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Thermal Properties and Industrial Evaluation of Hiswa Kaolin, South Jordan

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ABSTRACT

This study has concentrated on the Thermal Properties (Differential Thermal Analysis -DTA, Thermo-Gravimetry- TG, and Derivative Thermo-Gravimetry -DTG) and industrial evaluation of Hiswa Kaolin, South Jordan, with emphasis on the possible use of kaolin as a body former in tiles and sanitaryware, and as a filler and extender in paint industry.

The physical, chemical, mineralogical, technical and industrial characteristics of Hiswa clay deposit conform to the standard specifications. The industrial testing of Hiswa clay deposits indicates that it is suitable for being used as a body former in tiles and sanitary ware, and as a filler and extender in paint industry.

The results of thermal analysis curves of the original representative samples from Hiswa area, South Jordan, indicate the presence of moderately to well crystalline varieties of kaolin.

Keywords: Thermal Properties, Ceramics, Tiles, Sanitaryware, Filler, Paint, Hiswa, Kaolin, Jordan.

1. INTRODUCTION

Clays have always played a major role in human life. Kaolin is one of the most common examples of clay minerals and is an important natural industrial substance. They are largely used because of their wide-ranging properties, high resistance to atmospheric conditions, easy access to their deposits near the earth's surface and their low price (Konta, 1995). Kaolin is a commercial term generally used to describe white clay composed essentially of the clay mineral kaolinite. The term is typically used to refer to both the raw clay and the refined commercial product.

Each industry specifies the composition method and the properties of the raw materials for a particular manufacturing. A ceramic product or processed material is a solid composed of materials which have been subjected to heat above 468°C (875°F). In spite of the expansion of the field where the term "ceramic" may be applied, the volume of clay-based manufactured ceramic is much greater than that of non-clay ceramic, and clay may still be regarded as the basic and the most important type of ceramic materials (Ryan, 1978; Jones and Berard, 1981; Ridgway, 1982; Worrall, 1982; Mitchell, 1983; Harben, 1999).

Clays and clay minerals show variability, diversity and complexity in their structural chemical and physical properties. A variety of instruments and experimental techniques are usually employed in clay-minerals studies (Sudo *et al.*, 1981). Of all the techniques currently in use for the characterization of clays, thermal analysis is one of the oldest (Wilson, 1987). Thermal analyses are the most popular simultaneous methods measuring thermal properties. The Differential Thermal Analysis (DTA) curves reflect the changes in the thermal behavior of the sample. The combined techniques are the Differential Thermal Analysis (DTA), the Thermo-Gravimetry (TG), and the Derivative Thermo-Gravimety (DTG).

This study has concentrated on thermal properties (Differential Thermal Analysis- DTA, Thermo-Gravimetry- TG, and Derivative Thermo-Gravimetry-DTG) and industrial evaluation of Kaolin, South Jordan, with emphasis on the possible use of kaolin as a body former in tiles and sanitaryware, and as a filler and extender in paint industry.

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2. THE STUDIED AREA

The study area lies in Aqaba region, and it is situated in southern Jordan. The area is located 20 km to the South-east of Ad-Disa village at a distance of about 100 km east of Aqaba town (Figure 1).

The principal geological sequences cropping out in the study area are of Paleozoic age. Three formations are cropping out in the study area, with a general dip towards the South-east. These are, from bottom to top:

1. Umm Sahm Sandstone (Bedded brownish weathered sandstone) Formation.
2. Hiswa Sandstone (Graptolite sandstone) Formation.
3. Dubaydib Sandstone (Sabellarifex sandstone) Formation.

The Hiswa Sandstone (Graptolite Sandstone Formation) of Khreim Group is subdivided into the Shale Member and the Sandstone-Siltstone Member. The Shale Member consists of kaolinite of various colors; which range from light gray, dark gray, violet, brown-red and red.

