Assessment of Some Clay Deposits from Fatha Formation (M. Miocene) for Brick Manufacturing in Koya Area, NE Iraq

Nawzat R. Ismail[1] and Hemn M. Omar[2]

[1]Department of Petroleum Engineering, Faculty of Engineering, Koya University
University Park, Danielle Mitterrand Boulevard, Koya KOY45, Kurdistan Region - F.R. Iraq

[2]Department of Geotechnical Engineering, Faculty of Engineering, Koya University
University Park, Danielle Mitterrand Boulevard, Koya KOY45, Kurdistan Region - F.R. Iraq

***Abstract*— This paper deals with the evaluation of physical, chemical and mineralogical properties of claystone sediments of Miocene age (Fatha Formation) and their suitability to use them as raw materials in manufacturing of building clay brick in Kurdistan (Koya city). The study based on the field reconnaissance for three sites of claystones which were selected from three different locations within Fatha Formation in Koya city, includes Haibat-Sultan area, Koya-Sulaimania road and central of Koya city. The clay samples were subjected to particle size distribution, chemical composition, mineralogical analysis, plasticity index and XRD tests. Clay tiles were produced by using Semi-dry method under load 78 kN/mm² and fired at 950 C°. The produced clay tiles were subjected to water absorption, efflorescence, shrinkage and compressive strength tests. The research has shown that the plasticity index depends on the mineral composition of the raw materials. The grain size analysis of raw materials, physical properties and mechanical properties of the produced tiles has shown the suitability of the used raw materials in producing class bricks of class A (first class) according to the requirements of specification of the Iraqi Standard (1993).**

***Index Terms*—Clay brick, physical properties, plasticity, X-ray diffraction.**

I. Introduction

Clay brick is made from selected clays that are molded or cut into shape and fired in oven; clay is one of the most abundant natural mineral on the earth. For brick manufacturing, clay must possess specific properties and characteristic, such as, having plasticity which permits them to be shaped or molded when mixed within sand, flux like CaO and water, and they must have sufficient wet and air-dried strength to maintain their shape after had been forming. Also, when subjected to high temperatures, the clay particles must be fuse together. Some studies were carried out on the same purpose (Lateef, 1976) evaluated the claystone sediments of Neogene age for foothill zone of Hamrin range which are mainly consistent of 20% - 50% clastic sedimentary sequence. Merza (1997) evaluated some clay deposits of Late Cretaceous-Tertiary age in the North East Iraq for manufacturing of ceramic tiles. Al-hakim (1998) studies some clay deposits of Neogene age for brick manufacturing. Merza (2002) evaluated some clay deposits from the upper part of Gercus Formation (M-Miocene), North East Iraq for brick manufacturing. Merza (2004) used the recent deposits salty clay around the Aliawa village, in south of Sulaimania city for production of glazed ceramic tiles through mixing recent deposits, Sirwan river deposits and gorge. She found that some of raw materials are suitable for manufacturing ceramic tiles for covering the walls of kitchens, public building balconies and baths. Also, (Merza and Mohyaldin, 2005) used fourteen types of clay were selected from different locations in Kurdistan region and found that some of these raw materials are suitable for manufacturing the solid and perforate bricks. Maala, et al. (2007) dealt with evaluation of the physical, chemical and mineralogical properties of mudstone sediments of Neogene age (Injana and Bai Hassan Formations) and their suitability to use them as a raw material in manufacturing of building bricks. This research focuses on raw materials which were taken from three different locations in Koisanjaq (Koya) city and have the same formation (age) and depositional environment (Buday, 1980; Buday and Jassim 1987; Al Jaboury and McCann, 2008). The locations of studied samples are shown in Fig. 1, which are intersected between latit. (36° 03′ 40″ – 36° 06′ 00″) North and long.(44° 38′ 00″ – 44° 42′ 00″) East.

