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ASSESSMENT OF SOME CLAY DEPOSITS FROM THE GERCUS FORMATION (MIDDLE EOCENE) FOR BRICK MANUFACTURING IN THE DOKAN AREA, NE IRAQ

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ABSTRACT

The objective of this research is to evaluate the suitability of some clay deposits from the Gercus Formation (Middle Eocene) in the Dokan area, Northeastern Iraq for brick manufacturing. Physical properties of the raw material including grain size analysis and Atterberg limits showed that composed mostly of sand and silt with a minor proportion of clay and classified as muddy sand. According to the plasticity chart, the studied sample plotted on the field of silt and organic clay with low plasticity. The geochemical analysis by X-ray fluorescence revealed that composed of a low percentage of silica and alumina and a high percentage of calcium oxide and magnesium oxide. The mineralogical analysis by X-ray diffraction showed that the studied samples were composed of non-clay minerals (dolomite, quartz, hematite, albite, anatase, and orthoclase) and clay mineral (montmorillonite, kaolinite, and illite). Twelve ceramic briquettes were prepared from the clay sample by semi-dry pressing method and pressed by 200 kg/cm² pressure with 14 – 15 % moisture content and fired at 880, 900, and 920 °C for evaluation tests of linear firing shrinkage, apparent porosity, water absorption, bulk density, efflorescence, and compressive strength. Results of physical and mechanical properties of the studied ceramic briquettes compared with the specification of Iraqi standard (1993) for clay brick manufacture, according to this specification the studied sample was not suitable for brick manufacturing due to a high percentage of water absorption and low compressive strength.

1. INTRODUCTION

Ceramics is an inorganic, non-metallic material that is consolidated by firing at high temperatures (Ryan, 1978). Clay is used in the ceramics industry because its versatility allows it to be effectively cast into any shape and gives hardness and quality to the ceramic body after firing. The reaction of clay with other minerals during firing including silica, and other fluxes, such as feldspar, are responsible for the final product properties (Kingery, 1967). The researchers have studied clay deposits in Iraq for the ceramic industry. Lateef (1976) evaluated the claystone sediments of the Neogene age for the Foothill Zone of the Hamrin range, which are essentially consistent with a 20% – 50% clastic sedimentary sequence. Merza (1997) evaluated some Late Cretaceous to Tertiary clay deposits in northeastern Iraq for ceramic tile manufacture. Al-hakim (1998) investigated some clay deposits from the

Neogene period for brickmaking. Merza (2002) Studied clay from the Gercus Formation (Middle Eocene) in the Sulaimaniya area for the brick industry through evaluation testing, comprising mechanical and physical characteristics of ceramic briquettes. The researcher elucidated that increasing linear shrinkage percentage with increasing firing temperature is referred to as high firing temperature due to $CaCO_3$ content. Merza (2004) used the recent saline clay deposits around Aliawa village in the south of Sulaimaniya City for the manufacture of glazed ceramic tiles by mixing Sirwan River sediments, which were recently deposited with the gorge. She revealed that some of these raw materials used to make ceramic tiles are suitable for cladding kitchen walls, balconies, and bathrooms in public buildings. Moreover, Merza & Mohyaldin (2005) used clays selected from different places in the Kurdistan Region and determined that some of the selected raw materials can be used to make solid and perforated bricks. Maala et al. (2007) evaluated the mineralogical, chemical, and physical characteristics of the Neogene mudstone sediments (Bai Hassan and Injana formations) and their suitability for use as raw material for manufacturing building bricks. Aqrawi (2009) studied the improvement of the clay used by the Duhok brick factory in Duhok, Iraqi Kurdistan Region, to minimize the macro and micro cracking in brick production by adding non-plastic materials, such as sand to reduce its plasticity and obtain suitable manufacturing properties. Mayada S. Jodi (2012) studied the assessment of claystone suitability for brick manufacture from the Mukdadiya and Injana formations in the Al-Kand hills at Naenava Governorate by comparing the results of the assessment tests of the physical, chemical, mineralogical, and mechanical characteristics of the clay sample to the Iraqi Standard Specification No. 25, 1993 and decided that all the examined samples can be utilized in the brick industry. Hakeem (2012) studied the sedimentology of the Beduh Formation (Lower Triassic), the northern Thrust Zone in the Kurdistan Region, for some ceramic industries. Muhammad (2013) assessed the probability of utilizing Iraqi Kurdistan clay from a chosen place in the creation of the monoclonal (pottery) ceramic industry in different places in Kurdistan. Rafa’a & Dabby (2013) considered the factors influencing the quality of clay bricks created from the Quaternary sediments in Iraq and appeared that the mineralogical composition and efflorescence play a vital part and affecting brick quality. Whereas the presence of various chemical oxides influences volumetric and linear shrinkage with water absorption. Faraj (2014) examined the potential utilization of Tertiary and Quaternary clays with certain additive raw materials for ceramic industries situated in the Iraqi Kurdistan region. The researcher has concluded that water absorption and apparent porosity decrease, whereas the linear shrinkage ratio, compressive strength, and bulk density increase with rising firing temperatures. Najim & Yousif (2020) revealed the effect of firing and using cordierite as an additive raw material on the mechanical and physical characteristics of ceramics prepared from some raw materials in Iraq by semi-dry pressing method and the finding of the study revealed that samples fired at 1400 °C exhibited the most optimum results in evaluation tests. Khalaf & Issa (2021) investigated the chemical and physical characteristics of soil in the Babylon region to produce clay bricks that conform to the standards stipulated in Iraqi Standard Specifications No.25, the aim was to achieve bricks of both Grades (i.e., A and B). Mahmood & Aqrawi (2022) studied the evaluation of ceramic specimens from east of Erbil City, in the north of Iraq for use, in different building applications. The researchers found that deposits from the Injana and Bai Hassan formations could be used for the floor and wall tile industry, and certain materials in Bestana village, which are Quaternary sediments, can be utilized in the roofing tile industry, and ceramic specimens from the Mukdadiya and Bai Hassan formations when fired at 1080 °C can be utilized as chemical resistant tiles. The purpose of this investigation is to assess the availability of red clay deposits from the Gercus Formation in the Dokan area for brick manufacturing.