3. SAMPLING AND LABORATORY TECHNIQUES

Three main kaolinte rich beds were recognized as a result of field investigations. Accordingly, three representative bulk composite samples (Kaolin A1, Kaolin A2, and Kaolin A3) of different varieties (about 200 kilograms for each) were collected from the Hiswa Shale Member for the industrial evaluation studies (Al Momani, 2000):

1. The light-grey kaolinite bed (kaolin A1).
2. The grey-dark-grey kaolinite bed (kaolin A2).
3. The violet-brick-red kaolinite bed (kaolin A3).

Thirty one (31) different representative samples of Hiswa kaolin deposits were obtained for the Differential Thermal Analysis (DTA), Thermo-Gravimetry (TG), and Derivative Thermo-Gravimetric (DTG) data using a Thermoanalyzer TG A92 apparatus at a constant heating rate (10°C/min.). This work was carried out at the Jordan University for Science and Technology (JUST)-Irbid /Jordan.

Ceramic Applications

The measurements were carried out on test pieces extruded from the different particle-sizes of Hiswa kaolin types (-2mm, -63μm, and -15μm). In the laboratory, test pieces were fired at 1085°C for 50 min. and at 1230°C for 14 hour. The process was carried out with separate stage firing of tested pieces in a muffle furnace. The fired color, Loss On Ignition (L.O.I %), shrinkage (%), water absorption (%), and brightness were determined after firing at 1085 °C and 1230 °C.

The suitability of Hiswa kaolin deposit for industrial use in Sanitaryware was carried out at Mousily for Ceramic and Sanitaryware Industry, Amman-Jordan. The Sanitaryware articles were produced based on the typical body composition of whiteware ceramics (% of total solids) as indicated in Table (1), and illustrated in (Figure 2).

Chemical Composition

Generally speaking, the industrial applications of kaolin are based largely on a combination of physical characteristics, and different applications demanding distinct combinations of functional properties. Specific grades are, therefore, rarely suitable for all applications. With the exception of kaolin for usage in ceramics, chemical composition is not generally a critical property. Some of the commercial world kaolin production comes from UK, Italy, Turkey, and Argentina. Table (2) shows the chemical composition of commercial kaolin used for ceramic applications from different countries as compared to Hiswa kaolin.

The chemical results obtained for the different bulk samples show that SiO_2, Al_2O_3, and Fe_2O_3 are the essential constituents. MgO, TiO_2, Na_2O, SO_3, and K_2O are the minor constituents (Al-Momani, 2000).

Body Preparation

Body preparation involves intimately mixing the various raw materials with the right proportions (Table 1), and the right degree of fines (Table 3) to produce a mixture with a water content and consistency required for the next stage of shaping or making process. The body of the sanitaryware articles was prepared by using slip casting method. Generally, the moisture content of the body at the time of shaping ranged between 25-50%. The slip is poured into a plaster mould from which the liquid drains. After the slip has been set, the formed article is removed from the open mould and then allowed to dry, at least partially, before the next stage of firing.

Glaze and Firing

Sanitarywares are generally required to be covered with hard, abrasion resistant, high glossy glazes in either white or a range of colors. Basically, glazes are incorporated into ceramics to render the ceramic body impermeable. They also serve to increase the strength of the finished article, and provide a smooth decorative surface when fired over the surface of the ware. The sanitaryware articles were fired at 1,200-1,250°C (Skillen, 1993; 1994) to convert the weak, soft article into a strong, hard product.

Important Technological Properties:

Fired Color

Iron oxides, especially hematite, occur in Hiswa clay deposits in the range of 1% to 9% (Al-Momani, 2000). Clays, whose depositional or diagenetic environment has been oxidizing, tend to contain iron oxides as coloring agents. Hematite produces a deep red color. However, the color resulting from the presence of hematite is temperature dependent; at low temperatures it is almost orange but as the temperature rises darker reds are produced until 1316°C, when the color becomes almost black (Ridgway, 1982). Fired color was determined by the use of Methuen Handbook of Color (Kornerup and Wanscher, 1981).

Loss on Ignition

Loss on ignition is the result of driving off the combined water of the clay structure. The presence of carbonates, carbon (organic matter), sulfates etc., contributes also to the total loss (Ridgway, 1982).

