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ORIGINAL PAPER

Mineralogical, geochemical, and geotechnical evaluation of Al-Sowera soil for the building brick industry in Iraq

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Abstract The raw material soil of Al-Sowera factory quarry (quarry soil and mixture) used for building brick industry was tested mineralogically, geochemically and geotechnically. Mineral components of soil are characterized by Clay minerals (Palygoriskite and chlorite) and non-clay minerals like calcite, quratz, feldspar, gypsum and halite. The raw material is deficient in SiO_2, Al_2O_3, K_2O, Fe_2O_3 and MgO, while enriched in CaO. Loss on ignition and Na_2O are in suitable level and appear to be concordant with the standard. Grain size analyses show that the decreasing sand and clay, and increasing silt ratio in both quarry soil and mixture caused decreasing in strength of brick during molding and after firing. The quarry soil is characterized by high plasticity clayey soil of 30.49 plastic index (P.I), whereas the mixture considered a clayey soil has a low plasticity of 7.7 plastic index (P.I). To improve the chemical and physical properties of the raw material, alumina-silicate minerals rich in K_2O, Fe_2O_3 and MgO are recommended as additive materials to the main mixture.

Keywords Geochemistry · Liquid limit · Plastic limit · Raw materials · Building bricks

Introduction

Humans have been using bricks for thousands of years for building houses. The quality of bricks depends on the material they are made from. A specific soil is used as a raw material for industrial bricks. This soil must have distinct geochemical properties. Mud bricks dealing with the firing process to make bricks are best for dry and wet climates. The non-flammable material and relative low cost of mud bricks made them preferable.

This work was carried out on soil of Al-Sowera brick factory which is located about 17 km southwest of Al-Sowera city (Fig. 1). The study area is part of the Mesopotamian plain which comprises fluviatile flood silt and aeolian silt as unconsolidated sediments. The natural processes forming the Mesopotamian plain have been modified by human activities for several thousand years. Many artificial irrigation canals have behaved as rivers eroding the original sedimentary cover of the plain (Jassim and Goff 2006). Loam, a mixture of clayey silts and silty clays, are dominant. Generally, alluvial quaternary sediments cover the study. These deposits are formed from a mixture of sand, silt, and clay as sequence beds having a variety of thicknesses. The upper part of these sediments is mostly silt. The water table level appears at 4 m depth.

Many authors have studied soils that may be used in mud brick industry in different localities of Iraq. One of those authors is Al-Helali 1980 who studied some geochemical and physical properties of clay in the Diala area and found a high concentration of some heavy elements. Al-Nuaaimy 1982 pointed a suitable use of soil of Al-Nahrawan for the building brick industry. The important study in this topic was done later by Al-Bassam 2004 who classified the physical and chemical properties of the raw materials used in the brick industry, which has been used by a whole review of brick topics.

The aims of this work are to evaluate the mineralogical, geochemical, and geotechnical properties of soil that were collected from the quarry that have been previously and