1.1. Geological Setting

The research site is situated in the Dokan area; which is located in the central northern part of Iraq, Iraqi Kurdistan Region within Sulaimaniya Governorate. The study area is situated within the High Folded Zone of the Outer Platform of the Arabian Plate (Fouad, 2012). The Gercus Formation is part of the Paleogene sequences in northern Iraq and has been represented by a thick section of the Middle-Late Eocene clastic sediments. A complete section of these rocks forms an outcrop on the northeastern side of the Unstable Folded Zone (Al-Qayim & Al-Shaibani, 1991; Al-Rawi, 1980; Jassim & Goff, 2006).

The Gercus Formation consists of claystone, sandstone, and siltstone all red, with very rare conglomerate lenses (Al-Shiwaily et al., 2011; Kassab, 1972; Van Bellen et al., 1959). The formation exhibits variation in thickness within the ranges of 35 to 150 m. The age of the formation is probably Middle Lower–Middle Eocene (Sissakian & Fouad, 2015). The studied sample was taken from the red clay deposits of the Gercus Formation (Middle Eocene), which cropped out at the Kalka Smaq area (Figure 1). It is located at the intersection of latitude 35°55'21.28" N and longitude 44°54'21.72" E with an elevation reaching 890 m above sea level. The Gercus Formation in the studied area is underlain by the Sinjar Formation (Early Eocene), which is conformable and graditional and the appearance of the first red clay bed represents the contact between them. The overlying formation is the Pilaspi Formation (Late Eocene) with unconformable contact, marked by the presence of a bed of conglomerate. In this research study, the red clay deposits from the lower part of the formation.

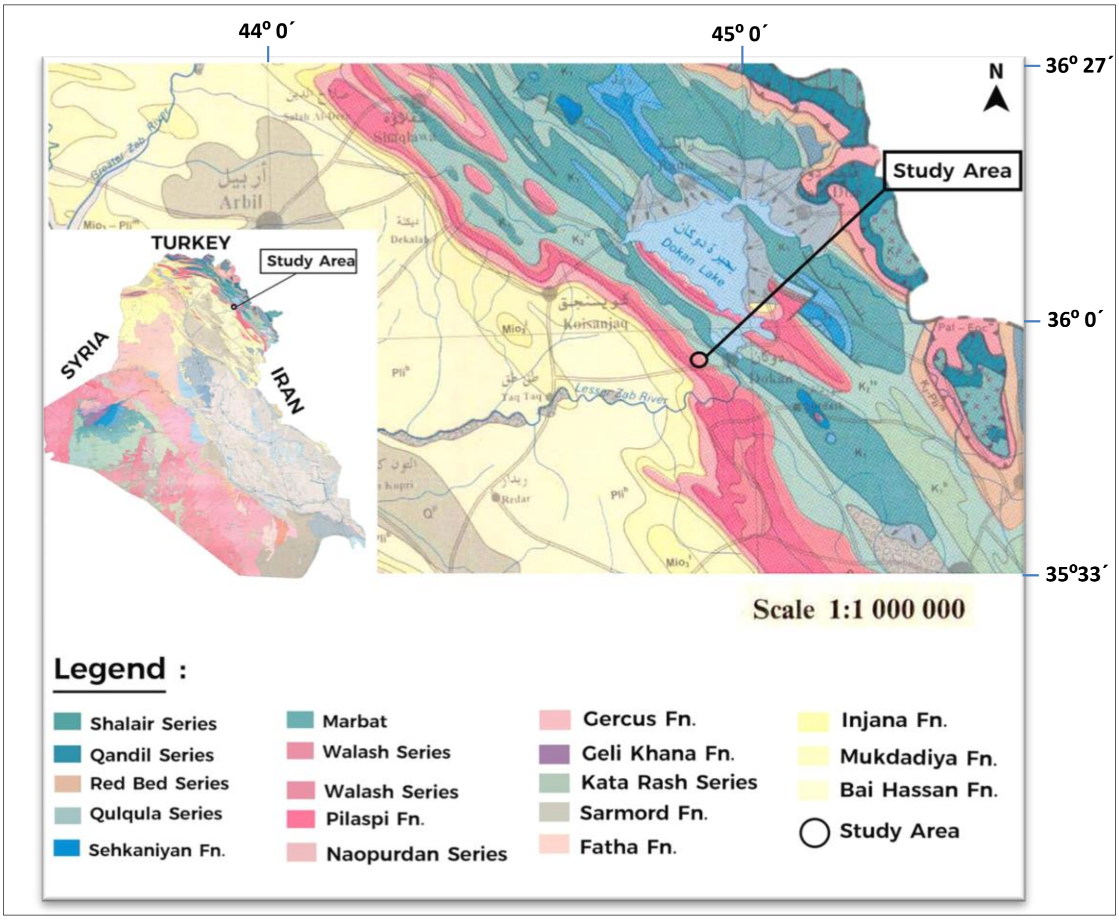


Figure 1: Geological map of Iraq with the location of the studied sample (Sissakian & Fouad, 2015)