Shrinkage

Shrinkage is the reduction in the size of a mass of shaped clay (using dry pressing techniques) when pore and adsorbed water are driven off by drying. It is normally expressed as per cent reduction in size. The amount of shrinkage is related to the firing temperature.

Water Absorption

To find water absorption for a mass of shaped clay, each sample is dried in an oven at 100°C to a constant weight (w_1). Then, the specimen is soaked overnight in a beaker filled with water. The saturated specimen gains a new weight (w_2). The water absorption is calculated as follows:

$$\mathbf{W = (w_2 - w_1) / w_1 * 100}$$

Where, W = water absorption, w_2 = weight of sample after saturation, and w_1 = weight of dried sample.

In addition, the water absorption tests for the powdered clay are carried out using the formula from (British Standard - BS 3483: Part B7: Method for testing pigments, 1974):

Water absorption = [(water volume) * 100]/ sample mass

Where the number 100 corresponds to the specific gravity of the water (1.00 gm/ cm^3) multiplied by 100 (BS 3483, 1974).

Atterberg Limits

The Plastic Limit (PL) of clay (the water absorbed by it before it becomes plastic) and the Liquid Limit (LL) (the water absorbed by a clay before it becomes a liquid) are called Atterberg Limits. These limits are determined using the standard tests in soil mechanics (BS 1377: 1975). The difference between Liquid Limit (LL) and Plastic Limit (PL) is termed the Plasticity Index (PI). Plasticity is the ability of clay to take up water and of the clay-water mass at its optimum consistency to be shaped and to hold that shape after the forming forces are removed. Clay’s plasticity is affected by mineralogical composition, particle size, shape and distribution, pH, and water content (Ridgway, 1982).

Laboratory Techniques of Hiswa Clay Deposits as Filler Materials in Paints:

Oil Absorption

Oil absorption could influence the desirability of mineral fillers for many applications. Low oil absorption is an important property for paints applications, basically; the less oil absorption is by the filler, the greater is the quantity of active material available for actually binding the compound. Oil absorption tests were carried out for nine (9) samples using the method and instructions from BS 3483: Part B7 British Standard method for testing pigments for paint. Oil absorption was calculated by using the following formula:

Oil Absorption = [(Oil volume) x 93] / (sample mass)

Where 93 correspond to the specific gravity of the linseed oil used in the test (0.93 g/cm^3) multiplied by 100.

Bulk Density (BD)

The Bulk Density (BD) is carried out by using the formula:

Bulk Density (BD) [g/cm^3] = mass (g)/ volume (ml) (British Geological Survey-BGS, 1992).

4. RESULTS AND DISCUSSION

Thermal Properties

The temperature at which the major amount of crystal lattice water is lost is the most indicative property for the identification of clay minerals.

The results of thermal analysis curves [The Differential Thermal Analysis (DTA), Thermo-Gravimetry (TG), and Derivative Thermo-Gravimetric (DTG)] of the representative samples from Hiswa area are represented in Figure (3). The thermal behavior of the separated kaolinite samples indicates the presence of moderately to well crystalline varieties.

The obtained DTA curves exhibit a great similarity (Figure 3), first endothermic peak corresponds to absorbed water on the surface of the particles. The dehydration endothermic reaction takes place at temperature range between 69°C and 108°C, whereas the dehydroxylation endothermic peak that is associated with the expulsion of combined water, takes place at temperature range between 553°C (Figure 3). The exothermic peak lies between 976°C, 986°C and 990°C (Figure 3). The DTA curve shows the general trend for the kaolinite thermal behavior.

The obtained TG curves show a great similarity. Representative curve is shown in Figure (3). The TG curve indicates that the total loss in weight of the representative kaolinite samples ranges between 11.0% and 17.0% (Table 4). The dehydration loss ranges between 1.0% and 4.0%, whereas the dehyroxylation loss ranges between 8.5% and 13.75% (Table 4 and Figure 4).

The derivative thermo-gravimetric curve (Figure 3) indicates the presence of two main endothermic peaks at (108°C-125°C) and (555°C-565°C) which correspond relatively to the removal of non-structural and structural water.

