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Assessment of waste clays in the Qusseir region of east central Egypt for production of lightweight bricks

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Abstract

Background: Egyptian Upper Cretaceous waste clay samples from Yunis Mines, Qusseir vicinity, Eastern Desert, were investigated for their chemical and mineralogical compositions as well as for firing. These investigations were carried out to assess the suitability to use the waste clays for the production of lightweight bricks. X-ray fluorescence (XRF), scanning electron microscopy (SEM), X-ray diffraction (XRD), and Fourier transform infrared (FTIR) techniques were applied for characterizing chemical and mineral compositions of the raw clays. On the other side, densification parameters of the fired samples up to 1100 °C were examined by using Archimedes water-saturation methods and by determining the density and crushing strength of the fired bodies.

Results: Two types of concrete were prepared using different grain sizes: coarse and a mix of coarse and fine aggregates. Concrete batches were prepared, and the mechanical strength and the bulk density were determined. Mineralogically, the waste samples consist of montmorillonite as the predominant clay mineral, with quartz, calcite, fluorapatite, anhydrite, and pyrite as impurities. Bulk density and apparent porosity of the fired clay sample at 1100 °C were 0.89 g/cm^3 and 67.19%, respectively, while the bulk density of the two types of concrete range from 0.76 g/cm^3 in coarse type with no fines to 0.90 g/cm^3 in the coarse with 20% fine fraction. The crushing strength of both types is 25 kg/cm^2 for coarse type and 45 kg/cm^2 for coarse and fine types, respectively.

Conclusions: The results showed that the data provides a useful application of waste clay ramps of ancient Yunis mining tunnels in Qussier area with an additional mean to assess their suitability for the production of lightweight brick concretes to reduce density and their relatively good strength in modern buildings for non-loading building units and to enhance the thermal insulation of buildings.

Keywords: Clays, Montmorillonite, Lightweight, Concrete

Background

Clay deposits are widely distributed within many geological formations from Carboniferous to recent age. They are located in the region of Nile Valley and Delta, as well as in the Western and Eastern Desert of Egypt. Most of these deposits are used for the applications in many ceramic industries, for example, whiteware, refractories, heavy clay products, and Portland cement (Hanna and Stoops 1977; Said 1990; Youssef 2008). Clays are classified according to their particle size, mineral and chemical compositions, and other properties (Grim 1962, 1968; Grimshaw 1971; Norton 1969; Konta 1979, Burst 1991). Many authors indicated that kaolinite-rich clay materials are refractory with a high vitrification range, low plasticity, white-to-buff burning colour and a low-drying and firing shrinkage. Moreover, montmorillonite-rich clays are non-refractory with low vitrification ranges, high plasticity, buff-to-red burning colour, and a high-drying and firing shrinkage. In contrast, illite-rich clays are falling between kaolinitic and montmorillonitic clays and exhibit wide variations. Lightweight clay aggregates may be produced by firing pellets of low-grade montmorillonite-rich clays with or without adding to the vitrification range. After firing, the clay pellets swell or bloat owing to gas releases within the firing bodies during the liquid phase. On cooling,

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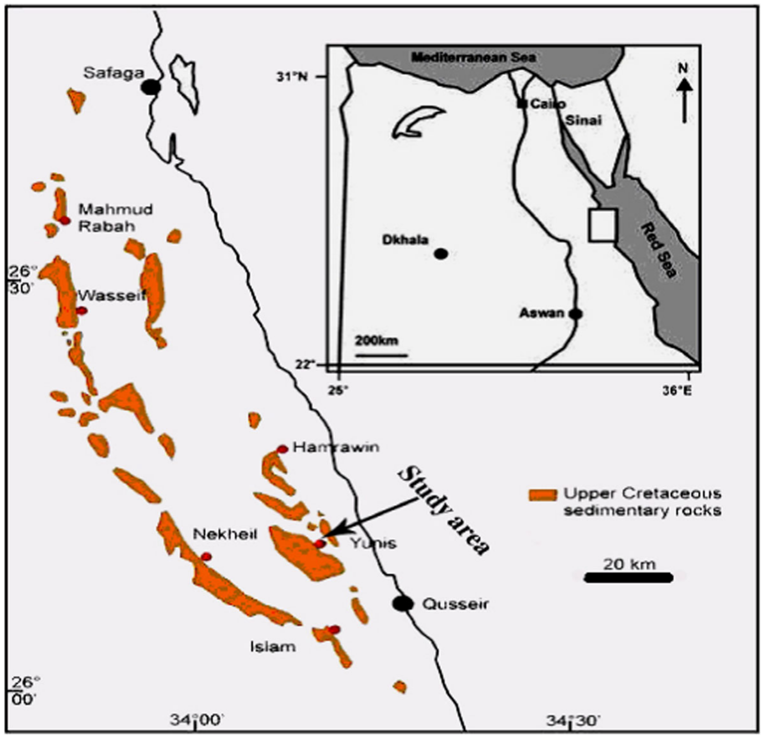

