28	70	7	High

3.2.5. Compressive strength test

3.2.6. Molding

Twelve samples were molded using the extrusion method. The claystone samples' extrusion process was completed at the central laboratories in Iraq Geological Survey (GEOSURV), Baghdad, Iraq.

4. Results and discussion

The geotechnical properties of claystone have been tested and evaluated for suitability in the brick industry as follows:

4. 1. Chemical characteristics of claystone

The claystone beds in the Injana Formation are presented in Table 2. They composed of SiO_2 (40.9%), Al_2O_3 (9.1%), Fe_2O_3 (5.6%), CaO (17.1%), MgO (5.2%), K_2O (1.6%), Na_2O (1.7%), TiO_2 (0.77%), MnO (0.09%), LOI (16.1%), Cl (0.7%), and SO_3 (0.6%). The average content of elements was compared to the results of Al-Qazaz *et al.,* 2005, (Table 2).

Alumina, MgO, LOI, and Fe_2O_3 concentrations of the claystone appear to be slightly below the range of the analyses by Al-Qazaz *et al.,* 2005, while the silica concentrations, CaO, K_2O, and Na_2O are slightly higher than the limits of Al-Qazaz *et al.,* 2005.

The presence of quartz in the claystone of the Injana Formation (Late Miocene) contributes to affecting the weight due to its low specific gravity. (Al-Bassam, 2004). In the study area, the amount of quartz is high and appears to be effective. At high temperature, quartz reacts with Al_2O_3 and CaO forming Al, Ca, and silicates; in this case, the free CaO that causes cracking of the bricks will be reduced (Awadh & Abdullah, 2009). The claystone appears to have a slightly higher content of CaO, which suggests that the calcite and clay minerals are the source of the Ca. The carbonate content in claystone is a very important factor in forming bricks and must not exceed 40% (Al-Qazaz *et al.,* 2005). If the amount of carbonate is in excess of 40%, the bricks will swell due to the effect of carbon dioxide. LOI (CO_2 and H_2O) appears below the limits than the limits of Al-Qazaz *et al.*, 2005, attributable to the presence of substantial volatiles originating from the clay minerals (mainly hydrous species) and decomposition of carbonates (Mezencevova *et al.,* 2012). The amount of alkalis (K_2O and Na_2O) that act as flux materials was slightly higher due to the relatively high content of illite (Monterio & Vieira, 2004). The chemical analyses of samples of claystone are within acceptable limits published by Al-Qazaz *et al.*, 2005. As a result, shown in Table 2, the claystone is favorable for the brick industry.

4.2. Mineralogy of claystone

The XRD analysis provides information about the mineralogical composition. The XRD analyses show that the samples chosen from the Injana Formation consist of the non-clay and clay minerals. The average percentage of non-clay minerals, i.e., quartz is 36.4%, calcite is 32.8%, feldspar is 2.6%, gypsum is 1.3%, and dolomite is 0.7%. The average percentage of the clay minerals can be described as kaolinite (10.5%), illite (7.7%), chlorite (6.7%), and palygorskite (6.0%) (Figure 3A and B).

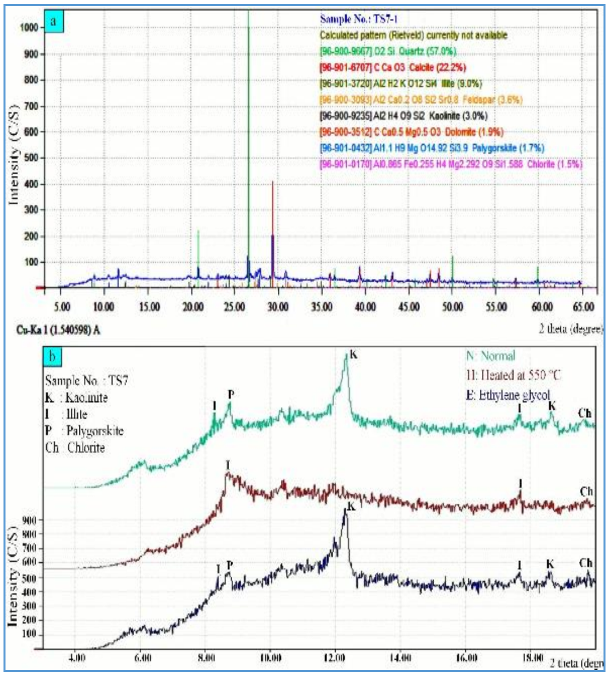

Fig. 3. XRD diffractograms of claystone sample TS7-1; **A)** Bulk sample, **B)** oriented clay fraction in different treatment stages.