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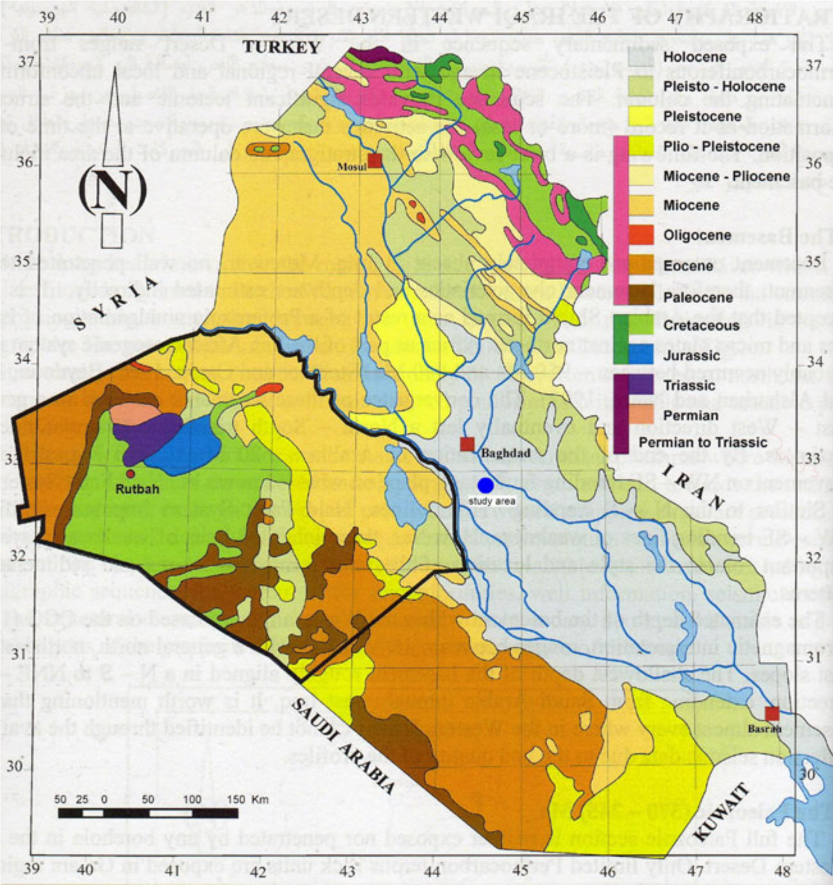

Fig. 1 The geological map of Iraq shows location of the study area (after Fouad 2007)

recently used in the brick industry; this work is also expressed as a contribution to the study of construction material subjects.

Sampling and methodology

The field work was done in purpose to collect samples and investigate the exposures of industrial clay. Both samples from the three selected sites of the quarry and mixture that has been prepared for use in the brick industry in the Al-Sowera factory were collected. Clay minerals are separated from samples; thereafter, the minerals were identified under polarized microscope. Mineral content is calculated in Table 1 based on the quantitative presence of mineral as well as the molecular proportion.

The clay mineral separation procedure of Carver (1971) and Folk (1974) was applied in the geochemical laboratory

Table 1 Mineral content (%) of the quarry soil

Sample	Halite %	Calcite %	Clay minerals%	Quartz %	Gypsum %	Feldspar %
1S	1.2	19.6	66	7.5	0.3	2
2S	2.0	17.3	72	6.5	0.5	1.5
3S	0.9	20	75	4.1	0.6	3
Average	1.4	19	71	6	0.46	2.2
1H	1.9	16.9	67.5	9.5	1.1	2.7
2H	2.0	17.5	69	8.0	0.6	2.9
3H	3.7	20.5	61	12.2	0.8	1.1
Average	2.5	18.3	65.8	10	0.83	2.2
1R	2.3	11.4	79	4.1	1.9	0.8
2R	1.5	16.7	64	12.5	1.5	3.3
3R	0.5	17.0	65	13.0	1.0	2.7
Average	1.4	15	69	9.9	1.5	2.3

Table 2 Clay mineral content (%) of the quarry soil

Sample	Chlorite %	Palygorskite %
1S	16.5	48.5
2S	18	54
3S	18.75	56.25
1H	16.8	50.6
2H	17.25	51.75
3H	15.25	45.75
1R	19.75	59.25
2R	16	48
3R	16.25	48.75

of the University of Baghdad. The X-ray diffraction technique used for the identification of clay minerals (Table 2) and chemical analyses of SiO_2, Al_2O_3, CaO, MgO, K_2O, Na_2O, SO_3, and loss on ignition (LOI) (Table 3) was done at the Ministry of Science and Technology, Center of Chemical Research. SO_3 is a part of loss on ignition, but it had been calculated separately in order to correlate with gypsum.

The geotechnical tests (liquid limit and plastic limit) and hydrometer analyses (Table 4) were done at the College of Engineering, Civil Engineering Department.

