JJEES

Volume 9, (Number 2), August, 2018
ISSN 1995-6681
Pages 81 - 88

Jordan Journal of Earth and Environmental Sciences

Physical and Technical Characteristics of Jarash Clay deposits from Northern Jordan

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Received 18 December, 2017; 6 June, 2018

Abstract

Detailed analysis of the physical and technical characteristics of Jarash clay deposits in northern Jordan reveals the strong potentiality of those deposits from the industrial point of view. The results of this study show the usefulness of those deposits in various industrial sectors, with emphasis on the possible usefulness of the clay in pottery, ceramic tiles, and brick-making industries. One hundred and two samples were collected from seven different outcrops for the physical and technical analysis. The results of physical properties after attrition and wet sieving obtained in this study include: whiteness, bulk density, oil absorption, and specific gravity. Whiteness ranges from (25.4% to 54.9%) with an average value of (40.1%). Bulk density ranges from (0.86 to 1.22 g/cm^3) with an average value of (0.99 g/cm^3). Oil absorption ranges from (23.25 to 46.5 ml/100gm) with an average value of (33.1 ml/100gm). Specific gravity ranges from (2.02 to 2.7) with an average value of (2.24). the grain size analyses for the bulk samples range from sandy clay to clayey sand on the Shepard sediment classification ternary diagram. The technical characterization resulting after attrition and wet sieving have also been examined. The plastic limit ranges from (15.9 to 26.3%) with an average value of (10.74%), liquid limit ranges from (34.2 to 71.5%) with an average value of (48.18%), and plasticity index ranges from (18.3 to 45.2%) with an average value of (19.74%).

According to the physical, chemical, technical properties, clay identification and the clay workability chart of Jarash clay deposits after attrition and wet sieving, it can be said that Jarash clay deposits are suitable for pottery, ceramic tiles, and the brick-making industries.

Keywords: Clay, Kaoline, specific gravity, oil absorption, bulk density, liquid limit, plastic limit, grain size, Jordan.

1. Introduction

Clay minerals are of high importance in the mineral industries. Kaolin group encompasses different hydrosilicates minerals, i.e., kaolinite, dickite, nacrite and halloysite with kaolinite being the most common (Murray, 1988; Murray, 1999; Murray, 2007). For many industrial applications, kaolin must be refined and processed from the crude state to enhance its whiteness, purity, and other important commercial characteristics. The impurities in kaolin including quartz, micas, illite, montmorillonite, goethite, hematite, pyrite, anatase, rutile, ilmenite, tourmaline, zircon and other heavy minerals can be removed by wet processing (Murray, 1999).

Clay minerals represent about 16 % of the total volume of the sedimentary rocks of the earth's solid surface. Deposits of less than two microns of the grain diameter are termed clay. As a rock, clay usually consists of a mixture of clay minerals and other rock debris of varying composition (Khoury 2002; Khoury et al., 2008).

Kaolinite [$Al_2Si_2O_5(OH)_4$] is the most interesting phyllosilicate clay mineral. It is widely employed as raw material in ceramics, paper filling and coating, refractory, fiberglass, cement, rubber and plastics, paint, catalyst, pharmaceutics and agriculture (Aras, et al., 2007; Diko et al., 2011; Diko et al., 2016; Ediz, et al., 2015; Ekosse, 2010; Murray, 2007). The main uses of kaolinite are in paper filling and coating (45 %), refractories and ceramics (31 %), fiberglass (6%), cement (6 %), rubber and plastic (5 %), paint (3 %), and other industries (4 %) (Baba et al., 2015).

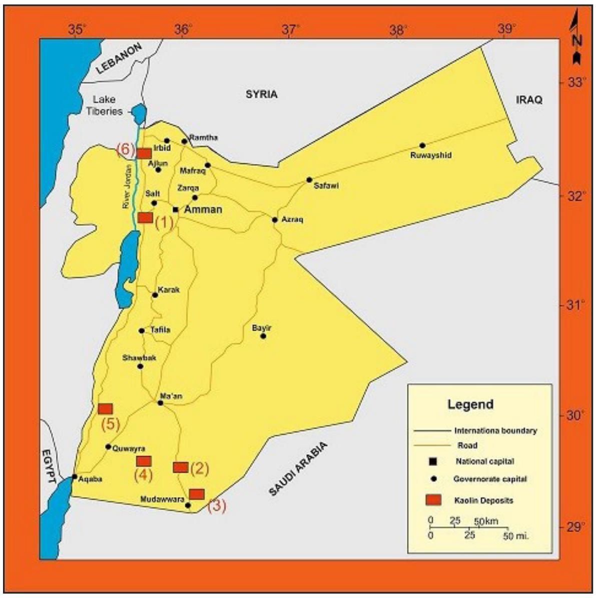

Figure 1. Occurrences of Kaolin clay deposits in Jordan (modified after Yasin and Ghannam, 2006).