Fig. 1 Location map of the studied area

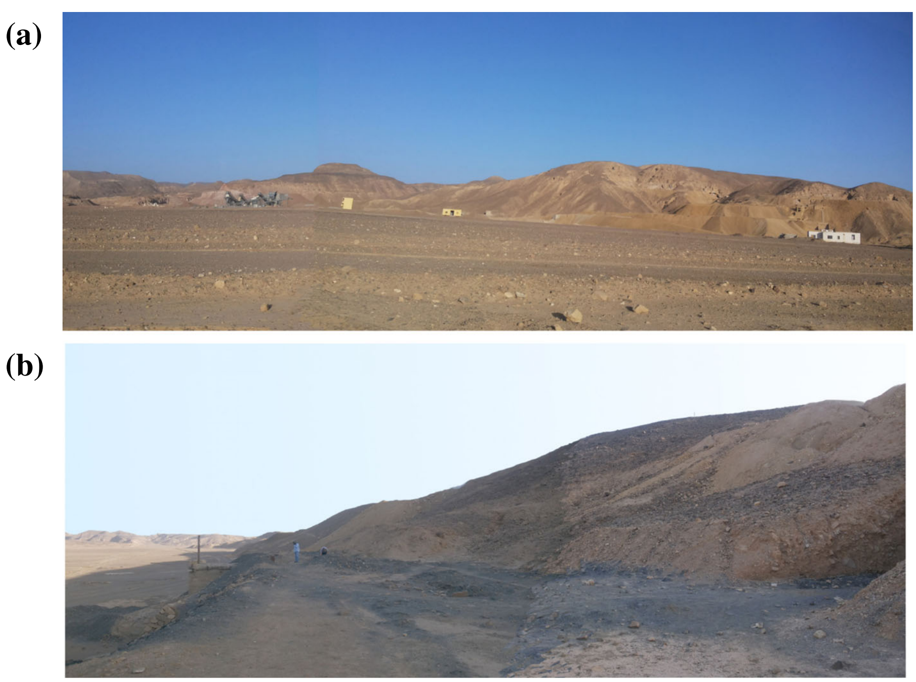

Fig. 2 Field photography of the studied area. **a** Recent Yunis active mining surface quarry. **b** Waste clay ramp of Yunis abandoned mining tunnels

Table 1 Chemical analyses of the used sample in weight %

SiO_2	Al_2O_3	Fe_2O_3*	TiO_2	MnO	CaO	MgO	Na_2O	K_2O	P_2O_5	SO_3	LOI	Total
21.27	7.51	1.98	0.24	0.02	15.2	0.82	0.24	0.45	4.54	4.81	42.90	99.98

*Total iron as ferric oxide

these low-grade montmorillonite clays conserve the cellular texture, and lightweight aggregate is obtained (Serry et al. 1985; Konta 1995; Karaman et al. 2006; Bernhardt et al. 2013; Ismail et al. 2016, Ismail et al. 2018; Risdanareni et al. 2017).

Many authors have studied the effect of using a pore-forming agent to increase the porosity of the ceramic body such as Duchan and Kopar (2001), Chemani and Chemani (2013), and Ismail et al. (2016). Others studied the replacement of cement with lighter materials, e.g. Mashaly et al. (2016, 2018), Bian et al. (2012) and Pelisser et al. (2012). Also, clay and pore-forming agent are shaped insulating refractory bricks with a true porosity of more than 45% and a service temperature of at least 800 °C (Grimshaw 1971; Sargeant and Stone 1981; Courtault et al. 1983; Routschka 1997).