Mineralogy

The mineral content of the soil collected from the quarry appears to be formed from calcite, clay minerals with little quantity of quartz, gypsum, and traces of feldspar (Table 1). Chlorite and palygorskite are the main dominant clay minerals. The ratio of chlorite/palygorskite is approximately 4/1. The clay mineral contents are summarized in Table 2.

Geochemistry

The average chemical analyses results of soil have been compared with the results of Qaduri et al. (1999) and Al-Bassam (2004) (Table 3).

Silica, MgO, and Fe_2O_3 concentrations of the mixture appear to be less than those of Qaduri et al. (1999) and Al-Bassam (2004). The amount of alumina is also less and out of range of Al-Bassam, but within the range in comparison with Qaduri et al. (1999). All these variations may be attributed to the relation of decreasing clay minerals that involved SiO_2, Al_2O_3, MgO, Fe_2O_3, K_2O, and CaO.

Calcium oxide appears to be higher than the range of both Qaduri et al. (1999) and Al-Bassam (2004), which is attributed to the presence of calcite as well as palygorskite and CaO in their structure as major components; also, SO_3 seems less than the minimum limit because of the decreasing gypsum content in the quarry soil. Loss on ignition (CO_2 and H_2O) appears to be within the range (Table 3).

The differences in chemical results between quarry sites and mixture are attributed to the heterogeneity of on-site mixing.

Geotechnical properties

The geotechnical properties of soil in the study area (the quarry and the mixture soil) had been tested; thereafter, they were evaluated for sustability in the building brick industry. This evaluation normally required many laboratory tests such as the following:

1. Grain size analyses

Sieve analyses of soil were not used because this method is much suitable for engineering purposes (Bowles 1984);

Table 3 Results of chemical analyses of both quarry soil and mixture compared with the results of three authors

Oxides	Razuqi (1980) (%)	Qaduri et al. (1999) (%)	Al-Bassam (2004) (%) (at 950°C)	Al-Qazaz et al. (2005) (%)	The quarry (%)				The mixture (%)
					Site 1	Site 2	Site 3	Ave.	
SiO_2	40.14–48.34	35–45	38–40	40.4	26.6	24.9	28	26.5	27
Al_2O_3	10.9–20.4	5–12	10.5–11	10.38	8.2	7.2	7.1	7.5	6.9
CaO	11.29–23.99	Max 20	15–16	17.08	11.55	25.14	25.0	20.6	21.25
MgO	0.20–5.7	Max 10	4–6	6.0	5.3	3.6	6.7	5.1	3.18
K_2O		1–6		1.27	0.57	0.58	0.54	0.57	1.0
Fe_2O_3	2.08–8.6	4–8	3–4	6.08	3.9	3.5	3.2	3.4	3.3
SO_3	0.06–3.4	1.0		0.65	0.8	1.3	0.9	1.0	0.7
Na_2O		1.2		1.54	0.29	0.62	0.56	0.52	0.42
LOI	16.2–18.24 at 1,000°C		16–18	17	20.8	16.5	21.0	19.8	17.9

SO_3 had been calculated separately, then subtracted from total loss on ignition (LOI)

Table 4 Grain size analyses of quarry and mixture soil

Quarry		Mixture	
Diameter (mm)	Cumulative ratio	Diameter (mm)	Cumulative ratio
0.297	100	0.297	100
0.149	99.69	0.149	99.1
0.075	96.426	0.075	93.7
0.05887	93.16533333	0.061113143	91.752676
0.041628	93.16533333	0.044342068	75.9332491
0.029435	91.4	0.032286157	56.9499368
0.020925	90.05982222	0.023364518	41.1305099
0.013183	84.62517778	0.016632972	34.0594414
0.007821	76.08502222	0.008722411	25.311083
0.001217	26.39684444	0.001296563	14.6

in addition, this method does not have enough significance for recognizing the soil components, especially those that are able to pass through sieve 200 mesh (less than 75 μm grain size). This is because of two reasons: first is the difficulty of the process and the second one is the cohesive soil. Therefore, hydrometer analyses were carried out on both quarry and mixture soils, a perfect description of the hydrometer analyses is shown in Table 4.