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Kaolin deposits occur in different localities in Jordan. Figure (1) shows the occurrences of different localities of kaolin clay deposits in Jordan. These deposits are distributed throughout Jordan in the north (e.g. Jarash area), central (e.g. Mahis area) and in the south (e.g. Batn El-Ghoul, Al Mudawwara, Ghor Kabid, Jabel Umm Saham, and Dubaydib areas). The current research paper focuses on Jarash clay deposits located in northern Jordan. Figure (2) shows the geological map of the study area.

2. Geological Setting of the Study Area

The study area is located thirty-eight km to the south of Irbid city and around forty-five km to the north of Amman city. The coordination are 32˚ 12′ 00″ N – 32˚ 14′ 00″ N and 35˚ 51′ 50″ E – 35˚ 53′ 25″ E. Figure (2) shows a geological map of the study area. The geology of the study area was studied by several researchers (Amireh, 1996; Amireh and Abed, 1999; Ahmad et al., 2012; Abu Hamad et al., 2016). The sandstone of the study area belongs to the lower Cretaceous Sandstone (Aptain-Albian age) which consists of clastic sedimentary rocks including sandstone with intercalation of claystone where the sandstone dominates over the claystone. It also contains conglomerates, siltstone, and three inter-bedded carbonates sequences (Amireh, 1996).

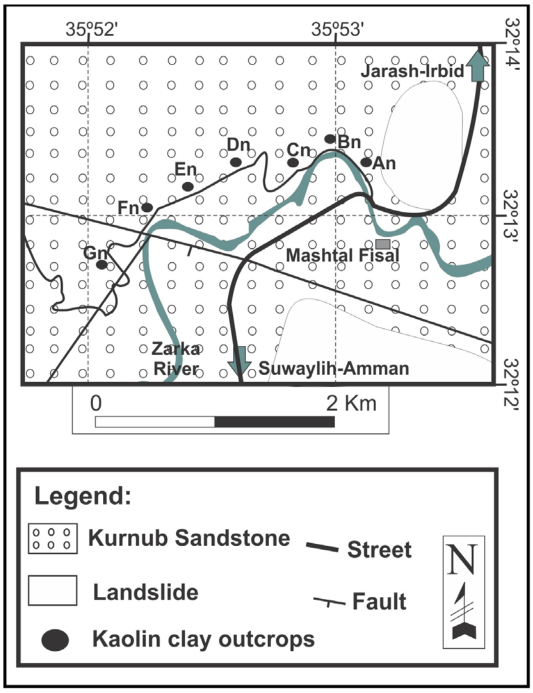


Figure 2. Geological map of the study area (Modified from Sawariah and Barjous, 1993; Royal Jordanian Geographic Center, 2003).

3. Materials And Methods

3.1. Field Work and Sampling

Field works were performed during summer of 2015 focusing on Jarash clay deposits. One hundred and two samples were collected from seven different outcrops abbreviated as (An, Bn, Cn, Dn, En, Fn and Gn). The samples were chosen from Jarash clay deposits, using the channel sampling methods. Table (1) shows the coordinates and description of these outcrops and the elevations of the selective outcrop.

Table 1. Coordination of the seven outcrops in the study area and there elevation above the sea level.

Outcrop	N	E	Elevation in meter	Description
An	32˚13′ 20″	35˚53′05″	225	Clay, vary-colored, light grey to light brown, medium to fine grained, soft to hard, red intercalation.
Bn	32˚13′ 33″	35˚52′ 55″	231	Clay, light grey- with brown, medium to fine grained, soft.
Cn	32˚13′ 23″	35˚52′ 45″	229	Clay, vary-colored, light grey - yellowish brown, medium to fine grained, soft to slightly hard.
Dn	32˚13′ 26″	35˚32′ 35″	239	Clay, vary-colored, mainly grey, fine to medium grained, soft.
En	32˚13′ 10″	35˚52′ 25″	244	Clay, light grey to brown and yellow, medium to fine grained, soft to hard.
Fn	32˚13′ 06″	35˚52′ 12″	274	Clay, light grey to yellow, medium to fine grained, slightly hard.
Gn	32˚12′ 50″	35˚52′ 05″	323	Clay, light brownish grey to yellow, medium to fine grained, soft to slightly hard.

3.2. Laboratory Works

Size reduction, grain size analysis, whiteness, specific gravity, oil absorption, bulk density, plastic limit (PL), liquid limit (LL), and plasticity index tests were carried out on one hundred and two representative samples after performing the attrition scrubbing test and wet sieving using the 63µm mish.