ARO-The Scientific Journal of Koya University
Volume II, No (1)2014, Article ID: ARO.10030, 8 pages
DOI: 10.14500/aro.10030
Received 26 August 2013; Accepted 24 February 2014
Regular research paper: Published 05 June 2014
Corresponding author's e-mail: hemn.omar@koyauniversity.org

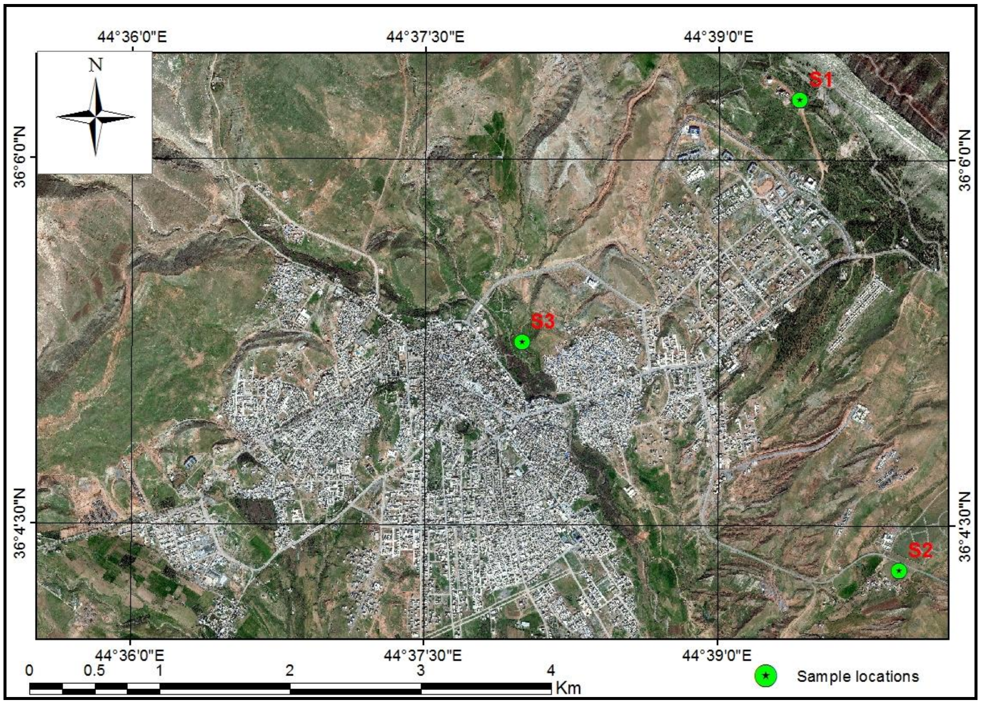

Fig. 1. Location map of Koya city, which indicates the test locations (Basir, 2013).

In order to point out the different parameters, which are conditioning the behavior of the raw materials and their suitability for clay brick industry, many tests are made on the collected raw materials such as, plastic properties and grain size distribution. Qualitative and quantitative mineral investigations were carried out by means of X-Ray Diffraction (XRD).

II. Geological Setting

The raw materials were collected from different locations in Koya city are belonging to Fatha Formation. The Fatha Formation is one of the most widespread and economically has an important formation in Iraq especially in Kurdistan region. It forms continuous belt at the foot South West limb of Haibat-Sultan Mountain in Koya area and lies in Unstable Shelf, High Folded Zone with North West–South East trends parallel to Zagros belt (Buday and Jassim, 1987). It is from Middle Miocene age, comprises anhydrite, gypsum, and salt interbedded with limestone and marl (Buday, 1980).

The thickness of the formation is greatly variable. In the central parts of the basin thickness up to 900 m, was reported whereas the thickness of the formation in the studied area ranges between 60 – 200 m (Youkhana and Sisskian, 1986; Omer, 2009). The formation represents the deposit of a relatively strength sinking basin, which often had been separated from the open sea by rising ridges (Buday, 1980). The formation consist of cyclic deposits of mudstone and limestone with gypsum beds in lower cycles, mudstone, reddish brown in color are soft and highly fractured which represent the main consistent of the formation (Omer, 2009). In the studied area, the formation comprises cycles of claystone, siltstone, and sandstone with gypsum and limestone bed. Claystones, reddish brown in colour are fine to very fine grained and moderately thick bedded which represent the main constituents of the formation.

III. Methodology and Test Procedure

This research concerns the raw materials from three different locations in Koya area of Kurdistan region, Table I. Three samples were collected which are representing the clay from Fatha Formation.