2. MATERIALS AND METHODS

For this study, the sample was taken from the red clay deposits from the lower part of the Gercus Formation at Kalka Smaq from the Dokan area. To study the suitability of this type of clay for brick manufacture first grinding the sample into very small pieces like clay, the material was mixed with about 14 to 15% water to make it moist. Thereafter, the mix formed as rectangular molds using a method where the mixture was partly dry, which is a semi-dry pressing method, and then pressed by 200 Kg/cm² pressure with 8.5*2.45*2.45 cm dimensions. The pressed brick samples dried at room temperature and then fired at three different firing temperatures 880 °C, 900 °C, and 920 °C, three briquettes for each firing temperature. Preparing these briquettes was carried out at Aso Brick Factory.

Grim (1962) and Dondi et al. (1992) proposed numerous tests for evaluating clay for the brick industry. Many tests performed on the raw material are grain size distribution by sieve and hydrometer (B.S., 1967) and Atterberg limits (liquid limit, plastic limit and plasticity index) (ASTM, 1972), both tests performed at the Sulaimaniya Architecture Laboratory. Geochemical composition of the raw material identified by X-ray fluorescence (XRF) at Mass Cement Factory. Mineralogical composition of the raw material determined by X-ray diffraction (XRD) at Amethyst Lab Co. Mashhad, Iran. Tests conducted on the fired specimens are linear firing shrinkage (ASTM, 1982a), apparent porosity, water absorption, and bulk density (ASTM, 1986). Both tests of compressive strength (ASTM, 1982b) and efflorescence (Iraqi Central Organization for Standardization and Quality Control, 1988) determined the ceramic briquettes at Aso brick Factory.

3. RESULTS AND DISCUSSION

Results and discussion of the tests done on the sample are listed below:

3.1. Grain size analysis

The analysis of grain size characterizes the proportional distribution of sand, silt, and clay present within a specific sample. It is known that decreasing particle size results in greater plasticity and reactivity of the clay (Ryan, 1978). Furthermore, this increase in the fineness of particles increases the silica melt that binds crystals together and then becomes more coherent (Kingery, 1967; Rado, 1969). The results obtained from the analysis of grain size by sieve and hydrometer of the studied sample show that composed mostly of sand (76.65%) and silt (13.94%) portions, with a small quantity of clay (9.41%; Table 1).

The result of the grain size distribution of the studied sample is plotted on the Folk classification triangle (Folk, 1980) to classify the sample, based on the proportion of sand, silt, and clay (Table 1). It revealed that the sample was plotted on a field of muddy sand (Figure 2).

Winkler (1954) produced the diagram for evaluating the suitability of clay samples in different ceramic products depending on the ratio of fine particles sized (< 2 μm, 2 – 20 μm and > 20μm) (Table 1). According to the Winkler diagram (Figure 3), the studied sample is neither suitable for manufacturing bricks nor roofing tiles. Winkler divided clay ceramics into A: Solid bricks B: Vertically perforated bricks C: Roofing tiles, lightweight blocks D: Thin-walled hollow bricks.

Table 1: Particle size distribution percentage of the studied clay sample.

Sample	The particle size distribution%			Type of soil	Percentage of grain size %		
	Sand% > 0.063 – 2 mm	Silt% 0.002 – 0.063 mm	Clay% < 0.002 mm	Texture classification	< 2 µm %	2 – 20 µm %	> 20 µm%
Clay deposits	76.65	13.94	9.41	Muddy sand	6	6	88

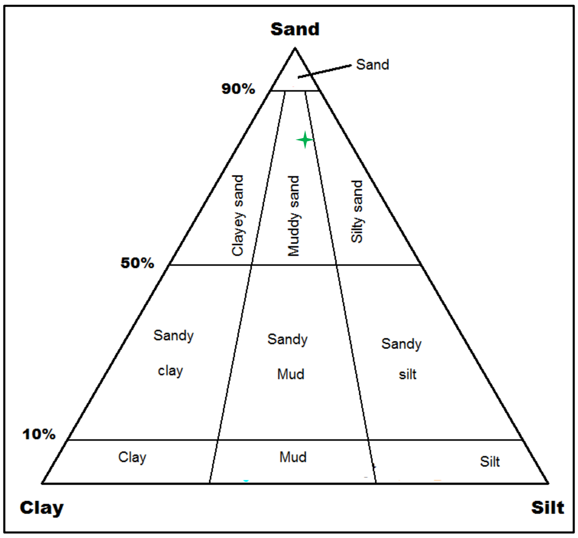


Figure 2: Relative distribution of sand, silt and clay proportions of the studied sample (Folk, 1980).