4.3. Physical characteristics of claystone

4.3. 1. Grain-size distribution

The grain size distribution is presented in Table 3. In the present study, the percentages of clay and silt were calculated by using the hydrometer test method while the percentages of sand by a wet sieving method (ASTM D422-63 2007). The silt fraction ranges from 37.1% to 54.8%, followed by clay (29.0% to 39.1%), and sand (14.1% to 26.8%). Thus, the grain size falls within the parameters recognized for industrial-grade clay.

4.3.2. Plasticity of claystone

Plasticity is one of the most important factors for manufacturing claystone products. The clay plasticity is based on the Atterberg limits method that includes liquid limit (LL), plastic limit (PL), and plasticity index (PI). The LL and PL tests were performed using the Casagrande apparatus using the method described by Casagrande (1947). The PI represents the size of the range of water content where the clay shows plastic properties and exhibits the difference between the LL and the PL (Punmia *et al.*, 2003). The claystone samples have LL range from 42.2% to 56.2% with an average of 49.0 %, PL varies from 20% to 29.3% with an average of 24.5%. Accordingly, the PI of the claystone of Injana varies from 20.1% to 29.84 %.

According to the ASTM for liquid limit, plastic limit, and PI D 4318-05 (2005) and the modified Casagrande plasticity diagram (Keystone, 2003), Figure 4 shows that the samples (TS1-1, TS2-1, TS5-1, TS6-1, TN2-2, and TN6-1) are of low plasticity index (CL). On the other hand, the samples (TS3-1, TS4-1, TS7-1, TH7-1, TN3-2, and TN5-2) are of high plasticity index (CH). Bain, 1974, stated that the plasticity of clay depends on the PI, which varies from 20.12% to 29.84%, with an average of 24.3%. The average of PL is 24.5%, and the average of LL is 49.0 % (Table 4). These values meet the standard Iraqi (ISS, 1993), for brick manufacturing.

Table 2. Geochemical analysis results (%) of claystone samples in the study area.