In order to point out the different parameters which have the fractures of raw materials and their suitability for brick industry, as many tests have been done on the collected raw materials by laboratory of geological survey and mineral investigation, Baghdad.

 http://dx.doi.org/10.14500/aro.10030

TABLE I
LOCATIONS OF THE STUDIED SAMPLES

Sample No.	Formation	Locations	Coordinate (Latitude & Longitude lines)
S1	Fatha	Haibat-Sultan area	36° 06′ 15″ North & 44° 39′ 25″ East
S2	Fatha	Koya-Sulaimania road	36° 04′ 18″ North & 44° 39′ 54″ East
S3	Fatha	Central of Koya city	36° 05′ 15″ North & 44° 38′ 00″ East

The following points are based on the tests results:

- Particle size by sieve analysis based on Triangular Folk diagram, (Folk, 1974) were grouped into three fraction (sand, silt and clay), Table II, to estimate the percentage of each fraction content and evaluate the type of soil texture classification for suitability of different clay brick manufacture. Based on Triangular Folk diagram the samples (S1 and S3) are clayey silt (Mud), and the sample (S2) is Sand-Silt-Clay (Sandy mud) which may be suitable for clay brick manufacturing.
- Chemical composition analysis based on XRF (X-Ray Florescence) shows the percentage oxides content of elements such as (SiO_2, Fe_2O_3, Al_2O_3, CaO, MgO, Na_2O, K_2O and SO_3), Table III.
- The plasticity values based on Standards American Society for Testing and Materials (1996), casagrandes plasticity chart is directly related to the mineralogical composition (Bill, et al., 1992; Moulluid, 2000) which is depending on plasticity index. There are no effect of organic matter on the plasticity properties because the chemical analysis shows that the studied samples are empty from organic matter as well as the type of clay is belong to inorganic clays of low to medium plasticity (CL), Table IV.
- X–Ray Diffraction test (XRD) is now a common technique and most widely used for the identification of unknown crystalline materials (minerals). All diffraction methods are based on generation of X–ray in an X–ray tube, these X–ray are directed at the sample, and the diffracted rays are collected. The intensity of diffracted X–rays is continuously recorded as the sample and detector rotate through their respective angles. A peak in intensity occurs when the mineral contains lattice planes with d – spacing appropriate to diffract X–ray at the value of θ. Results are commonly presented as peak positions at 2θ and X–ray counts (intensity) (Brady, et al., 1995). Merza and Mohyaldin (2005) studied the Fatha Formation in Kurdistan for brick manufacture and found that it contain some of clay minerals such as (illite, smectite, kaolinite and chlorite) which are suitable for manufacturing of bricks. In the present research the X – Ray Diffraction (XRD) used to estimate the clay minerals by orientated sample curve, whereas non clay minerals estimated by bulk sample curve. XRD charts in Fig. 2, Fig. 3, Fig. 4 and Fig. 5 show that the studied samples are components of clay minerals (chlorite, illite, montmorillonite and illite–smectite mixed layer), and non-clay minerals (quartz, calcite, muscovite and plagioclase). These tests are done by laboratory of geological survey and mineral investigation in Baghdad.

TABLE II
THE PARTICLE SIZE DISTRIBUTION PERCENTAGE OF THE STUDIED SAMPLES

Sample No.	The particle size distribution %			Type of soil
	Clay % < 0.002 mm	Silt % 0.002 – 0.063 mm	Sand % > 0.063 – 2 mm	Texture classification
S1	40	59	1	Clayey silt (Mud)
S2	31	48	21	Sandy mud (Sand-Silt Clay)
S3	30	66	4	Clayey silt (Mud)

TABLE III
CHEMICAL COMPOSITION PERCENTAGE OF THE STUDIED SAMPLES

Sample No.	SiO_2 %	Fe_2O_3 %	Al_2O_3 %	CaO %	MgO %	L.O.I %	Na_2O %	K_2O %	SO_3 %
S1	45.8	5.98	17.45	10.08	2.8	11.6	0.8	2.66	< 0.07
S2	49.9	6.06	19.0	6.16	3.8	8.54	0.91	2.8	< 0.07
S3	46.72	5.26	15.5	11.76	2.7	11.87	1.0	2.34	< 0.07