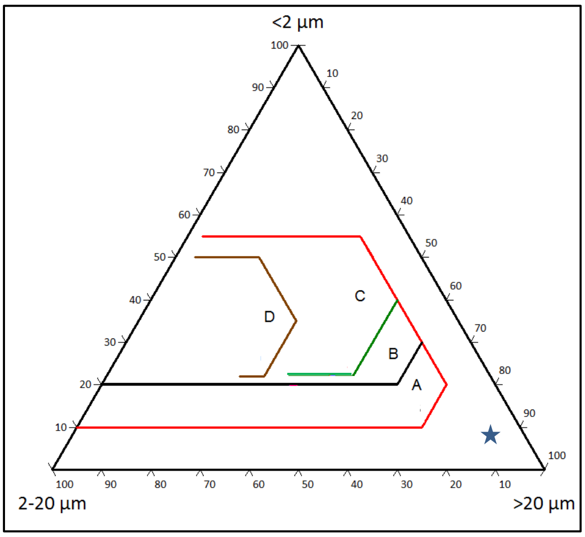


Figure 3: Winkler diagram (Winkler, 1954) for the technological classification of bodies for structural clay products and plots of the studied sample.

3.2 Atterberg limits

The ceramics industry needs materials that are easy to shape and work without breaking, so having good plasticity is very important (Grim, 1962). The plasticity is affected by the size of the grain and the typology of the clay minerals, the plasticity increases due to the clay minerals, where the layers are weakly bound such as minerals of illite and/or montmorillonite nature (Manfredini & Hanuskova, 2012). Atterberg limits include the plastic limit, liquid limit, and plasticity index for the studied sample, Table 2 shows the results of these tests. The plasticity of clay is evaluated by the plasticity index, which is determined by the difference in moisture content between liquid limit and plastic limit.

The clay workability chart (Bain & Highley, 1979); (Figure 4) was used to evaluate the suitability of the studied sample in different ceramic industries, depending on the plasticity index and plastic limit. According to this chart in Figure (4), the studied clay sample is suitable for the brick industry with some treatments. The plasticity chart by Krynine et al. (1957) was used for the classification of the studied sample (Figure 5), which represents the relation between the plasticity index [PI = 0.73 (LL-20)] and liquid limit (LL %). Depending on this chart, the sample is located on the field of silt and organic clay with low plasticity.

According to Budnikov (1964), clay with a plasticity index of less than 10 can be utilized in the ceramic industry. Hence, the studied sample with a plasticity index of less than 10 so can be utilized in the ceramic industry, such as the brick industry.

Table 2: The result of Atterberg Limits of clay sample and the corresponding type of soil.

Sample	(Liquid Limit) L.L	(Plastic Limit) P.L	(Plasticity Index) P.I	Type of Soil Grade Symbol
Clay deposits	43	38	5	ML & OL

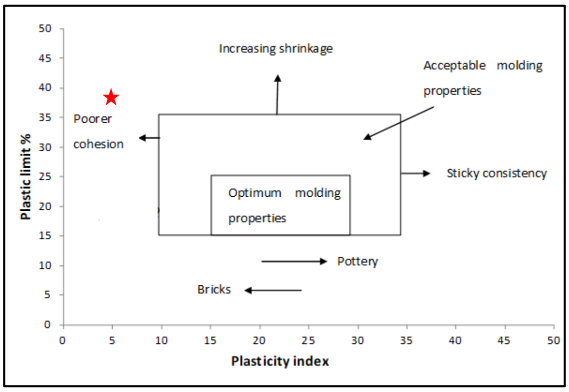


Figure 4: Clay workability chart (Bain & Highley, 1979) and plots of the studied sample.

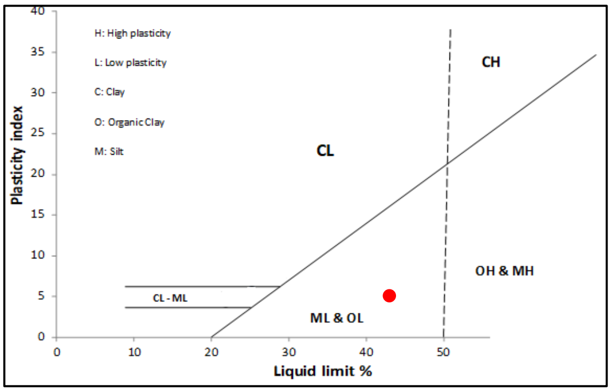


Figure 5: Plasticity chart by (Krynine et al., 1957) and plots of the results of the studied sample.