3.3. Size Reduction, Attrition Scrubbing and Wet Sieving

The size reduction is one of the most important processes used during sample preparation. The attrition scrubbing can be referred to as the first step of the wet sieving. The purpose of this process was to reduce the coarse size of the sample into finer size by the disintegration and separation of the fine particles by water (Preston and Tatarzyn, 2013; Sandgren et al., 2015). Laboratory attrition scrubber model (IKA-Werk TR-50) was used in this study. The wet sieving was done according to the method of British Geological Survey Laboratories for kaolin (Bloodworth et al., 1993). Sieves that were used in the wet sieving process included the size fractions 2 mm, 1 mm, 0.500 mm, 0.250 mm, 0.125 mm, and 0.063 mm.

The grain size analysis and wet sieving was used to: 1- Determine the percentage of the sand, silt, and clay available in the sample, 2- Separate the fine particles from the coarse particles, 3- Eliminate the major impurities (Sandgren et al., 2015; Bloodworth et al., 1993).

The whiteness is an indicator of the purity of the sample. Sixty five representative samples from Jarash clay including twenty seven samples before attrition scrubbing and wet sieving and, and thirty eight samples after attrition scrubbing and wet sieving (<63µm) were analyzed using (KETT Electric Laboratory Whiteness test C130 instrument) at the laboratories of Ministry of Energy and Mineral Resources.

Specific gravity was carried out for the samples based on standard methods of ASTM D 854-00. Oil absorption is one of the most important factors used in testing the materials for different industrial application and industries. The tests of oil absorption were done according to the BS 3483: part B7: British Standard method for testing of pigments paint. Representative samples from Jarash clay after attrition and wet sieving were chosen and examined at Earth and Environmental Sciences Department in Yarmouk University. The bulk density is defined as the mass of many particles of the material divided by the total volume. Representatives samples were chosen for the density test.

The liquid limit (LL) is arbitrarily defined as the water content. The plastic limit (PL) means that the lowest water content at which the soil samples stay plastic. The plastic index is the difference between the liquid limit (LL) and the plastic limit (LL). Fourteen bulk representative samples were selected from Jarash clay which included seven samples before attrition scrubbing and wet sieving and seven samples after attrition scrubbing and wet sieving. All applied using the methods of (ASTM D 4318).

4. Results and Discussion

4.1. Results of Physical and Technical Characteristics

Physical characteristics include whiteness, specific gravity, oil absorption, bulk density, and grain size distribution, while the technical characteristics include plastic limit, liquid limit and plasticity index which are both presented and discussed in this section.

The degree of whiteness which refers to the purity of clay is an important factor in the industrial evaluation of kaolin products. Whiteness values before wet sieving and attrition differ from whiteness values after wet sieving and attrition (Table 2). Whiteness values before wet sieving and attrition range between 24.90 and 50.02 % with an average value of 33.61 % and standard deviation of 6.09 %. On the other hand, whiteness values after attrition and wet sieving ranges from 25.4 to 54.9 % with an average value of 40.1 % and a standard deviation value of 6.61 %. Whiteness values after attrition and wet sieving for the fraction (<63 µm) has increased dramatically to 40.1 % compared to 33.61 % before attrition and wet sieving.

Table 2. Results of the physical characteristics of the representative samples of Jarash clay

Physical Characteristics	Min.	Max.	Average	Standard deviation
Whiteness before attrition and wet sieving (%)	24.90	50.20	33.61	6.09
Whiteness after attrition and wet sieving (%)	25.40	54.9	40.10	6.61
Specific gravity after attrition and wet sieving	2.02	2.70	2.24	0.14
Oil absorption after attrition and wet sieving(ml /100 g)	23.25	46.50	33.10	5.68
Bulk density after attrition and wet sieving (g/cm^3)	0.86	1.22	0.99	0.056

4.2. Technical Characteristics

The results of liquid limit (LL), plastic limit (PL), and plasticity index (PI) before and after attrition and wet sieving for the seven bulk representative samples are shown in Table (3).

Liquid limit before attrition and wet sieving ranges from 26.3 and 49.0 % with a mean of 31.89 %, while liquid limit after attrition and wet sieving shows different values that range from 34.2 and 71.5 % with a mean of 48.18 % (Table 3). When the plastic limit was examined, the results before attrition and wet sieving ranged from 13.9 and 23.5 % with a mean of 16.40 %, while after attrition and wet sieving the plastic limit ranged from 15.9 and 26.3 % with a mean of 10.74 %. In addition, plasticity index before attrition and wet sieving were around 10.1 and 25.5 % with a mean of 15.49 % in time the plasticity index after attrition and wet sieving were around 18.3 and 45.2 % with a mean of 19.74 %. The different values of standard deviation for liquid limit (LL), plastic limit (PL), and plasticity index (PI) in table (3) are related to the grain size variations in the samples. The percentage of the silt and clay size (<63 µm) (Table 4), and the contents of kaolinite and plastic kaolin (Figure 4 and Figure 6) for the representative samples of Jarash clay before and after the attrition and wet sieving are presented.