TABLE IV
THE RESULT OF ATTERBERG LIMITS SAMPLES AND THE CORRESPONDING TYPE OF SOIL

Sample No.	(Liquid Limit) L.L.	(Plastic Limit) P.L.	(Plasticity Index) P.I.	Type of soil
				Grade symbol
S1	38.35	22.79	15.56	CL
S2	25.48	16.99	8.48	CL
S3	22.34	15.65	6.70	CL

- Methodology for preparing the molded samples is semi – dry method of forming three tiles under press load 78 kN/mm² were adapted and fired at a temperature of 950 C°, the studying of physical and mechanical properties of the samples include the following:

- Compressive strength (three molded samples used for repeating the test).
- Linear shrinkage (very little affected).
- Volume shrinkage (very little affected).
- Water absorption.
- Efflorescence (none).

The results of the above properties were compared with the requirements of specification of the Iraqi Standard, 1993) as shown in Tables V and VI.

TABLE V
SPECIFICATION OF THE IRAQI STANDARD (1993) FOR CLAY BRICK MANUFACTURING

Efflorescence	High limit of water absorption %		Low limit of compressive strength Kg/cm^2		Classes
	(for one brick)	Average water absorption (for ten brick)	Compressive strength (for one brick)	Average compressive strength (for ten brick)	
Light	22%	20%	160	180	A
Medium	26%	24%	110	130	B
-----	28%	26%	70	90	C

TABLE VI
THE RESULTS OF SOME BRICK PHYSICAL AND MECHANICAL PROPERTIES OF THE STUDIED SAMPLES

Sample No.	Brick dimensions (cm)			Linear shrinkage %	Volume shrinkage %	Physical properties		Mechanical properties	Class
	Length	Width	Height			Water absorption %	Efflorescence	Compressive strength Kg/cm^2	
S1	7.38	3.9	2.58	0.5	0.6	20	None	407	A
S2	7.33	3.88	2.56	0.5	0.4	18	None	376	A
S3	7.24	3.77	2.48	0.5	2.5	19	None	429	A