3.3 Geochemical Analysis

The geochemical properties play an important role in the ceramics industry and determining the main oxide content of the raw materials helps in understanding the behavior of the ceramic body during firing by estimating the refractory oxides, flux, and melting temperature (Mahmood & Aqrawi, 2022). In addition, some oxides affect the mechanical and physical characteristics of ceramic products (Shreve & Brink Jr, 1977). Fluxes induce a restricted and regulated quantity of glass formation within ceramic compositions that serve to bond crystalline components together. Fluxes are important in the vitrification of clay bodies by lowering the melting temperatures (Jassim & Goff, 2006). CaO, Na_2O, K_2O, MgO, and Fe_2O_3 are common fluxes in clay (Fakhfakh et al., 2007; Rattanachan & Lorprayoon, 2005; Riley, 1951). The result of the geochemical analysis of the raw material from the Gercus Formation is shown in Table 3. It reveals that the raw material is composed basically of silica is about 33.5%. Silica is important in controlling firing shrinkage, which causes densification of the ceramic product (Aqrawi, 2009). Calcium oxide comprises approximately 12.76% of the raw material composition owing to the presence of calcite. This oxide can make the liquid phase form at high temperatures because it acts like a flux (Aqrawi, 2000). It is utilized as one of the techniques for controlling water absorption and firing shrinkage (Das et al., 2005). Furthermore, it provides the densification of the ceramic briquettes at high firing temperatures. Alumina shows a minor amount about 3.28%. Alumina and silica function as refractory oxides within the ceramic industry resulting in increasing water absorption and apparent porosity and decreasing the linear shrinkage, bulk density, and liquid phase (Aqrawi, 2009). The Magnesium oxide (MgO) shows a high proportion about 18.77% owing to the significant presence of dolomite mineral within the raw material. According to (Medhioub et al., 2010), magnesium participates in the structure of clay minerals, and magnesium oxide (MgO) operates as a sintering agent, which encourages the process of vitrification. Iron oxide is about 6.9% being responsible for the reddish color after firing (Faraj, 2014). Moreover, iron oxide with other fluxes can make a higher amount of liquid phase at a lower firing temperature which helps to accelerate the vitrification (González et al., 1998; Medhioub et al., 2010). Other oxides of Na_2O, K_2O, Cl, and SO_3 exhibit a minor amount (Table 3). Chloride salt exists as Cl. Na_2O and SO_3 represent the presence of sodium sulfate salts that cause efflorescence on the surface of bricks. Loss on ignition was determined during firing at 1000 °C and is approximately 21.01 %, the significant quantity of Loss on Ignition (L.O.I) is attributed to the decomposition of carbonate minerals and the release of CO_2 gas, in conjunction with the presence of both adsorbed and molecular water on and in the crystal structure of the clay minerals (Hakeem, 2012).

Table 3: Chemical analysis for the studied sample.

Sample	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	Cl	SO_3	L.O.I
Clay sample	33.50	3.28	6.90	12.76	18.77	0.89	1.33	0.48	0.22	21.01

3.4 Mineralogical Analysis

The XRD analysis provides information about the mineralogical composition. The XRD analysis shows that the sample chosen from the Gercus Formation consists of non-clay and clay minerals. Non-clay minerals can be described as dolomite, quartz, hematite, albite, anatase, orthoclase, and clay minerals can be described as montmorillonite, kaolinite, and illite (Figure 6). The average percentage of non-clay minerals and clay minerals in the studied sample is shown in Table 4. The high proportion of dolomite mineral during firing causes disintegration that results in a cracking body. Fine grain dolomite mineral acts as a flux mineral that enhances reactions during firing and decreases refractory degree (AL-KASS, 1985) disintegration of carbonate minerals during firing increases the porosity of the ceramic body and water absorption percent, and decreases its density. Quartz has a big role in the ceramic industry that decreases its plasticity, is responsible for decreasing shrinkage, and causes cracking of these ceramic bodies during dryness and firing. It causes viscous silica refractory material in higher temperatures (Rado, 1969). Hematite acts as a flux material and is responsible for the red color of the raw materials. Kaolinite mineral Kaolinite has low drying and firing shrinkage. It's used in ceramic industries to optimize green strength, plasticity, and casting behavior (Ciullo, 1996). So, illite has intermediate drying and firing shrinkage. It contributes to consistency and workability, smooth surface finish, and resistance to shrinkage and cracking in the ceramic industry use (Ciullo, 1996).

Table 4: The average percentage of minerals in the studied sample.

Minerals	Dolomite	Quartz	Hematite	Montmorillonite	Kaolinite	Illite	Albite	Anatase	Orthoclase	Others
%	52.01	24.42	9.81	8.17	2.84	1.89	0.42	0.23	0.11	0.10