As mentioned before, a ceramic product is a solid composed of materials which have been subjected to heat above 468°C (875°F). The results of thermal analysis curves (DTA, TG, and DTG) of the representative kaolin samples from Hiswa area (Figure 3) show the general trend for the kaolinite thermal behavior. Thermal properties may affect the end use for ceramic industry. Accordingly, thermal behavior of kaolinite may still be regarded as the basic and the most important quality of ceramic materials.

The properties of a fired kaolin product provide additional information on the potential of the clay for usage in ceramics. Change in physical properties such as shrinkage, porosity, water absorption and color are monitored over the temperature range generally used to produce clay body ceramics (900-1250°C). Variation in firing behavior is mainly resulted from differences in chemistry and particle-size distribution (Bloodworth *et al.*, 1993).

Results of the Experimental Procedures of Ceramic Applications

The results of the different conditions of firing tests of the three bulk composite samples (Kaolin A1, Kaolin A2 and Kaolin A3) of Hiswa clay deposits are given in Table (3). The color of the produced biscuits is shown in Table (3). Shrinkage increases for a given clay mineral with the increase of temperature and the decreases of particle size (Table 3).

Figures (5 and 6) show the produced sanitaryware articles: a) before firing; b) after single firing without glazing; and c) after single firing with glazing materials. The results indicate that single firing with a temperature range between 1180°C and 1230°C gives a smooth verified body without defects. The obtained color of the body is grey, and no deformation has occurred.

Table (5) shows a comparison between Hiswa kaolinite and the Watts Blake Bearne Co. (WBB) specifications (Sanblend 75) of commercial kaolinite for the sanitaryware industry. Depending on the particle size distribution and the chemical properties, it is concluded that Hiswa clay deposits could meet the Blake Bearne Co. (WBB) specifications (Sanblend 75). Accordingly, Hiswa clay deposits after simple hydrocyclone separation could be used for the sanitaryware applications.

The clay used for the ceramic tiles industry is characterized by a specific chemical composition, as well as other technological properties. Table (6) shows a comparison between the typical chemical composition and the technological properties of clay materials used for ceramic tiles.

With regard to the Atterberg limits (Figure 7), samples (Kaolin A1 and Kaolin A2) fall within the region of optimum molding properties, and (Kaolin A3) falls within the region of acceptable molding properties. On the clay identification chart of Bain (1971), all samples fall within the region of kaolinite (Figure 8). This result is in agreement with the chemical and mineralogical results. Depending on the technological and chemical properties, it is concluded that Hiswa clay deposits could meet the typical requirements of the raw materials used for manufacturing the ceramic tiles.

Possible Use of Hiswa Clay Deposits in Paints as Filler Materials

It is important to note that depending on the intended use, specifications for kaolin vary enormously; for example, brightness and oil absorption in paints, and viscosity and sheet opacity in paper. Kaolin used for papermaking needs to be fluid (low viscosity) whereas clay used for ceramic industry has to be plastic (high viscosity). In addition, the particles size distribution, and the particle shape may also affect the end use.

Filler may be defined as an inert material, which is added to the paint for two reasons:

1. To lower the cost.
2. To reinforce or modify the physical properties of a composition.

In paint industry, mineral fillers are known as 'extender'. Besides reducing the cost, extender pigments are capable of influencing the following properties of a paint film: improve application properties; increase hiding; improve surface properties; increase strength, stability and service life; reduce checking and cracking; control pigment settling; and control viscosity (Weitz, 1970; Bristow, 1992; Goodman, 1995).

It is clear from the results in Table (7) that oil absorption increases with the decrease of particle size. This is due to the relatively higher surface area. The results indicate that oil absorption (g/100g) of the different-size fractions ranges between 21.81 and 45.57 with a mean value of 34.51. The lower the oil absorption is the better is the used material.

The results of the bulk density measurements (Table 8) indicate that the bulk density (g/cm^3) of the different-size fractions ranges between 0.63 and 1.33. The bulk density decreases with the decrease of the particle size.