The aim of the present work is to study the mineral and chemical compositions and the properties of the fired, carbonaceous, clay-rich shale at the Yunis mines at Qusseir region (Fig. 1) to reveal their suitability for the production of lightweight bricks, that improve the thermal insulation of buildings.

Methods

The material used in this work is waste clay from Yunis mines, which is located south of the Hamrawin area and 12 km from Qusseir–Safaga Asphaltic Road to the west. The chosen area is located at longitudes 34° 03′ 12″ and 34° 03′ 24″ E and latitudes 26° 11′ 27″ and 26° 11′ 37″ N (Fig. 1). Upper Cretaceous in the Qusseir shales have a widespread distribution and are associated with the Egyptian phosphate mining zones. These shales occur as parts of a surface and subsurface sedimentary succession that ranges in age from Carboniferous to Eocene. Huge amounts of waste clays are located around Yunis from the abandoned mining tunnels and recent surficial (Fig. 2). Representative samples of these waste clays were investigated to determine their applicability for the production of lightweight bricks after firing at up to 1100 °C.

The chemical and mineralogical compositions of these clays were studied using XRF, XRD, FTIR, and SEM techniques. The chemical composition of the studied samples was determined by using an Axios Sequential WD_XRF Spectrometer, PAnalytical 2005 in the National Research Center Laboratories, Dokki, Cairo, Egypt. ASTM E 1621 standard guide for elemental analysis by wavelength-dispersive X-ray fluorescence spectrometer and the ASTM D 7348 standard test method for loss on ignition (LOI) on solid combustion were used as guidelines. X-ray diffraction analysis (XRD) was performed on a Philips X-ray diffractometer, Mod. PW 1390, with Ni-filtered Cu-Kd radiation. The morphology and the microstructure of the samples were characterized with SEM coupled with energy-dispersive spectroscopy EDAX (SEM Model Quanta FEG 250) carried out in the National Research Center Laboratories. FTIR absorption spectra were recorded by Elmer-783 double-beam dispersion spectrophotometer using standard KBr tablets. Three hundred milligram KBr was homogenized with 1 to 2 mg of the sample in a vibration mill and evacuated, and the