The detailed grain size distribution illustrated in Fig. 2 shows that the soil of quarry has sand which does not exceed 3.5%, while silt and clay are 70% and 26.5%, respectively (Table 5). Sand percentage in mixture sample appears to be 6.5%; silt is 68%, whereas clay is 25.5% (Table 5). However, the increase in silt causes a decrease in the strength of brick before and after fire (Hussain and Zinal 1985).

2. Consistency limit

Generally, water affects soil, especially clayey soil, which is obviously affected by water content (moisture). Two characters were tested in order to understand the consistency limit. These are the liquid limit and plastic limit:

(a) Liquid limit

It is the moisture content expressed as a percentage by weight of the oven-dried soil at which the soil just

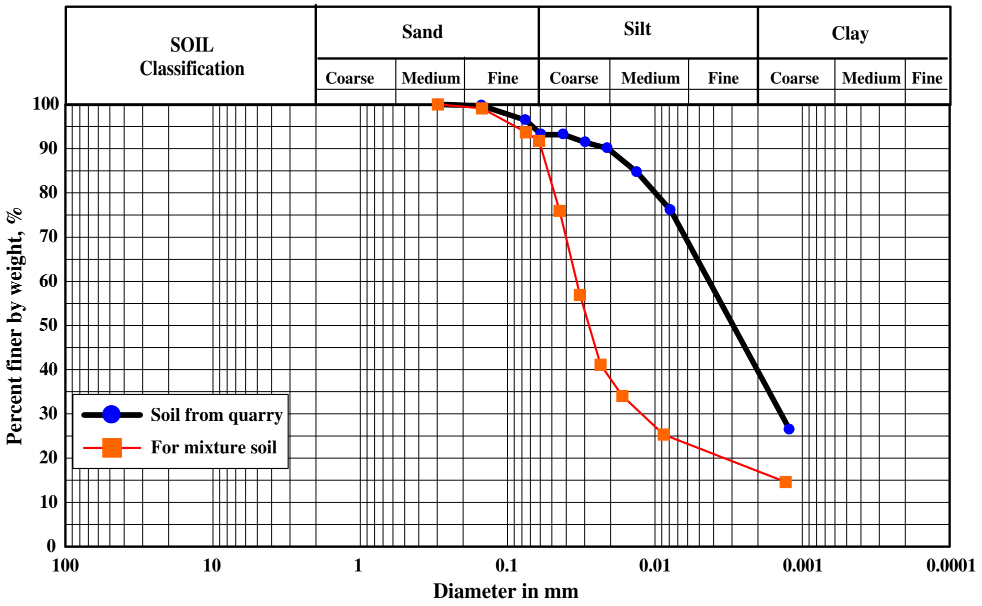

Fig. 2 Grain size distribution for quarry and mixture samples

Table 5 Percentage of grain size for quarry and mixture samples compared with Al-Hamadani 2002

Soil component	Size (μm)	Ratio (%) in quarry samples	Ratio (%) in mixture samples	Al-Hamadani (2002)
Sand	>20	3.5	6.5	25
Silt	2–20	70	68	35
Clay	<20	26.5	25.5	40

begins to flow when jarred slightly (Grim 1962). Liquid limit is the water content which can be easily read from the *x*-axis against 25 blows on the *y*-axis. Therefore, the flow curve of liquid limit is illustrated in Fig. 3. This curve shows the liquid limit of quarry soil and mixture as 56.5% and 27.4%, respectively (Fig. 3).