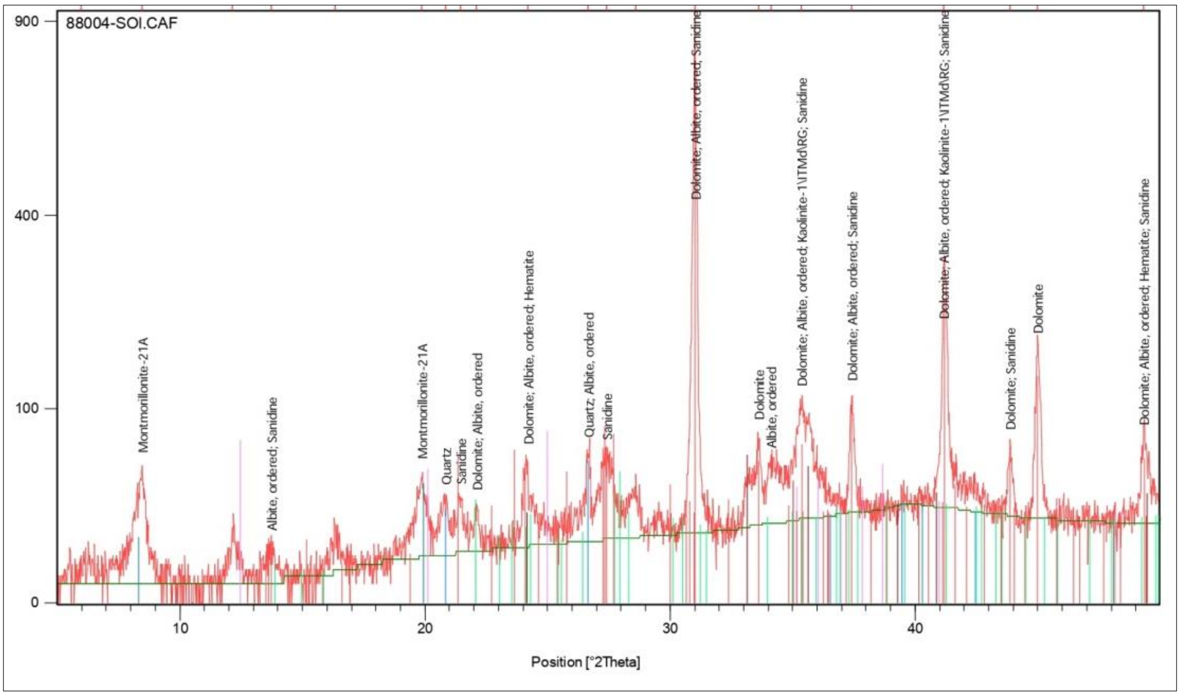


Figure 6: XRD diffractograms of the studied sample.

3.5 Apparent porosity, water absorption, and bulk density

The apparent porosity is the expression of the proportion of the volume of open pore space of the sample to its overall external volume and is expressed as a percentage. So, water absorption represents the percentage of water, absorbed by the porous structures present within ceramic material, the ratio of both is influenced by the grain distribution, grain size, and the degree of pressure utilized throughout the pressing process and molding process (Kingery, 1967). Bulk density is expressed as the ratio weight of the sample to the total volume which represents the volume of the solid material with the volume of any gaps or holes on its surface both opened and closed (Kingery, 1967). The results of the apparent porosity, water absorption, and bulk density tests were conducted on the ceramic specimens fired at 880, 900, and 920 °C shown in Table 5. Figure 7A shows the relationship between apparent porosity and different firing temperatures and illustrates that apparent porosity increases with increasing firing temperatures. Figure 7B shows the relationship between water absorption at different firing temperatures, as well as the results of water absorption, exhibiting a positive correlation with apparent porosity (Table 5). Figure 7C illustrates the relationship between the bulk density and firing temperatures. It demonstrates an inverse relationship between bulk density with apparent porosity and water absorption at all firing temperatures, the reason for the increase in apparent porosity and water absorption and decrease in bulk density is due to the extensive decomposition of $CaCO_3$ which occurred at about 900 °C, which leaves the pores in the ceramic body by releasing CO_2. These results are influenced by various factors, such as the composition of the fired materials, their grain size, the temperature employed, and the temporal length of the firing procedure as well as the time of maturation.

Table 5: Results of the water absorption, apparent porosity, and Bulk density for the studied ceramic specimens at different firing temperatures.

Sample	Properties	Firing temperatures		
		880 °C	900 °C	920 °C
Clay deposits	Water absorption%	44.15	45.42	45.84
	Apparent porosity%	53.62	54.87	54.96
	Bulk density gm/cm³	1.19	1.07	1.09