Table 3. Results of technical characteristics of the representative bulk samples of Jarash clay.

Technical Characteristics	Min.	Max.	Average	Standard deviation
Liquid limit before attrition and wet sieving	26.3	49.0	31.89	7.88
Liquid limit after attrition and wet sieving	34.2	71.5	48.18	13.74
Plastic limit before attrition and wet sieving	13.9	23.5	16.40	3.29
Plastic limit after attrition and wet sieving	15.9	26.3	10.74	3.34
Plasticity Index before attrition and wet sieving	10.1	25.5	15.49	5.23
Plasticity Index after attrition and wet sieving	18.3	45.2	19.74	10.50

Seven representative samples from Jarash clay were examined for their Atterberg limits before attrition and wet sieving, and then those samples examined for their Atterberg limits after attrition and wet sieving. Figures (3 and 4) show the results which were graphically used as an identification chart for clay and clay workability chart. The bulk samples before wet sieving and attrition are plotted graphically in the region of the kaolinite (Figure 4). According to the clay workability sheet (Bain and Highly, 1978), the following bulk samples (Cn, Dn, En, and Gn) fall within the region of the optimum molding properties; the bulk samples (An, Bn and Fn) fall within the acceptable molding properties (Figure 3).

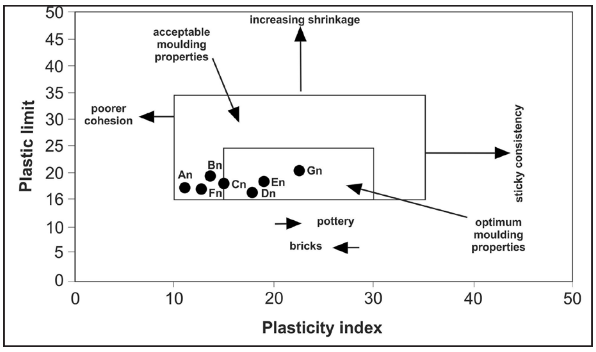


Figure 3. Clay workability chart of the samples before wet sieving and attrition [The standard figure modified after (Bain and Highly, 1978)].

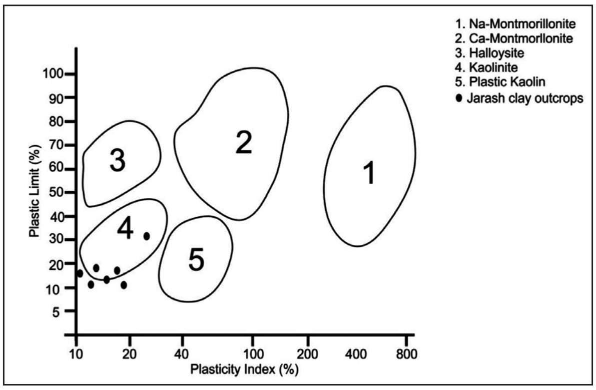


Figure 4. Clay identification of the bulk samples before wet sieving and attrition for Jarash clay [The standard figure modified after (Bain, 1971)].

For those samples where Atterberg limits were measured after attrition and wet sieving (<63μm), figures (5 and 6) show the results plotted graphically in the same way as aforementioned. The results show that the plasticity index in the (<63 μm) fraction of bulk samples is higher than the bulk samples before attrition and wet sieving (Table 3 and Figure 6). It means that the plasticity index has positive correlation with the clay grain size. This is due to the fact that (<63 μm) size contains more clay than the bulk sample. As a result of the process of the attrition and wet sieving, the clay content can increase the plasticity index of clay.

The bulk samples after attrition and wet sieving (<63 μm) are plotted graphically in the region of the kaolinite. While some samples plotted in the region of the plastic kaolin (Figure 6). According to the clay workability sheet (Bain and Highly, 1978), the following bulk samples (An, Bn, Cn, and Dn) fall within the region of the optimum molding properties; the bulk samples (En and Fn) fall within the acceptable molding properties expect for the bulk sample (Gn) (Figure 5). Figures (3, 4, 5, and 6) indicate that Jarash clay could be suitable for pottery and the clay bricks industry.