(b) Plastic limit

It is the lowest moisture content expressed as a percentage by weight of the oven-dried soil at which the soil can be rolled into threads 3 mm in diameter without breaking into pieces. This test can be done via rolling the spherical piece of soil on a glassy plate (Ali et al 1990). The laboratory tests determined the plastic limit of the quarry soil as 26.01, whereas it was 19.7 for the mixture.

Soil classification

Plasticity index (PI) was used in purpose to classify both soils taken from the quarry and mixture whether they are suitable for the brick industry or not. PI is the difference between the liquid limit and plastic limit (Grim 1962). Also, it is the range of moisture content at which the soil is plastic. When the plastic limit is equal to or greater than the liquid limit, the plasticity index is recorded as zero. Accordingly, the plasticity index is described by the following equation:

$$\mathrm{PI} = \mathrm{LL} - \mathrm{PL}$$

Where PI=plasticity index, LL=liquid limit, and PL= plastic limit.

$$\mathrm{PI}_{(\mathrm{quarry})} = 56.5 - 26.01$$
$$\mathrm{PI}_{(\mathrm{quarry})} = 30.49$$
$$\mathrm{PI}_{(\mathrm{mixture})} = 27.4 - 19.7$$
$$\mathrm{PI}_{(\mathrm{mixture})} = 7.7$$

PI values were plotted on the plasticity discriminative curve (Fig. 4). The results show that the quarry soil appears to be highly plastic clayey soil, whereas the mixture is a clayey soil with low plasticity.

Specific gravity

Specific gravity is the ratio between density of the soil and density of the water at 4°C (Poland 1984). From the laboratory test, the specific gravity of the quarry soil was found to be 2.82, whereas it was 2.7 in the mixture. These values tend to fit with standard values as shown in Table 6.

Discussion and conclusions

The quality of bricks depends on constituents of the raw materials and the technique used for manufacturing bricks. On this basis, Mineralogical content and chemical composition play an essential role in determining the quality of brick.

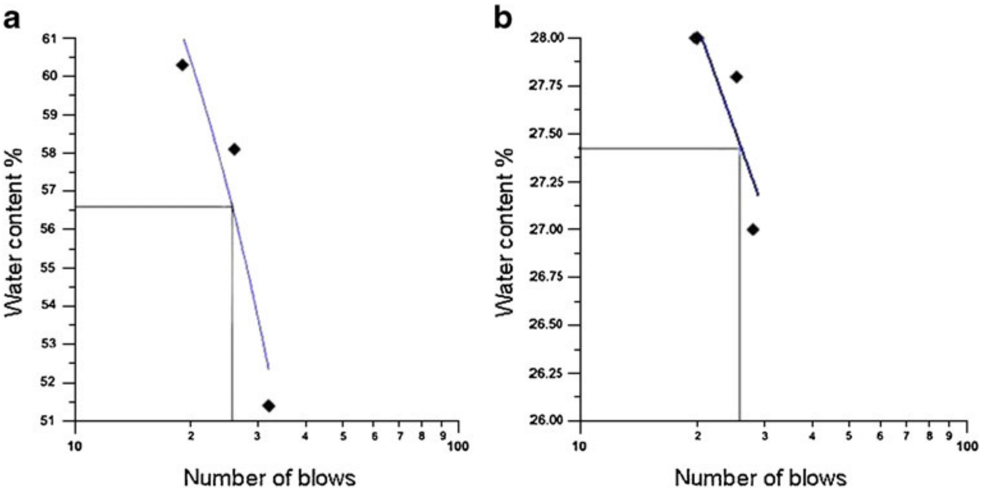

Fig. 3 The flow curve of liquid limit for the quarry samples (**a**) and the mixture (**b**)