The results of the particle size distribution, physical characteristics, and chemical properties of the Hiswa clay deposits are obtained at different conditions of hydrocyclone separation. These results are listed in Table (9), which shows a comparison between Hiswa Kaolinite and the Jordan specifications (JS 433:1985 and JS 771:1991) of commercial kaolinite used as fillers and extenders materials for paints, and British Standard (British Standards (BS) 1795) for china clay used as extenders in paint (Toon, 1985). The properties of Hiswa clay deposits indicated that it is suitable for being used as a filler and extender in paint industry.

5. CONCLUSIONS

The results of thermal analysis curves (Differential Thermal Analysis-DTA, Thermo-gravimetry-TG, and Derivative Thermo-gravimetry-DTG) of the original representative samples from Hiswa area indicate the presence of moderately to well crystalline varieties of kaolinite.

Depending on the particle size distribution and the chemical properties, it is concluded that Hiswa clay deposits could meet the Blake Bearne Co. (WBB) specifications (Sanblend 75). Accordingly, Hiswa clay deposits after simple hydrocyclone separation could be used for the sanitaryware applications.

Depending on the technological and chemical properties, it is concluded that Hiswa clay deposits could meet the typical requirements of the raw materials used for manufacturing the ceramic tiles.

Depending on the physical characteristics (mainly particle size distribution and oil absorption) and chemical properties, it is concluded that Hiswa clay deposit meets the Jordan and British specifications (JS 433:1985, JS 771; 1991, and BS 1795, respectively). Accordingly, Hiswa clay deposits could be used as filler materials used for manufacturing paints after simple hydrocyclone separation.

The physical, chemical, mineralogical, technical and industrial characteristics of Hiswa clay deposit found to be compatible with the standard specifications. The industrial testing of Hiswa clay deposits indicated that it is suitable for being used as a body former in tiles, sanitaryware and as a filler and extender in paint industry.

Table (1): Typical Body Compositions of Whiteware Ceramics (% of Total Solids).

Whiteware Type	*Kaolin*	*Ball Clay*	Flux[1]	Quartz[2]	Others
Earthenware	25	25	15	35	--
Porcelain	60	10	15	15	--
Bone China	25	--	25	--	50 bone ash
Vitreous-china sanitaryware	20-30	20-30	15-25	30-40	0-3 talc
Electrical porcelain	20	30	30	20	--
Wall tiles	20	30	--	30-35	10-12 limestone

[1]Usually k-feldspar or nepheline-syenite. (Robbins, 1984; Loughbrough, 1993; Bertrand, 1996).

[2] Silica sand.

Table (2): Typical Chemical Composition for the Commercial Raw Kaolin for Ceramic Wares from Different Countries As Compared With Hiswa Kaolin.

Country	Turkey[1]		Italy[2]		UK[3]		Niger[4]	
Type	Hard	Soft	CL.21	CS2.4	KTS	WBB	AKN	ROG
SiO_2	68-70	48-53	65.43	60.81	61.1	56.8	62.26	55.30
Al_2O_3	19-22	32-37	19.61	23.04	24.6	27.5	16.91	24.49
Fe_2O_3	0.5-1.0	0.5-1.5	5.72	5.11	1.0	1.0	5.62	8.60
TiO_2	0-0.4	0-1.0	0.59	0.51	1.4	1.3	0.04	0.03
CaO	0.05	0-1.0	0.16	0.24	0.3	0.2	0.49	--
MgO	0.05	0-0.5	0.15	0.13	0.5	0.3	0.64	0.21
K_2O	0.05	0-0.3	1.30	0.10	1.4	2.2	0.80	0.13
Na_2O	0.05	0-1.0	0.48	0.16	0.2	0.3	0.24	0.10
SO_3	--	--	0.12	0.37	--	--	--	--
L.O.I	7.5-9.5	11-14	6.39	9.32	9.5	9.5	7.54	9.88