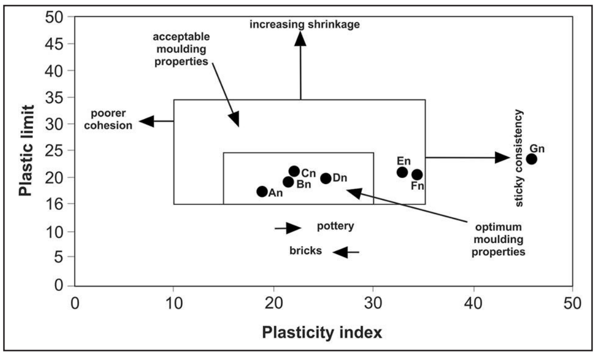


Figure 5. Clay workability chart for samples after wet sieving and attrition (<63 μm) [The standard figure (modified after Bain and Highly, 1978)].

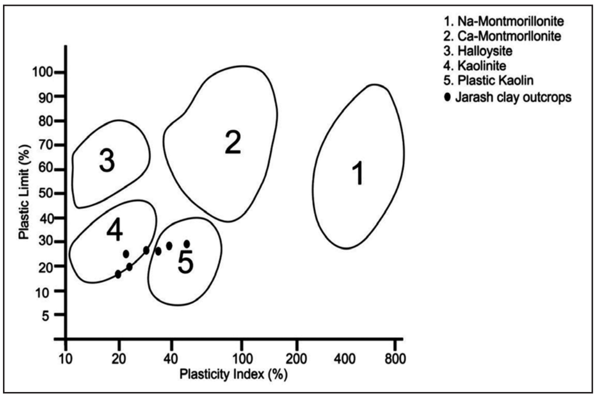


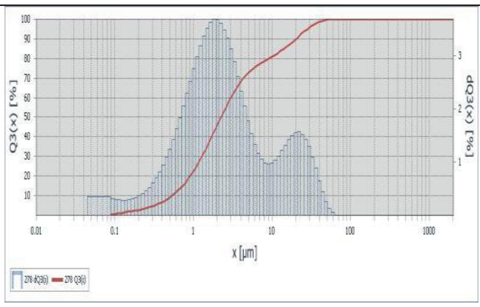
Figure 6. Clay identification for bulk samples after wet sieving and attrition for Jarash clay (<63μm) [The standard figure modified after (Bain, 1971)].

Table 4. Showing the grain size of the tested bulk samples after wet sieving.

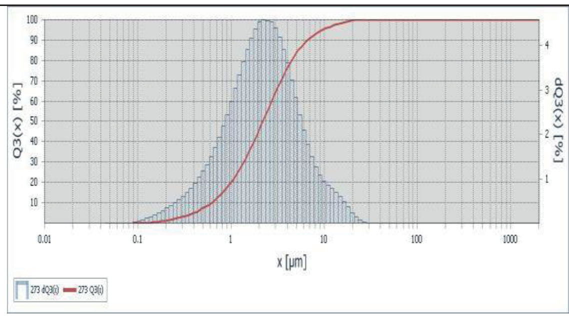
Size (mm)		Sample No						
		Bulk An	Bulk Bn	Bulk Cn	Bulk Dn	Bulk En	Bulk Fn	Bulk Gn
+2	Wt. (g)	179.5	13.50	100.9	53.8	80.9	194.2	51.0
	(%)	20.37	1.54	11.46	6.08	9.07	21.8	5.675
+1	Wt. (g)	49.1	5.9	43.8	47.8	77.6	60.34	19.2
	(%)	5.57	0.671	5.0	5.4	8.7	6.8	2.14
+0.5	Wt. (g)	66.4	15.3	44.2	20.7	61.6	26.9	27.9
	(%)	7.54	1.74	5.027	2.34	6.9	3.02	3.105
+0.25	Wt. (g)	32.4	40.23	29.2	51.4	82.2	28.9	47.4
	(%)	3.68	4.58	3.32	5.80	9.21	3.24	5.274
+0.125	Wt. (g)	35.1	44.08	38.2	81.0	50.2	59.58	68.74
	(%)	3.98	5.014	4.35	9.15	5.63	6.7	7.65
+0.063	Wt. (g)	97.8	220.0	123.3	70.7	59.7	51.6	155.4
	(%)	11.10	25.03	14.011	7.99	6.7	5.79	17.3
-0.063	Wt. (g)	420.7	540.0	500.0	560.0	480.0	470.0	520.0
	(%)	47.75	61.425	56.832	63.24	53.8	52.72	57.9
Total	Wt. (g)	881	879.01	880.0	885.4	892.2	891.52	898.64

Results of Grain Size Analysis for Samples after Wet Sieving and Attrition

Grain size analysis is used to determine the amount and the percentage of the different grain sizes which consist mainly of gravel, sand, silt, and clay in the sample. Table (4) shows the percentage of different grain sizes for the seven bulk samples. Figure (7) shows results of grain size analysis for the bulk samples from Jarash clay after attrition and wet sieving (<63μm), and figure (8) illustrates the bulk representative samples of Jarash clay ranging from sandy clay to clayey sand.