Sample No.	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2	MnO	LOI	SO_3	Cl	Total
	%												
TN1-1	41.1	9.1	6	13.6	5.4	2	0.8	0.67	0.13	20.2	0.1	0.5	99.7
TN1-2	48.6	10.4	5.7	12.1	5.5	2.2	0.5	0.59	0.14	12.2	0.2	-	98
TN2-1	42.4	10.7	5.9	15.6	5.2	1.3	1.9	0.75	0.1	14.9	0.4	-	99.1
TN2-2	34.7	7.7	5.5	18.9	4.4	1.1	1.8	0.77	0.1	22.8	1	0.8	99.6
TN3-1	35.4	7.4	4.1	27.6	4.1	1.4	1.6	0.66	0.1	16.5	0.3	0.6	99.6
TN3-2	37.6	9.1	6.6	18.5	5.3	1.4	1.8	0.87	0.11	17.4	0.3	0.7	99.6
TN4-1	36.2	8	5.4	21.7	4.9	1.2	2.4	0.84	0.1	17.4	0.7	0.9	99.6
TN4-2	40.6	9.2	4.8	19.3	4.4	1.2	2	0.74	0.1	16.9	0.7	-	99.9
TN5-1	40.8	9	5.2	21.8	4.9	1.7	1.7	0.82	0.08	12.5	0.6	0.5	99.6
TN5-2	42.2	9.1	5.4	14.3	5	1.9	3.7	0.83	0.07	14.7	0.2	2.3	99.6
TN6-1	40.5	9.1	5.8	15.2	5	1.5	1.8	0.85	0.09	18	1	0.8	99.6
TN6-2	40.4	9.1	6	16.9	6.2	2.1	1.5	0.72	0.05	15.8	0.3	0.7	99.7
TS1-1	40.6	10.2	5.5	16.3	5.6	1.5	1.7	0.66	0.1	16.3	0.3	-	98.8
TS1-2	38.6	9	6.2	19.7	6.3	2.1	1.8	0.74	0.08	14.3	0.2	0.7	99.7
TS2-1	46.6	11.2	7.8	10.5	6.7	2.4	1.2	0.91	0.13	11.2	0.5	0.5	99.6
TS2-2	37.5	8.8	6.2	18.3	6.1	2	1.6	0.83	0.09	17.4	0.2	0.7	99.7
TS3-1	37.1	8.8	6.1	18	5.2	1.4	2.1	0.83	0.1	16.6	1.2	0.5	98
TS3-2	47.5	11.1	5.8	13.1	4.8	1.8	1.6	0.77	0.1	13.2	0.2	-	99.97
TS4-1	37.6	9.1	6.6	18.6	4.8	1.4	1.5	0.9	0.11	17.9	0.3	0.6	99.6
TS4-2	47.2	9.1	4.6	15.9	3.8	1.5	1.5	0.61	0.08	15.1	0.3	-	99.6
TS5-1	36.8	8.8	6.7	17.3	5.4	1.6	1.3	0.8	0.11	19.6	0.6	0.6	99.6
TS5-2	41.9	8.8	4.2	15.8	3.1	1.6	1	0.76	0.07	22.1	0.2	0.4	99.7
TS6-1	33.3	8.1	5.8	26.6	4.8	1.2	1.9	0.75	0.1	15.9	0.5	0.7	99.6
TS6-2	42.8	10.5	5.7	15.6	5.4	1.4	1.9	0.71	0.1	15.3	0.6	-	100
TS7-1	38.1	8.6	5.8	19.9	5.2	1.4	1.9	0.84	0.09	15.7	1.2	0.8	99.5
TS7-2	42.5	9.3	4.9	15.9	5.2	1.5	1.8	0.63	0.08	16.4	1.4	-	99.4
TH10-1	45.2	7.8	4.6	8.6	7.9	1.6	2.6	0.72	0.07	17.4	2.1	1.1	99.7
TH9-1	53.1	11	6.2	8.9	6.1	2.5	1.3	0.98	0.06	8.9	0.3	0.2	99.6
TH7-1	43.1	9.1	4.7	16	5.2	1.6	1.7	0.64	0.09	17.1	0.7	-	99.99
TH1-1	35.2	7	5.6	22.6	4	1.3	1.7	0.77	0.11	14	0.5	1.4	94.1
TH1-2	36.7	8.9	4.2	18	5.2	1.4	2.1	0.83	0.1	19.6	1.2	0.8	99.03
TH-1	52.9	7.5	6.2	13.4	6.2	2.6	0.6	0.7	0.08	6.9	2.2	0.5	99.78
TH-2	35.9	10.6	4.4	18.6	4.8	1.4	1.5	0.9	0.11	19.9	0.3	0.9	99.31
MAX	53.1	11.2	7.8	27.6	7.9	2.5	3.7	0.98	0.14	22.8	2.1	2.3	100
MIN	33.3	7	4.1	8.6	3.1	1.1	0.5	0.59	0.05	8.9	0.1	0.2	98
AV.	40.9	9.1	5.6	17.1	5.2	1.6	1.7	0.77	0.09	16.1	0.6	0.7	99.5
***Q. AV.**	40.4	10.3	6.08	17.08	6	1.2	1.5			17			

***** Al-Qazaz *et al.*, 2005.

Table 3. Results of the grain size analysis.