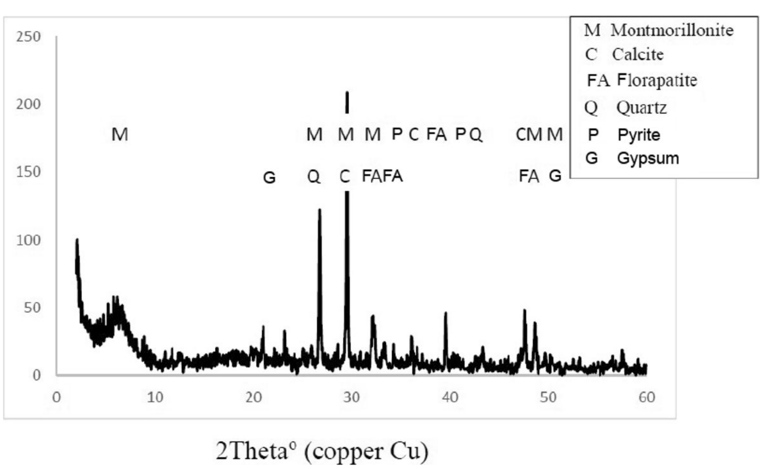

Fig. 3 XRD pattern of raw clay technological sample

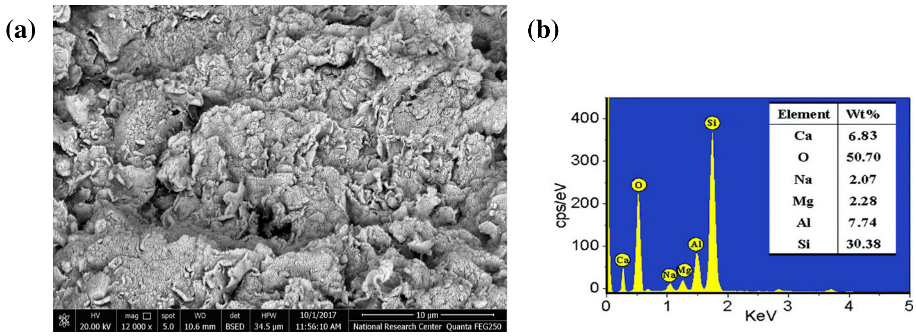

Fig. 4 SEM and EDAX of the raw clay. **a** Scanning electron micrograph showing a well-crystallized montmorillonite with well-developed "oak leaf" and cellular morphology with tightly interwoven flakes. **b** EDAX analysis of Ca-montmorillonite

tablets were then pressed for 5 min under pressure of 10 MPa. The recording time was 20 min, and the range is 4000–400 cm^{-1}.

The preparation of lightweight brick regime starts with the firing of a crushed representative waste clay sample at 1100 °C and then broke up using a jaw crusher until obtaining a grain size ranging from 2 to 10 mm with minimum amounts of finer-grained material. Two mixes of concrete were prepared using two different grain sizes of the fired waste clay grains: the first mix consisted of coarse grains ranged from 2 to 10 mm with no fines, and the second mix composed of coarse grains (2 to 10 mm) with 10% finer ones. The percentages of the cement and water were applied as per standard specification (British standard 2028 1968). The concretes were casted into cubic molds with a dimension of 5 × 5 × 5 cm^3 then demolded after 24 h and cured in ~ 95% humidity chamber for 28 days. The prepared cubes were tested for crushing strength and bulk density according to ASTM C20 2010.

Results

Characterization of the waste clays

The chemical analysis data from the raw waste clays are summarized in Table 1. It is evident that the clays are calcareous, i.e. rich in CaO (15.2%). The weight percent of silica and alumina are 21.27 and 7.51, respectively. Meanwhile, the loss on ignition of the sample was 42.90%. The percentages of MgO, TiO_2, Fe_2O_3, and MnO were 0.82, 0.24, 1.98, and 0.02, respectively. P_2O_5 and SO_3 are recorded at relatively high values (4.54% and 4.81%) due to the presence of apatite and gypsum, which are confirmed with XRD results (Fig. 3). Na_2O and K_2O occurred in minor amounts as 0.24 and 0.45%, respectively.

XRD analysis indicated that the main mineral component of the raw waste clays is montmorillonite, with calcite, fluorapatite, gypsum, and quartz impurities. Pyrite was also detected as in the clay-size fraction.

SEM examination of the studied sample showed the predominance of the clay mineral montmorillonite, which was verified by XRD data (Fig. 3). Figure 4 shows

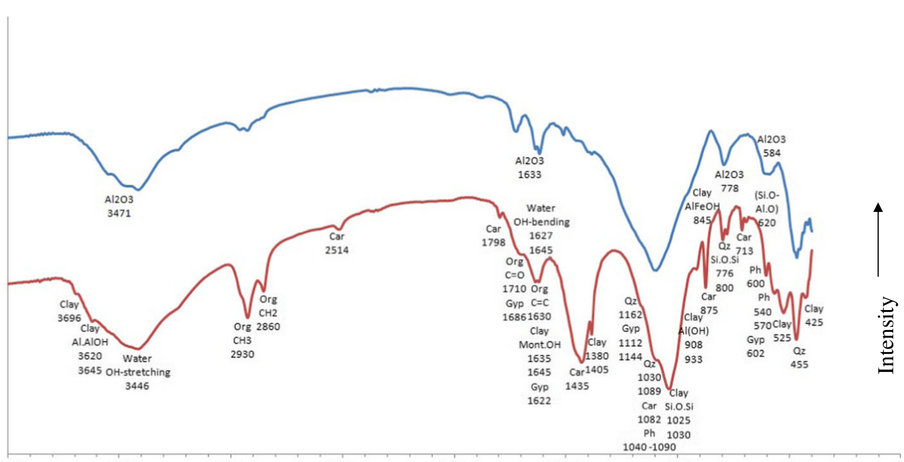

Fig. 5 FTIR spectra recorded for raw clay technological sample (down) and the fired sample (top)