Sample No.: Bulk An



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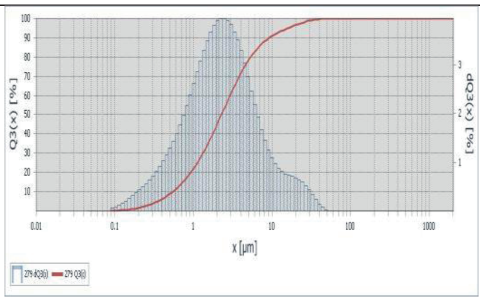
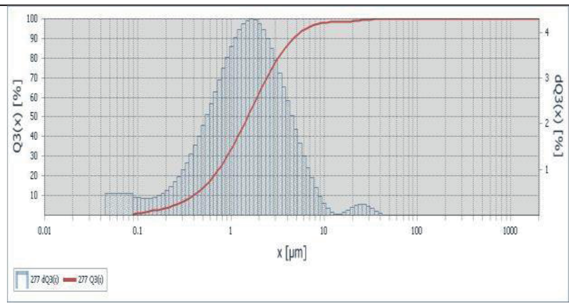
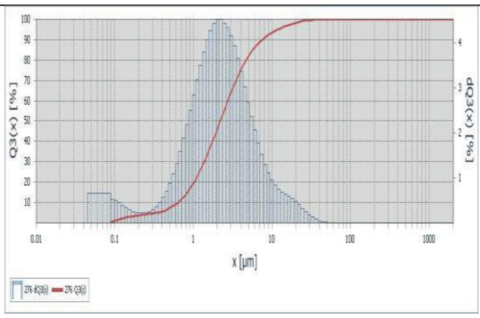


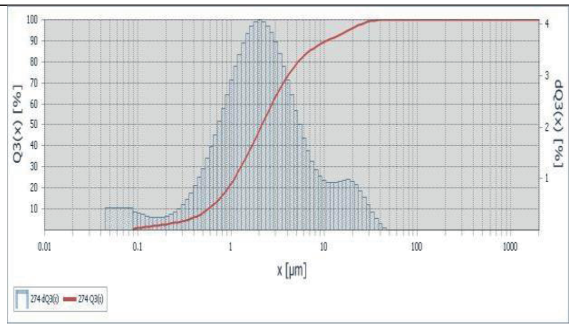
Sample No.: Bulk Cn



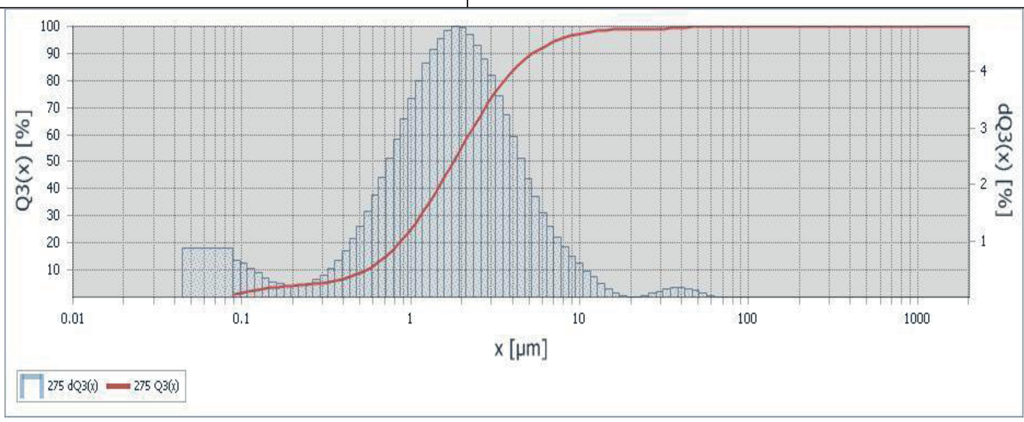
Sample No.: Bulk Dn



Sample No.: Bulk En



Sample No.: Bulk Fn



Sample No.: Bulk Gn

Figure 7. Grain size analysis of the bulk samples from Jarash clay after attrition and wet sieving (< 63μm).

Table (5) presents the physical, chemical, mineralogical, and technical properties of Jarash clay deposits after attrition and wet sieving. Values of major chemical components such as SiO_2, Al_2O_3, and Fe_2O_3 are (61.0%) (Range = 47.5 - 78.1%), (19.77%) (Range = 10.8 - 26.33%), and (4.58%) (Range = 1.41 - 10.15%) respectively. While other minor components such as K_2O, TiO_2, CaO, MgO, and MnO are of small values. The low Al_2O_3 content and the high Fe_2O_3 content indicate low-grade clay deposits.