Sample No.	Clay (%)	Silt (%)	Sand (%)
TS1-1	35	50.9	14.1
TS2-1	39	44.5	16.5
TS3-1	33	43.8	23.2
TS4-1	39.1	37.1	23.8
TS5-1	35	41.5	23.5
TS6-1	34	41.3	24.7
TS7-1	29.1	49.3	21.6
TN2-2	38	44.5	17.5
TN3-2	32	41.2	26.8
TN5-2	29	54.8	16.2
TN6-1	32.5	50	17.5
TH7-1	36	49.2	14.8
Av.	34.3	45.7	20
Min.	29.0	37.1	14.1
Max.	39.1	54.8	26.8

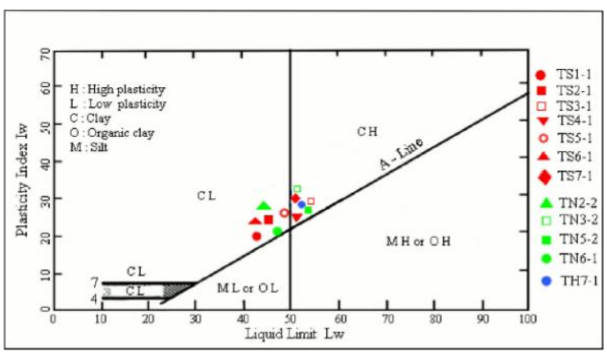

Fig. 4. The plasticity diagram shows the results of plasticity limits for claystone samples.

Table 4. Plasticity Limit values indicated by Casagrande test methods.

Sample No.	Plasticity Limit		
	Liquid Limit	Plastic Limit	Plasticity Index
	(%)		
TS1-1	43.7	21.74	21.96
TS2-1	46.28	23.62	22.66
TS3-1	56.16	27.2	28.96
TS4-1	50.66	21.25	29.41
TS5-1	49.05	26.75	22.3
TS6-1	42.24	21.33	20.19
TS7-1	50.58	25.5	25.08
TN2-2	44.51	20	22.51
TN3-2	53.04	23.2	29.84
TN5-2	52.25	29.25	23
TN6-1	47.26	27.14	20.12
TH7-1	52.5	26.53	25.97
Min.	42.24	20	20.12
AV.	49	24.5	24.3
Max.	56.16	29.25	29.84

4.3.3. Water Absorption capacity

The WA test is performed on a brick to determine the amount of moisture content absorbed by brick (Figure 5). The WA is determined by using Iraqi standard specification No.25, 1993, (ISS No. 25, 1993). It can be obtained from the following simple equation.

$$W = \frac{W2-W1}{W2} * 100 \quad (1)$$

Where W is the water absorption, W2 is the weight of brick after 24 hours in the water, and W1 is the dry brick weight.

The WA is an important factor in the clay bricks used in construction (Sonbul and Abu Seif1, 2019). The bricks characterized by low absorption need little quantity of cement bonds, but those of high absorption need more cement so that the cost will be high (Al-Beyate, 2011). The studied samples' values range from 19.3% to 27.6%, with an average of 23.2% (Table 5). The ISS No. 25 (1993) limited the acceptable WA (%) ranges to be from 22 to 28.

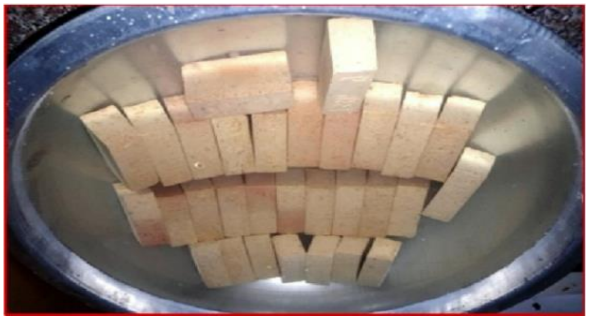

Fig. 5. Brick samples immerse in water during the water absorption test.

4.3.4. Efflorescence

Ef is defined as the residual salts on the brick surface after evaporating the water. According to the Australian Standards Relevant to Masonry, crystalline salts or amorphous crystals represent minor salts (ASRM, 2017).

The accepted value for brick manufacturing (class A) is 22% and 26% for class B. Thus, samples TS2-1, TS4 -1, TN5 -2, and TN6-1 are classified as class A; the rest are class B (Table 5). All samples are accordingly suitable for the brick industry. The Ef content ranged from nil to low, indicating the potential for use in the brick industry (Figure 6).