Table 2 Densification parameter of the fired samples at 1100 °C

Type of the clay	Bulk density (g/cm^3)	Apparent porosity (%)
Raw waste clay	2.21	6.55
Fired waste clay	0.89	67.19

the morphology of completely montmorillonized shards with typical, tightly interwoven flakes. Characteristically, a Na-montmorillonite is more open-textured or fluffy than the Ca-montmorillonite, presumably because the Na^+ interlayer ion is more easily hydrated than is Ca^{2+} (Keller et al. 1986). The texture of these montmorillonites which display the tight "cornflake," "oak leaf," or "cellular" texture (Fig. 4a), is more typical of Ca-montmorillonites (Fig. 4b).

FTIR techniques investigate bond vibrations of the radical groups, whose spectra absorption bands appear at different frequencies. The band position is compared with the spectra noted in Gadsden (1975), and possible assignments of the representative spectra for the raw waste clay and fired samples are presented in Fig. 5. The absence of organic matter bands located at 2860 and 2930 cm^{-1} in the raw clay spectra from the fired sample pattern reveals another result due to the disappearance destruction of organic matter during heating, which were located at the 713, 875, 1435, and 2514 cm^{-1} spectra in the raw clay record. Similarly, sulfate bands of gypsum were not detected fired sample spectra. Another noticeable difference on the major absorption band at 1000 cm^{-1} of the raw clay in the sample is that it shifted toward 1100 cm^{-1} in fired sample due to the breakup of the clay structure (bands region 900–1000 cm^{-1}) and predominance of quartz (bands region 1000–1100 cm^{-1}) during firing. The clay structure bands at 525, 845, 908, 933, 1380, 1405, 3645, and 3696 cm^{-1} are mostly "extinct" in the fired sample, while water bending and stretching at 1645 and 3446 cm^{-1} remain in the record of the fired sample, but these bands may also reveal water absorption from lab environment and absorption of water molecules from atmospheric air while recording the spectra.

The physical properties of the waste clay before and after firing are shown in Table 2. The bulk density of the raw waste clay was 2.21 g/cm^3 while after firing, it was 0.89 g/cm^3. The apparent porosity of the raw clay was 6.55% while that of the fired one is 67.19%.

Properties of the casted mixes

Table 3 presents the properties of the two casted mixes. In mix 1, the fired waste clay aggregates are coarse grains ranged from 2 to 10 mm, while mix 2 aggregates are composed of coarse grains with 10% finer ones. The concrete mixes 1 and 2 are prepared as 6:1 aggregate to cement ratio with a binder to water ratio of 0.4. The physical and mechanical properties of the casted mixes including the bulk density and the crushed strength are summarized in Table 3. The bulk density is 0.76 and 0.90 g/cm^3 for mix 1 and mix 2, respectively, while the crushing strength for mix 1 and mix 2 was 25 and 45 kg/cm^2, respectively.

Discussion

Effect of clay firing

The effect of increasing firing temperature up to 1100 °C on crystal phases of the selected samples was studied using XRD technique (Fig. 6). It was shown that quartz, cristobalite, and hematite phases are present at 1100 °C with high liquid phases of calcium aluminium silicate binding everything in a glassy groundmass.

Table 2 indicates that the bulk density of the fired clay decreased from 2.21 g/cm^3 for the raw waste clay to 0.89 g/cm^3, while the apparent porosity increased from 6.55% for the raw waste clay to 67.19% after firing. The enormous expansion indicated by the porosity is due to the gasses generated by oxidation of the organic material contained in the raw clay, note in Fig. 5 the absence of organic matter bands from the fired sample IR pattern due to the oxidation. This expansion occurs until the surfaces of the particles have attained sufficient strength to prevent the gasses from escaping.