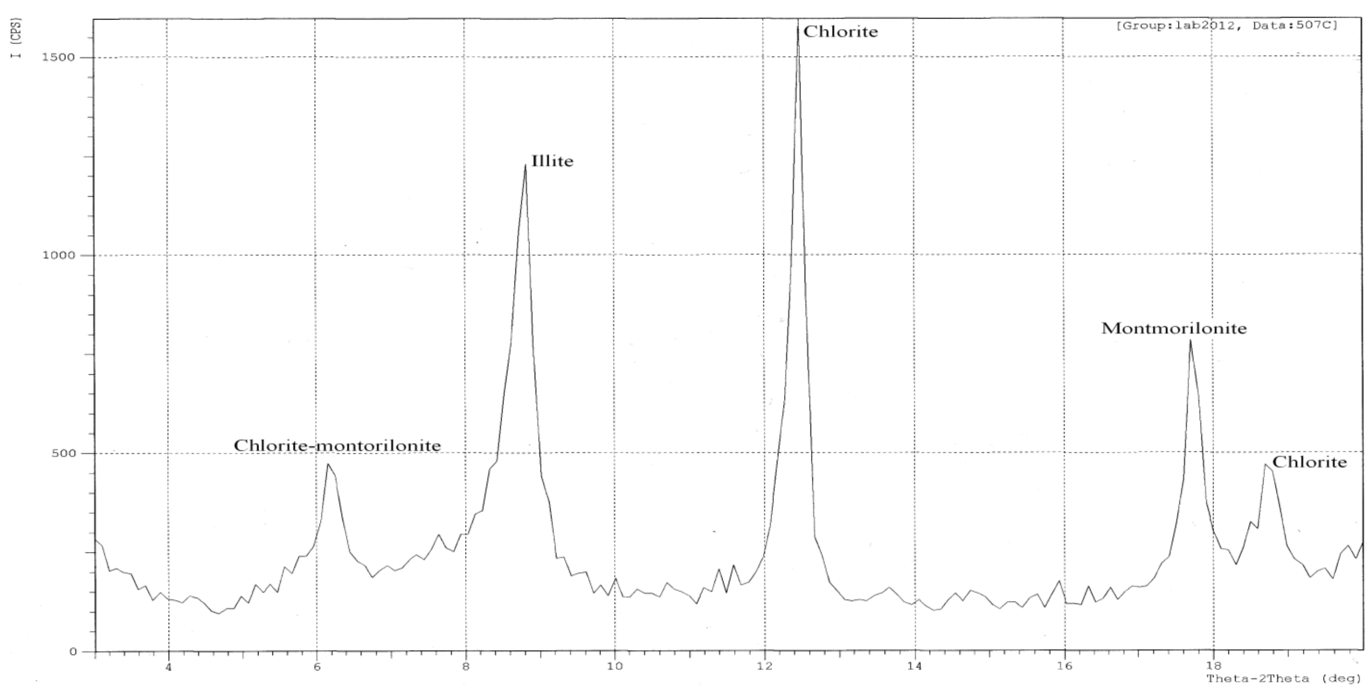

Fig. 2. XRD chart for the Sample No. S1 (Oriented sample)

 http://dx.doi.org/10.14500/aro.10030

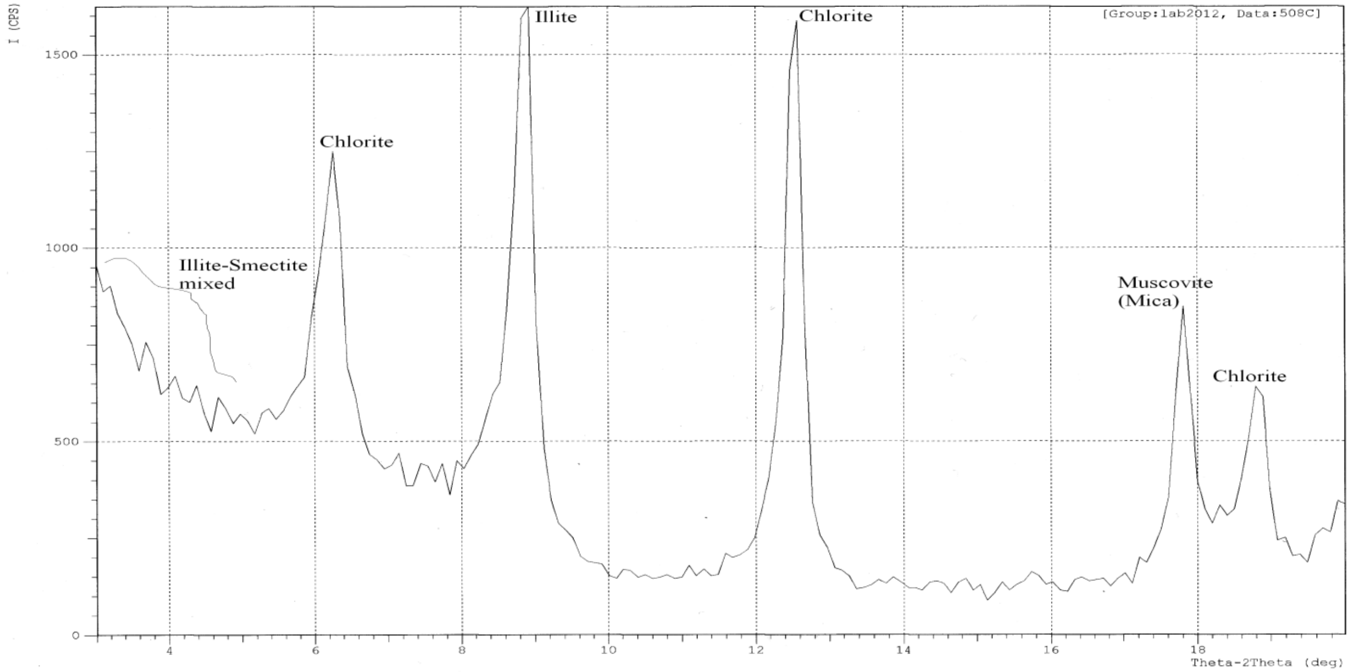

Fig. 3. XRD chart for the Sample No. S2 (Oriented sample)