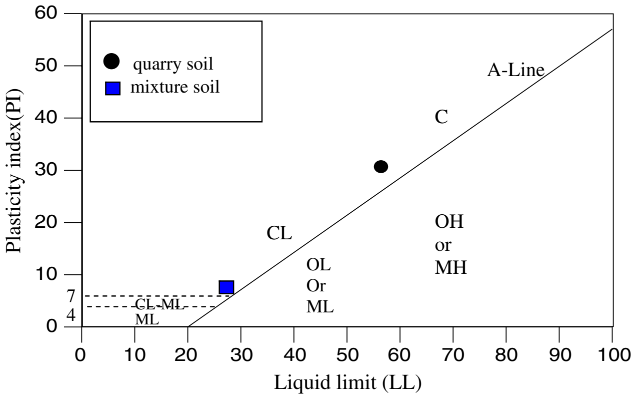

Fig. 4 Plasticity discriminative curve shows the nature of plasticity index nature of the quarry and mixture soils. *C* clay, *M* silt, *O* organic, *H* high plasticity, *L* low plasticity (according to Unified Soil Classification System)

The high amount of gypsum in mixture soil causes hydration under wet conditions. Also, the high amount of gypsum during fire processes will lose the SO_3 and H_2O, leaving bubbles which will surely generate stress and make the bricks weak. Gypsum content in the study area is not high; therefore, the released SO_3 is lower than the standard. On this basis, gypsum appears to be suitable for the building brick industry. The presence of feldspar is very useful because it is a fusion material which helps decrease the needed temperature. The fluctuating low percentage of feldspar in Al-Sowera soil makes bricks less durable and with lesser strength, which is considered a negative agent for the brick industry; therefore, a high temperature for this case will be needed.

The presence of quartz in the soil used in the brick industry participates in decreasing the weight (Al-Bassam 2004). In the study area, the amount of quartz is little and appears to be not effective. At high temperature, quartz reacts with CaO and Al_2O_3 forming Ca, Al, and silicates; in such a case, the free CaO that produces bricks with cracks will be reduced. The carbonate content in soil is a very essential factor in forming bricks, but in limited percentage not exceeding 40% (Al-Qazaz et al. 2005). If the amount of $CaCO_3$ increased over 40%, the bricks will swell because of the CO_2 effect. During fire processes, of course, CO_2 is released leaving CaO which is able to absorb moisture from the atmosphere, especially during rainfall; this mechanism eventually causes swelling (Grim 1962). The soil of Al-Sowera quarry appears to have a slightly higher content of CaO coming from calcite, clay minerals, and gypsum.

A high content of montmorillonite causes cracks during the drying process which follows the molding process; also, a high content of montmorillonite will crack the brick during firing, too. A high content of calcite enlarges the brick volume, causing trouble during the firing process. Palygorskite and sepiolite will not make the bricks swell because of their fibrous shape. Eventually, the concentration of SiO_2, Al_2O_3, K_2O, Fe_2O_3, and MgO appears to be less than that of the optimum required limit. The quarry soil appears to be a highly plastic clayey soil, whereas the mixture is a clayey soil with low plasticity. Based on the results of evaluation, the soil of Al-Sowera quarry should be mixed if possible with soil from other places rich in fibrous clay minerals to substitute the deficiency in SiO_2, Al_2O_3, K_2O, Fe_2O_3, and MgO.

Accordingly, the future study of the fluviatile facies surrounded the Al-Sowera area within the Mesopotamia

Table 6 Standard specific gravity values of different type of soil (after Wilun and Starzewski 1975 in Djoenaidi (1985))

Type of soil			Specific gravity
Cohesionless	Inorganic	Coarse and medium sand	2.65
		Fine sand	2.65
	Organic	Sand	2.64
Cohesive	Inorganic	Sandy silt	2.66
		Silt	2.67
		Silt	2.70
		Clayey sand	2.67
		Clayey sandy silt	2.67
		Clayey silt	2.68
		Sand–clay	2.68
		Sand–silt–clay	2.69
		Silt–clay	2.71
		Sand–clay	2.70
		Silt clay	2.75
		Lean clay	2.75
		Clay	2.80

plain is recommended to find an integral raw material that will become as a stand by additive material which will add to the main mixture in known ratios when it is necessary.

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