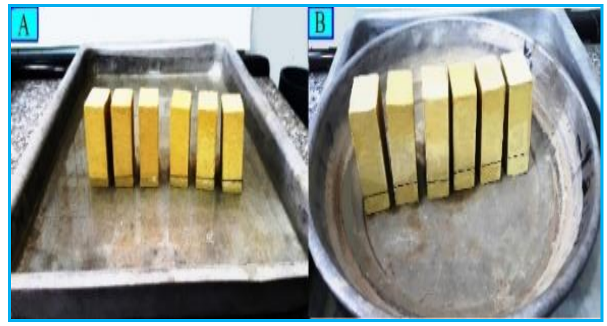

Fig. 6. Efflorescence test for some brick samples A-during immersed in water, B-after dried from water.

Table 5. Results of engineering and physical properties of Injana claystone.

Sample No.	Brick dimensions (cm)			DL (%)	DV (%)	Physical characters			
	L	W	H			CS (Kg/cm^2)	WA (%)	Ef	Class
TS1-1	6.85	3.7	2.4	0.05	0.5	104	26.1	Low	B
TS2-1	6.9	3.7	2.4	0.1	0.9	204	20.2	Nil	A
TS3-1	6.87	3.7	2.4	0.07	0.7	113	25.9	Low	B
TS4-1	6.83	3.7	2.4	0.03	0.3	183	21.2	Nil	A
TS5-1	6.87	3.7	2.4	0.07	0.7	150	24.6	Low	B
TS6-1	6.88	3.7	2.4	0.08	0.8	167	21.1	Low	B
TS7-1	6.91	3.7	2.4	0.02	0.1	123	23.7	Low	B
TN2-2	6.89	3.7	2.4	0.01	0	165	26.2	Low	B
TN3-2	6.86	3.7	2.4	0.06	0.7	118	25.6	Low	B
TN5-2	6.86	3.7	2.4	0.06	0.7	225	19.3	Nil	B
TN6-1	6.88	3.7	2.4	0.08	0.8	181	21.8	Nil	A
TH7-1	6.85	3.7	2.4	0.05	0.5	127	22.9	Low	B
Average	6.87	3.7	2.4	0.06	0.56	155	23.2	Low	B

4.3.5. Dimensional changes

Linear shrinkage is determined by measuring the length of the sample before and after drying or firing. At high temperatures, the brick particles merged, leading to better proximity and a more enhanced linear shrinkage (Nkalih *et al.*, 2018).

The burning bricks must have linear shrinkage < 8% in order to maintain good mechanical performance (Rguibi, 2017). High linear shrinkage leads to tension and breakage, resulting in reduced mechanical strength. Furthermore, the linear shrinkage and mechanical strength are negatively correlated. Linear strength (before and after drying) is calculated as follows:

$$Linear\ drying\ shrinkage\ \% = \frac{Lv - Ld}{Lv} * 100 \quad (2)$$

Where Lv is the length of the viscous sample (cm) and Ld is the length of the dried sample (cm).

The longitudinal deflation ranges from 0.01% to 0.1% with an average of 0.06%, whereas volume deflation ranges from 0.1% to 0.9% with an average of 0.56% (Table 5). The produced bricks are characterized by smooth surfaces with parallel sharp and straight edges. It has a good general appearance that is free from cracks, and the color ranges from yellow to yellowish-white (Figure 7).

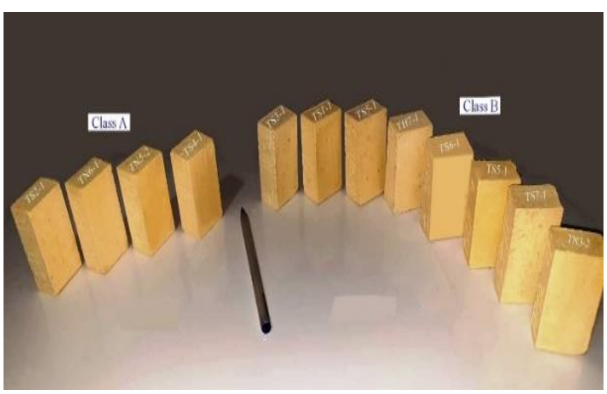

Fig. 7. Claystone brick samples belonging to categories A and B.