Assessment of lightweight bricks

To consider the blocks produced from the fired aggregates as lightweight bricks according to the British Specification No. 2028, bulk density should be between 0.55 and 1.05 g/cm^3. The bulk density of the concretes ranges from 0.76 to 0.90 g/cm^3 for the coarse type with no fine aggregates mix 1 and the coarse type with 10% fine aggregates mix 2, respectively (Table 3). The crushing strength of both types after curing for 28 days was

Table 3 Mix composition and properties of the prepared lightweight concrete

Type of the fired waste clay aggregate in the mixture	Mix composition (ratio by volume)		Bulk density (g/cm^3)	Crushing strength (kg/cm^2)
	Aggregate/cement ratio	Water/cement ratio		
Mix 1 Coarse aggregate (2–10 mm grain size)	6:1	0.4	0.76	25
Mix 2 Coarse aggregate with 10% finer particles	6:1	0.4	0.90	45

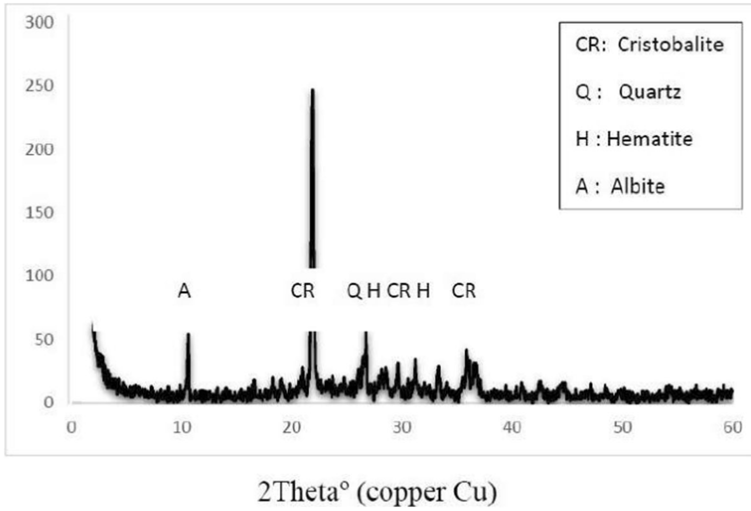

Fig. 6 XRD pattern of the fired clay sample

25 kg/cm^2 for coarse-grained types only and 45 kg/cm^2 for coarse-fine-grained types. The above results indicate that the concretes, containing the fine portion of the grain sizes, gave a higher compressive strength and a higher density than those without any fine fractions. Therefore, it is possible to produce lightweight concrete blocks of low density and relatively good strength to be utilized in modern building trend for non-loading building units and in the partition wall construction, as well as for improving the thermal insulation of buildings.

Conclusions

- The materials used in this work were waste clays from Yunis mines, which are located south of the Hamrawin area and 12 km from Qusseir–Safaga Asphaltic Road to the west.
- XRF, XRD, FTIR, and SEM data confirmed that the predominant mineral components present are montmorillonite, with quartz, calcite, fluorapatite, gypsum, and pyrite impurities.
- Bulk density and apparent porosity of the fired samples at 1100 °C are 0.89 g/cm^{3}and 67.19%, respectively.
- Two types of concrete were prepared using two different grain size fractions of the fired waste clay grains. The first grain type ranges from 2 to 10 mm with no fines while the second contains the coarse grows (2 to 10 mm) with a 10% finer fraction.
- The bulk density of the two types of concrete ranges between 0.76 g/cm^3 in coarse-grained type with no fines and 0.90 g/cm^3 in the coarse-grained fraction with 10% fine fraction. The crushing strength of both types after curing for 28 days is 25 kg/cm^2 for coarse type and 45 kg/cm^2 for coarse and fine types.
- The thousands of small, air-filled cavities give the two types their strength and thermal insulation properties. The base material was waste clay and was fired up to 1100 °C. Finally, the clay materials were mixed and molded to form lightweight concrete block products.
- The above results indicate the possibility of producing low-density and relatively high-strength concrete block products for the utilization in modern building trend for dead-load construction for partition wall construction, as well as for improving the thermal insulation of buildings.

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Availability of data and materials

The authors declare that the work data and material are available.

Authors' contributions

EAE-A, HM, and WA contributed in the field, geochemistry, mineralogy, and application works. ME contributed to the mineralogy, physical parameters, and application works. All authors read and approved the final manuscript.

Ethics approval and consent to participate

The authors declare that the work is ethically approved and consent to participate.

Consent for publication

The authors declare that the work has a consent for publication.

Competing interests

The authors declare that they have no competing interests.

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