Many localities in Jordan and in the world are correlated to Jarash clay. For instance, the (Kaolin A3) from Hiswa clay deposits in Jordan is considered as low-grade, Another example, kaolin from Oboro deposits in Nigeria is considered low-grade as well. The aforementioned clay deposits are used and applied as raw materials for ceramic tiles, pottery, and brick-making (Mark, 2010; Al-Momani, 2000). Similarly, Jarash clay deposits could be suitable for pottery, ceramic tiles, and brick-making industries.

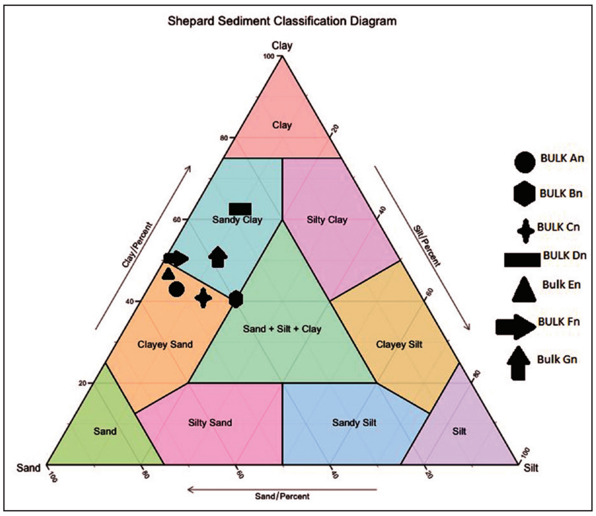


Figure 8. Shepard sediment classification for the bulk samples (Based on Shepard, 1945; Poppe and Eliason, 2008).

Table 5. Comparison between chemical, physical and the technical properties of Jarash clay with properties of other clay deposits from different countries.

The Present Study			I	II
Chemical composition				
SiO_2%		61.00	60.21	58.73
Al_2O_3%		19.77	19.05	19.25
Fe_2O_3%		4.58	3.70	9.15
TiO_2%		1.75	--	0.83
Na_2O%		0.06	0.42	0.09
K_2O%		1.27	2.16	1.39
MnO%		0.006	--	0.04
MgO%		0.59	1.50	0.16
CaO%		1.22	0.30	0.05
P_2O_5%		0.09	-	0.08
LOI		9.35	10.2	7.14
Technological properties				
Plastic limit (wt%)	**Range**	15.9 - 26.3	19.0	18.09
	Average	10.74		
Liquid limit (wt%)	**Range**	34.2 - 71.5	42.4	30.05
	Average	48.18		
Plasticity index (wt%)	**Range**	18.3 - 45.2	23.0	11.96
	Average	19.74		
Physical properties				
Bulk Density (g/cm³)	**Range**	0.86 - 1.22	1.66	0.69-1.33
	Average	0.99		
Oil Absorption (g/100g)	**Range**	23.35 - 46.5	--	21.81-35.34
	Average	33.1		
Specific gravity	**Range**	2.01- 2.7	--	-
	Average	2.24		
Whiteness (%)	**Range**	25.4- 54.9	--	-
	Average	40.1		
Other properties				
pH	**Range**	6.73 - 8.45	--	5.30- 6.50
	Average	7.74		
Moisture content	**Range**	0.25- 6.81	--	-
	Average	2.40		
EC (mS/cm)	**Range**	108.1- 573	--	-
	Average	281.7		

I. Oboro clay deposits in Nigeria (Mark, 2010) Used as Clay refractory and ceramic
II. Hiswa clay Kaolin A3 (AL-Momani, 2000) Used as ceramic tiles.

Results of X- Ray diffraction (XRD) and Scanning electron microscope (SEM) are matching with the results of mineralogical composition presented before in figures (4 and 6). This means that the kaolinite content is one of the major constituents in Jarash clay. Figures (9 and 10) show typical X-ray diffraction analysis of the bulk samples before and after attrition and wet sieving (<63µm) respectively. Also, Jarash clay contains small or trace amounts of muscovite/ ilite, and smectite.