4.3.6. Compressive strength

The CS test is higher than the standard of the ISS No. 25 (1993) and ranges from 104 to 225 kg/cm^2 with an average of 155 kg/cm^2 (Table 5). The decrease in porosity leads to increased density, compressive strength, and claystone samples' mechanical strength (Baccoura *et al.*, 2008). The 160 Kg/cm^2 and 110 Kg/cm^2 are recommended as a minimum CS for class A and class B, respectively, for the manufacturing bricks based on the ISS No. 25 (1993). Brick samples are cracking at a peak load range of 55.2 to 25.6 KN/m^2 for example; the sample TS1-1 is cracking at 25.6 KN/m^2 (Figure 8).

Fig. 8. Brick sample (TS1-1) in the compression machine shows cracking at 25.6 KN/m^2 of the peak load.

4.3.7. Mineral phase transformation

The XRD analysis of the powdered brick is fired at 950 °C and derived from sample TS7-1 (Figure 9). The sample (TS7-1) formed from the firing up to 950°C resulting in the formation of new phases such as diopside (62.9%), quartz (18.4%), wollastonite (8.28%), akermanite (7.6%), Anorthite (6.25%), Nosean (4.9%), gehlenite (3.75%) and Lazurite (3.15%). The normal clay brick includes the following ingredients: silica (sand) 50%-60%, alumina (clay) 20%-30%, lime 2%-5%, iron oxides

5%-6%, not more than 7%, and magnetite less than 1% by weight (Punmia *et al.*, 2003). The disappearance of clay minerals can summarize the most important mineral changes since they do not tolerate the high temperatures due to a collapse of the crystalline structure and loss of crystalline water (Abd, 2000). Carbonate minerals are completely consumed, forming new mineral phases such as gehlenite, which is one of the melilite group minerals (Hibbard, 2002). The firing process causes the decomposition of carbonates, clay, and silicates and the formation of a melt phase rich in Si, Al, Ca, and K. The feldspar evolves into anorthite (Trindade *et al.*, 2009). In the sample TS7-1, kaolinite is consumed at 550ºC. Quartz is present throughout the entire temperature range. Gehlenite appears at 900ºC. Diopside appears at 900ºC to 1000ºC.

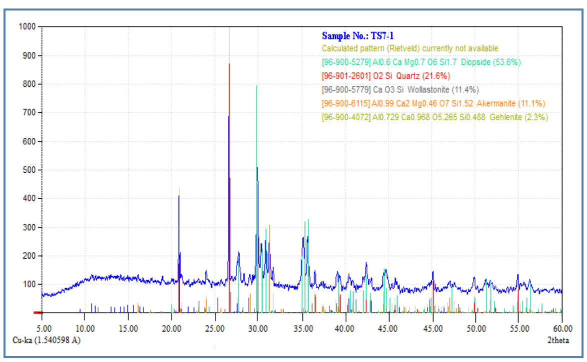

Fig. 9. XRD diffractograms of claystone (brick sample TS7-1**)** burned to 950°C.

5. Conclusions

1. A proven reserve of the Late Miocene claystone of Injana Formation in the study area meets the Iraqi standards of brick manufacture and suitable to the brick industry.
2. The Late Miocene claystone collected from Injana Formation is composed of kaolinite (10.5%), illite (7.7%), chlorite (6.7%), palygorskite (6.0%) and montmorillonite (0.7%), quartz (36.4%), calcite (32.8%), feldspar (2.6%), gypsum (1.3%) and dolomite (0.7%).
3. New mineral phases were formed after firing to 950 °C such diopside (62.9%), quartz (18.4%), wollastonite (8.28%), akermanite (7.6%), Anorthite (6.25%), Nosean (4.9%), gehlenite (3.75%) and Lazurite (3.15%).
4. The average of CS (155 kg/cm^2) for the burning claystone, the Atterberg limit values, and the WA (23.2%) contribute towards the hypothesis that the claystones are suitable for the brick industry.
5. The results of dimensional changes revealed that the volumetric and linear shrinkage for brick samples is low during drying and firing at 950 ° C.
6. The Ef is low, and thus salts are not a problem.
7. The grain size of the sample studied is composed of clay (34.3%), silt (45.7%), and sand (20%).
8. The positive results confirm the possibility of Late Miocene claystone from the Injana Formation can be utilized as a raw material for brick production in the Najaf- Karbala plateau, Central Iraq.

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