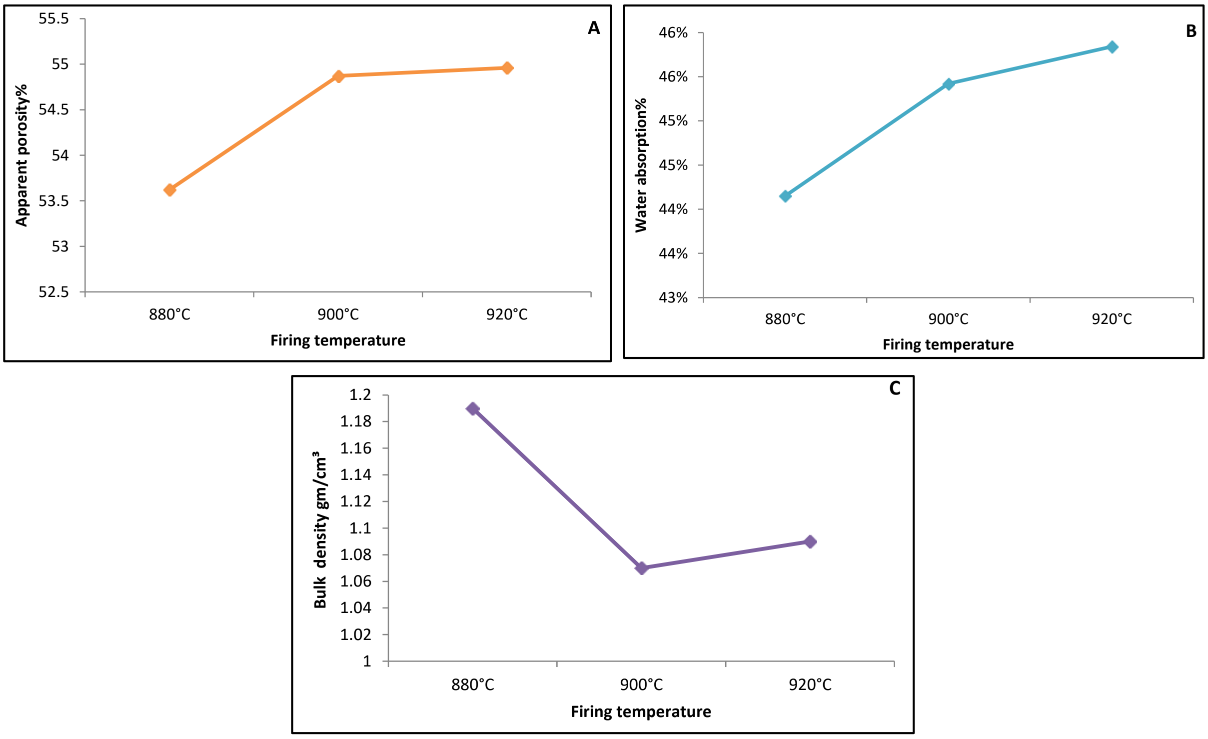


Figure 7: Relationship of the apparent porosity, water absorption, and bulk density with firing temperatures for the studied ceramic specimens.

3.6 Linear Firing Shrinkage

It refers to alterations in linear dimensions of ceramic briquette that have occurred at different firing temperatures. Shrinking in ceramic briquettes is characterized by the fusion of certain grains, consequentially leading to the convergence of the grains; the quantity of melt phase is directly proportional to the number of impurities that serve as flux agents (Aqrawi, 2000). Measuring the linear shrinkage is a vital point to understand the alters that take place during the firing process (Merza, 1997). The percentage of linear shrinkage was subsequently calculated according to ASTM (1982).

Linear shrinkage occurs when water is lost because of chemical and mechanical reasons, but overall clay shrinkage can only occur when a reaction between adjacent grains occurs (Prentice, 1988). Table 6 exhibits the results of the linear shrinkage of ceramic briquettes, and Figure 8A illustrates the change in linear shrinkage at different firing temperatures, linear shrinkage increases from 880 to 900 °C and decreases at 920 °C this is referred to as the liberation of CO_2 resulting from carbonate decomposition prevent the convergence of individual grains from each other during this firing temperatures (Al-hakim, 1998; AL-KASS, 1985), this expansion attributed to the bloating ability of clays and forming new mineral phases (Hakeem, 2012).

3.7. Compressive strength

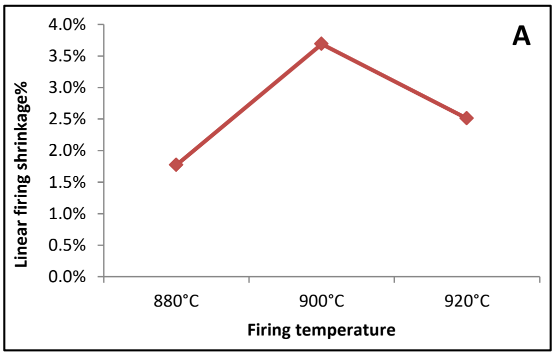
It is the essential degree of the load that a sample can withstand without being smashed. The compressive strength of a material is directly correlated with its bulk density while inversely correlated with its apparent porosity, to achieve a high level of compressive strength it is necessary to minimize the open porosity of the material (Kitouni & Harabi, 2011), alternatively, increasing in densification causes an increase in compressive strength, and the densification affected by the maximum firing temperature and concentration of lime that influences the creation of calcium silicate phase, and this phase is very important in densification of the ceramic specimens. According to Khalaf & Issa (2021), the uniform distribution of both grains and pores is responsible for the high compressive strength Table 6 exhibits the results of compressive strength for the ceramic specimens fired at 880, 900, and 920 °C. Figure 8B illustrates the relation between the compressive strength and different firing temperatures. It is noticed that there is an inverse relationship between compressive strength values and firing temperatures this is referred to the high amount of carbonate in the raw material which decomposed at these temperatures leading to decreasing density and increasing the porosity in the studied ceramic briquette.

3.8. Efflorescence

Efflorescence refers to the deposition of crystalline salt on the surface of the ceramic body as a consequence of moving the contaminated water through layers of clay deposits, leading to the formation of a white or gray powdery substance on the surface of the ceramic body (Kingery, 1967). The efflorescence test was performed on the ceramic specimens fired at 880, 900, and 920 °C, then boiling the briquettes for 1 hour and followed by allowing them to soak for additional 5 hours according to (Iraqi Central Organization for Standardization and Quality Control, 1988). Efflorescence is determined by comparing the fired briquettes at distinctive levels to None; does not correspond to efflorescence. Light; means that the amount of salt on the surface area is no more than 15% of the complete surface area of the sample. Moderate; means that the amount of salt on the surface area of the briquette is in the range of 15 – 50 %, and Dense; the amount of salt on the surface area of the briquettes is more than 50% (Aqrawi, 2009). Table 6 exhibits the results of the efflorescence test for the studied ceramic specimens fired at 880, 900, and 920 °C and shows that the efflorescence test for all specimens is light.