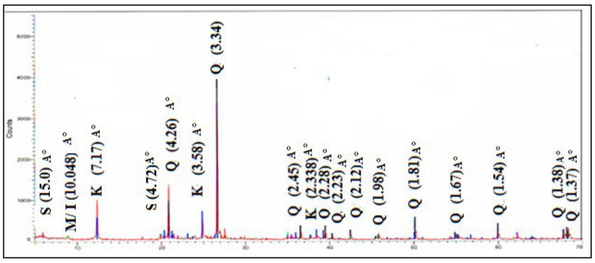


Figure 9. Typical XRD pattern for the representative sample before attrition scrubbing and wet sieving, with the d-spacing for the major peaks between brackets (Q: Quartz, K: Kaolinite, S: Smectite, M/ I: Muscovite/ Ilitte). The unit of d-spacing (in Angstrom A°).

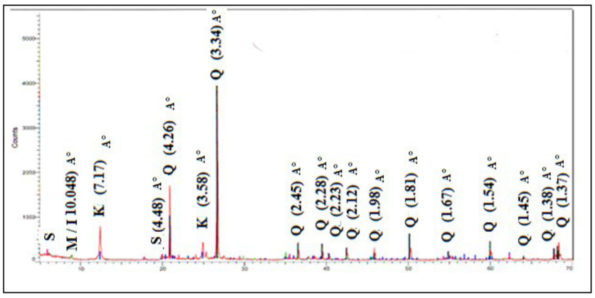


Figure 10. Typical XRD pattern for the representative sample after attrition scrubbing and wet sieving (<63µm), with the d-spacing for the major peaks between brackets (Q: Quartz, K: Kaolinite, S: Smectite, M / I Muscovite / Iilite). The unit of d-spacing (in Angstrom A°).

The crystal shape and texture of Jarash clay images obtained by scanning electron microscope are presented in figure (11). The clay samples, as shown in the SEM images, consist mainly of Kaolinite. Figure (11) shows the euhedral to pseudohexagonal shape of Kaolinite in particles sized less than 2 µm.

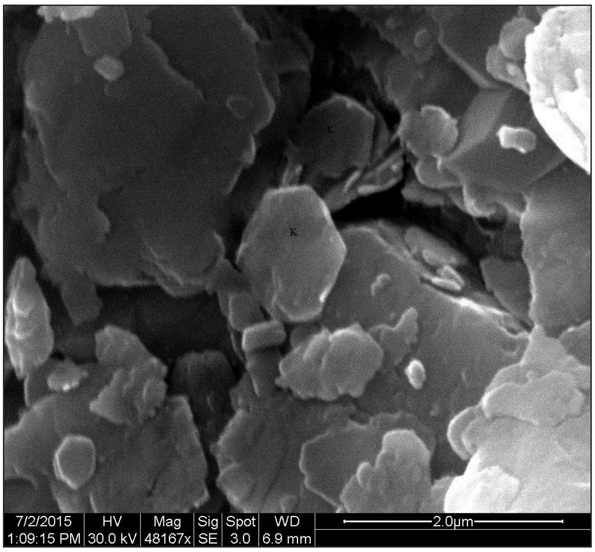


Figure 11. SEM Image of pseudohexagonal of kaolinite (48167x).

Conclusion

The results obtained by analyzing Jarash clay indicated that the plasticity index in the (<63 µm) size of Jarash clay after attrition and wet sieving is higher than that before attrition and wet sieving. It means that the plasticity index has positive correlation with the clay grain size. This is due to the fact that (<63 µm) size contains more clay than the bulk samples. As a result of the process of attrition and wet sieving, the clay content enhances the plasticity index of Jarsh clay.

According to the Shepard sediment classification diagram, the bulk representative samples of Jarash clay range from sandy clay to clayey sand.

The bulk samples of Jarash clay before attrition and wet sieving are plotted graphically in the region of the kaolinite in the identification chart of Bain (1971). While some samples were plotted in the region of the plastic kaolin. The contents of kaolinite and plastic kaolin may be affected by the variations of liquid limit (LL), plastic limit (PL), and plasticity index (PI) for different samples of Jarash clay.

Using the clay workability sheet (Bain and Highly, 1978), most of the bulk samples of Jarash clay fall within the region of the optimum molding properties, and the acceptable molding properties. This indicated that Jarash clay could be suitable for pottery, and the clay bricks industry.

In addition, the physical characteristics (whiteness, bulk density, oil absorption, and specific gravity), grain size analyses, chemical characteristics, and technical characteristics (liquid limit (LL), plastic limit (PL), and plasticity index (PI)) of Jarash clay deposits after attrition and wet sieving confirm that Jarash clay deposits could be suitable for pottery, ceramic tiles, and brick-making industries.

Acknowledgements

The financial support from the Deanship of Scientific Research and Graduate Studies at Yarmouk University is gratefully acknowledged. The authors wish to thank the editor of JJEES and the referees for their insightful comments and suggestions which greatly improved the presentation of this paper. Special thanks are due to Dr. Mohammad Al-Qudah for his assistance to improve this paper.

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