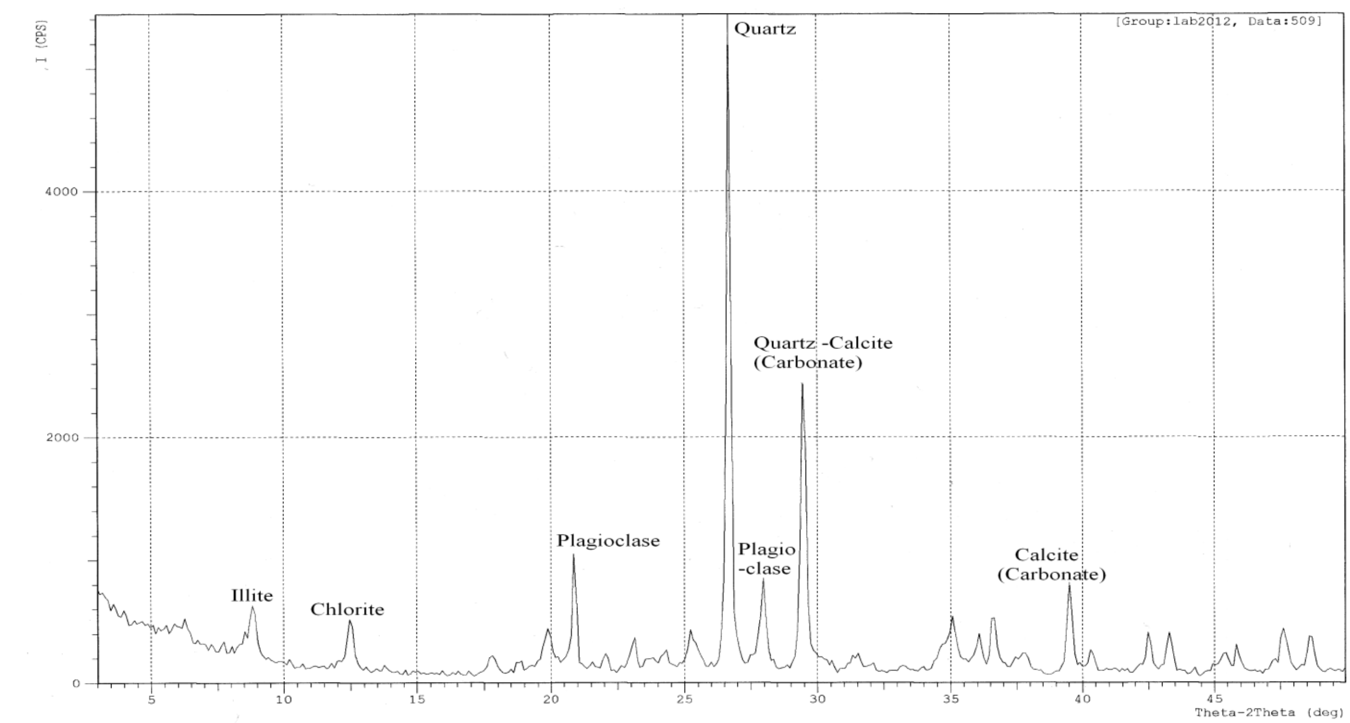

Fig. 4. XRD chart for the Sample No. S3 (Bulk sample)