Table 6: Results of linear firing shrinkage, compressive strength, and efflorescence tests for the studied ceramic briquette at different firing temperatures.

Sample	**Property**	**Firing temperatures**		
		880 °C	**900 °C**	**920 °C**
Clay deposits	Linear shrinkage %	1.77	3.69	2.51
	Compressive strength (Kg/cm^2)	38.46	30.77	30.22
	Efflorescence	Light	Light	Light



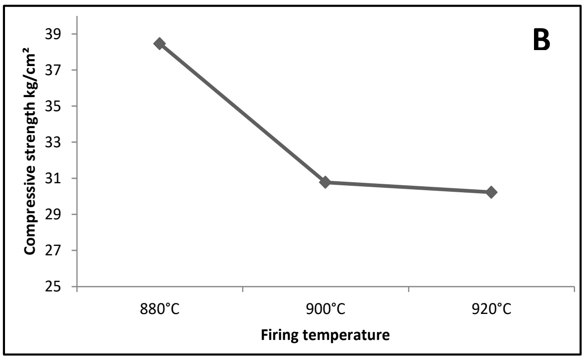


Figure 8: Relationship of linear firing shrinkage and compressive strength with different firing temperatures for the studied ceramic specimens.

3.9. Assessment of the Studied Sample for the Brick manufacturing industry

The results of the above properties were compared with the requirements of Iraqi Standards (1993) as shown in Table 7. According to this specification, the studied ceramic specimens are not suitable for the brick industry due to low compressive strength and high percentage of water absorption. The compressive strength of clay brick is positively associated with the percentage of clay minerals mainly with the concentration of Al, and Si, but the water absorption (term of porosity) is related to carbonate and evaporate minerals (Gypsum). Al-Bassam (2004) stated that the surface area of brick increased with the released CO_2 from carbonate and H_2O from gypsum after drying which caused to formation of high porosity (voids) on the brick surfaces but the studied samples indicate that have low compressive strength with a high water absorption ratio.

Table 7: specification of Iraqi Standards (1993) for clay brick manufacture.

Efflorescence	Maximum level of water absorption %		Minimum level of compressive strength kg/cm²		Classes
	For one brick	Water absorption average (for ten bricks)	For one brick	Compressive strength average (for ten bricks)	
Low	**22%**	**20%**	**160**	**180**	**A**
Medium	**26%**	**24%**	**110**	**130**	**B**
High	**28%**	**26%**	**70**	**90**	**C**

4. CONCLUSION

The following conclusions have been reached depending on the results of this investigation:

- The physical properties of the raw material in terms of grain size distribution by sieve and hydrometer show that it consists mainly of sand and silt with a small amount of clay and the sample is classified as muddy sand. The assessment of the studied sample according to grain size analysis exhibits that the studied sample is neither suitable for the production of bricks nor roofing tiles.
- The results of the physical properties (Atterberg limits) of the studied raw material and the clay workability chart the sample is suitable for the brick industry with some treatment and according to the plasticity chart the sample plotted on the field of silt and organic clay with

low plasticity. Therefore, the studied sample with a plasticity index of less than 10 can be utilized in the ceramic industry such as the brick industry.

- The results derived from the geochemical analysis of the sample being investigated indicate that the raw material consists mainly of silica with a high percentage of calcium oxide and magnesium oxide, which means the high content of carbonate minerals such as dolomite in the raw material and the significant quantity of Loss On Ignition (L.O.I) is attributed to the decomposition of carbonate minerals and release of CO_2 gas in conjunction with the of both molecular and absorbed water within the crystal structure of the clay minerals.
- The X-ray diffraction illustrates that the studied sample chosen from the Gercus Formation consists of non-clay minerals, such as (dolomite, quartz, hematite, albite, anatase, and orthoclase) and clay minerals like (montmorillonite, kaolinite, and illite).
- The results of the physical characteristics of ceramic briquettes under investigation demonstrate that an increase in firing temperatures leads to a corresponding increase in both apparent porosity and water absorption. Furthermore, there is an inverse relationship between bulk density with apparent porosity and water absorption at all firing temperatures the reason for the increase in apparent porosity and water absorption and decrease in bulk density is due to the extensive decomposition of $CaCO_3$ which occurred at about 900 °C which leaves the pores in the ceramic body by releasing CO_2 gas.
- Linear firing shrinkage of the studied ceramic specimens increases from 880 °C to 900 °C and decreases at 920 °C this is referred to as the escaping of CO_2 gas due to carbonate disintegration during this firing temperature that prevents the convergence of the grains from each other.
- The compressive strength value of the studied ceramic specimens progressively decreased with increasing the firing temperatures this is referred to the high ratio of carbonate mineral in the raw material which decomposed at these firing temperatures leading to decreasing density and increasing porosity in the studied ceramic specimens.
- The efflorescence tests for the ceramic specimens under investigation which fired at 880, 900, and 920 °C, are slight.
- The results of the physical and mechanical characteristics of the studied ceramic specimens compared with Iraqi Standards (1993) for clay brick manufacture according to this specification the studied ceramic specimens are not suitable for the brick industry due to low compressive strength and high water absorption.

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