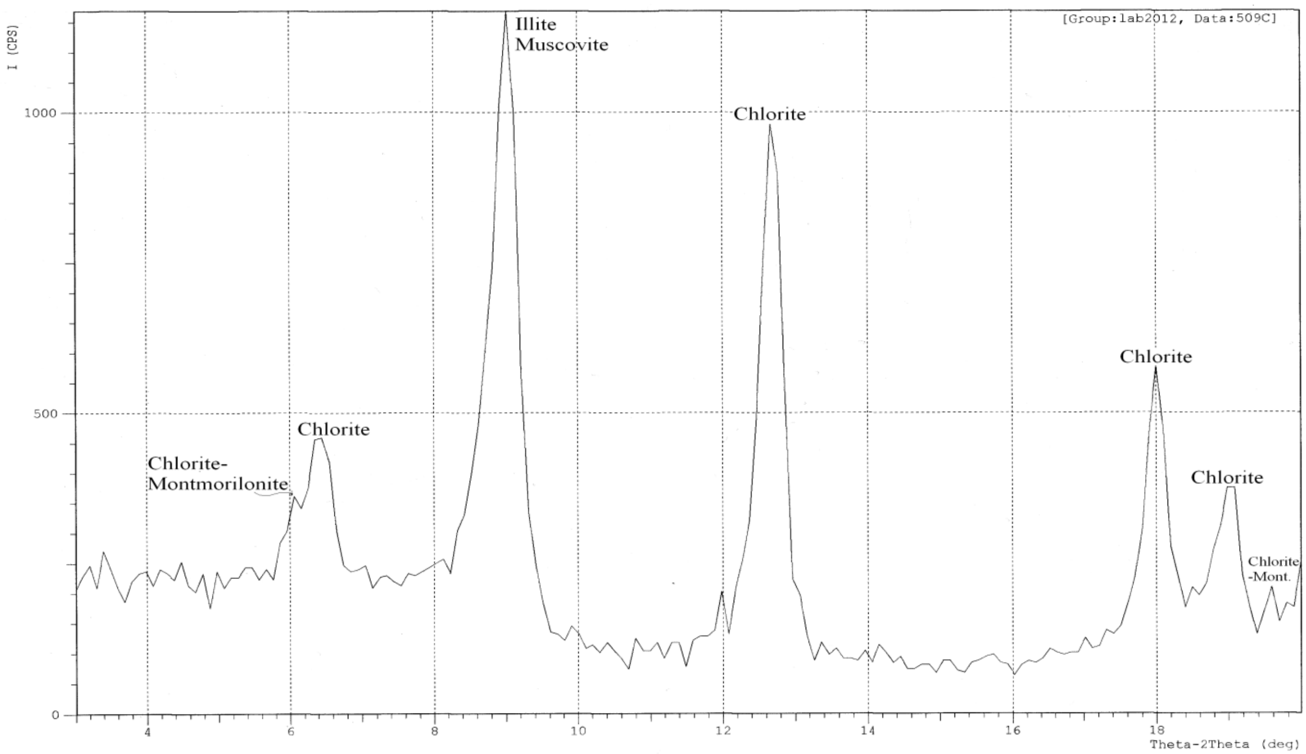

Fig. 5. XRD chart for the Sample No. S3a (Oriented sample)

IV. Results and Discussion

- The result of particle size analysis in Table II shows that the dominant percentage of silt fraction ranging 48% – 66%, the percentage of clay 30% – 40% and sand 1% – 21% in the three studied samples. Based on the Triangular Folk Diagram (Folk, 1974) which used to classify the clastic sediments, the studied samples consist of clayey silt (mud), and sand-silt-clay (sandy mud), these constituents and CaO about 10% have little amount of gypsum which are unaffected on the cohesive of the clay brick if they are occur in the chemical composition of the clays and cause failure of the brick (Allen and Lano, 2009), to compare between these results with the clay bricks of Iraqi Standard (1993), Table V, which are consist of the same fractions (silt-clay-sand), these indicators considered as good evidence for manufacture of clay brick from the studied samples.
- Punmia, Jain and Jain (2003) stated that normally clay brick contains the following ingredients:

a) Silica (sand) 50% – 60% by weight.
b) Alumina (clay) 20% – 30% by weight.
c) Lime 2% – 5% by weight.
d) Iron oxides 5% – 6%, not greater than 7% by weight.
e) Magnetite- less than 1% by weight.

The result of chemical composition in Table III shows that the main percentage of SiO_2 is not be changed, mostly in the studied samples ranging from 45.8% – 49.9%, Al_2O_3 15.5% – 19%, as well as different percentage of (Fe_2O_3, CaO, MgO, K_2O, Na_2O and SO_3). These constituents of oxides elements are directly proportional with the clay minerals' composition as well as they considered melting resistance materials. So from this discussion may detect that the studied samples are favorable for brick industry according to Iraqi Standard (1993), Table V.

- Plasticity index (PI) is a measure of plasticity of soil. The (PI) is the size of the range of water content where the soil exhibits plastic properties, and shows the difference between the liquid limit (LL) and the plastic limit (i.e PI=LL–PL). According to the Standards American Society for Testing and Materials (1996) the United State (US) soil classification is depending on the (PI):
  - 0 – Non plastic
  - (1 – 5) – Slightly plastic
  - (5 – 10) – Low plastic
  - (10 – 20) – Medium plastic
  - (20 – 40) – High plastic
  - > 40 very high plasticity

From the plasticity values the studied sample (S1) (PI = 15.56) is belong to medium plasticity inorganic clay (CL), but samples (S2 & S3) (PI = 6.70 – 8.48) are belong to low plasticity inorganic clay (CL) according to Standards American Society for Testing and Materials (1996) and Casagrandes plasticity chart (Casagrande, 1932).

Based on plasticity values in Table IV, range between (6.70 – 15.56) pointed out that this percentage is less proportional with the clay minerals water content such as (kaolinite, illite, chlorite), because molecular nature of these clay minerals have not ability to drawn the water (i.e., they does not absorb water, does not expand where they are contact with water) whereas montmorilonite derived by weathering of volcanic ash, it can expand by several times its original volume when it come in contact with water (Klein, 2002). So the result of (PI) document that the studied samples are suitable for clay brick industry.

- The results of some physical and mechanical properties of producing clay brick characterized by general appearance which is pointed out to the red and reddish brown colour with homogeneous and regular dimension, straight edges with right angles, planar surface without fractures or cracks, efflorescence is not occurs on the clay brick surface (i.e., free from the salty deposits). These parameters lead to good evidence that the type of clay brick is belong to class (A) because of smooth, rectangular surface with parallels sharp and straight edges, also free from cracks and stones with uniform texture (Punmia, 1993). According to specifications of the Iraqi Standard (1993) the studied samples are belong to class (A) due to high compressive strength range from 376 – 429 Kg/cm^2, water absorption 18% – 20% with linear shrinkage 0.5% and volume shrinkage 0.4% – 2.5%, compressive strength of clay brick is positively associated with the percentage of clay minerals mainly with the concentration of Al, Si, but the water absorption (term of porosity) is related with carbonate and evaporate minerals (Gypsum). Al-Bassam (2004) stated that the surface area of brick increased with the released of CO_2 from carbonate and H_2O from gypsum after drying which caused to form high porosity (voids) on the brick surfaces but the studied samples indicate that have high compressive strength with low percentage of water absorption.
- Maala, et al. (2001) used the ratio SiO_2/CaO percentage that if the percentage is equal to 2:1, it is considered to be suitable for brick manufacturing, but if it is less than this percentage, it does not become suitable for brick manufacture. In this study there are very little amount of CaO content nearly 10% that means the silicate clay minerals are dominant content in the studied samples, because the ratio of SiO_2/CaO percentage is equal to 5:1.

In general, when the temperature increased the water absorption capacity and volume decreased, the porosity diminished, the compressive strength increased significantly (Merza and Mohyaldin, 2005). The method which is used by laboratory of geological survey and mineral investigation in the presence research is semi – dry method, the tiles fired at 950 C° and the soaking time was only one hour.

According to the British Standard (1985) for the efflorescence test, the samples may be classified as no efflorescence, i.e, the surface area not covered by salt content (Punmia, 1993), this phenomena was not occurred in the studied samples, i.e., the studied samples are none efflorescence according to the laboratory tests as shown in Table VI. As a result, all these physical and mechanical properties are directly proportional with the suitability of studied samples for brick manufacturing.

V. Conclusion

Based on the results of this study the following conclusions have been reached out:

Firstly; the plasticity values show that sample no. (S1) is medium plastic, samples no. (S2 and S3) are low plastic, clays must have plasticity, which permits them to be shaped or molded when mixed with water, and they must have sufficient wet and air dried tensile strength to maintain their shape after forming. Also, when subjected to rising temperature, the clay particles must fuse together (i.e., the plasticity values show that the sample no. S2 and S3) have low plasticity range between 6.7 – 8.48, these values permit to made shaped tiles according to (Maala, et al., 2007).

Secondly; X-Ray Diffraction show that the samples are constitute of clay minerals (such as illite, chlorite, kaolinite, illite – smectite mixed layer) and non-clay minerals (quartz, calcite and plagioclase).

Thirdly; the physical and mechanical properties that most concern with the clay brick are;

- The type of clay brick class is (A) due to measure of physical and mechanical properties.
- Efflorescence (salt cover) has very little appearance on the clay brick surface.
- Clay brick affected by low volume and linear shrinkage during both drying and firing with higher temperature at 950 C°.

Fourthly; it was concluded that the raw materials taken from Fatha Formation in Koya city are suitable for producing high quality clay brick.

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