Country	Argentina[5]		Greece[6]		Hiswa Kaolin - Jordan[7]		
Type	NSFT	LMT	F2-.2	F2+.2	Kaolin A1	Kaolin A2	Kaolin A3
SiO_2	60.00	57.00	46.00	44.90	52.64	52.32	58.73
Al_2O_3	25.00	27.00	23.99	26.26	27.66	25.51	19.25
Fe_2O_3	4.57	4.15	6.05	5.00	1.80	6.28	9.15
TiO_2	--	--	0.33	0.33	1.12	1.09	0.83
CaO	0.29	0.59	0.53	0.36	0.06	0.08	0.15
MgO	0.30	0.42	1.96	1.86	0.16	0.15	0.16
K_2O	0.84	1.13	0.85	1.98	1.59	1.42	1.39
Na_2O	0.10	0.24	0.17	0.13	0.08	0.08	0.09
SO_3	--	--	--	--	0.31	0.75	0.83
L.O.I	9.78	10.89	12.74	13.60	13.92	12.41	9.36

1: Ozdemir and Sezer, 1987.
2: Ligas *et al.*, 1997.
3: Loughbrough, 1993.
4: Kabre *et al.*, 1998.
5: Cravero *et al*, 1997.
6: Michailidis and Tsirambides, 1986.
7: Al-Momani, 2000.

Table (3): Results of the Different Conditions of the Firing Tests of the Three Bulk Samples (Kaolin A1, Kaolin A2, and Kaolin A3).

CONDITIONS	FIRING TEMP. (°C)	L.O.I (%)	SHRINKAGE (%)	% of WATER ABSORPTION	BRIGHTNESS (%)	COLOR
KAOLIN A1						
After crushing (to -2mm)	a) Before firing	--	--	26.17	60.23	Pale Grey
	b) 1085	12.6	1.5	23.30	74.46	Grey
	c) 1230	12.7	8.5	8.80	65.27	Yellowish Grey
After wet sieving (-63µm)	d) Before firing	--	--	--	61.18	Grey
	e) 1085	12.6	1.8	24.80	72.55	White
	f) 1230	12.7	12.7	5.96	60.42	Yellowish White
After hydrocyclone separation (-15µm)	g) Before firing	--	--	--	61.23	Grey
	h) 1085	12.3	2.98	25.40	76.63	White
	i) 1230	13.9	13.9	1.20	54.23	Yellowish White
KAOLIN A2						
After crushing (to -2mm)	a) Before firing	--	--	28.16	50.84	Brownish Grey
	b) 1085	11.5	1.5	20.30	57.48	Brownish Grey
	c) 1230	11.5	8.3	7.60	36.52	Light Brown
After wet sieving (-63µm)	d) Before firing	--	--	--	50.05	Brownish Grey
	e) 1085	11.6	2.18	22.80	58.50	Brownish Grey
	f) 1230	11.7	12.7	5.10	31.07	Greyish Brown
After hydrocyclone separation (15µm)	g) Before firing	--	--	--	58.49	Orange Grey
	h) 1085	12.7	3.18	24.80	64.74	Orange Grey
	i) 1230	12.8	14.4	1.24	45.66	Greyish Green
KAOLIN A3						
CONDITIONS	**FIRING TEMP. (°C)**	**L.O.I (%)**	**SHRINKAGE (%)**	**% of WATER ABSORPTION**	**BRIGHTNESS (%)**	**COLOR**
After crushing (to -2mm)	a) Before firing	--	--	22.83	40.47	Light Brown
	b) 1085	8.13	0.8	16.60	37.55	Brownish Grey
	c) 1230	9.5	3.9	7.40	19.02	Brown
After wet sieving (-63µm)	d) Before firing	--	--	--	40.31	Brownish Orange
	e) 1085	10.1	1.7	18.00	38.02	Light Brown
	f) 1230	10.3	6.5	6.40	19.61	Brownish Grey
After hydrocyclone separation (-15µm)	g) Before firing	--	--	--	42.02	Brownish Orange
	h) 1085	8.0	3.2	20.00	37.55	Light brown
	i) 1230	8.1	12.1	0.60	12.38	Brown

Table (4): The Dehydration Loss%, the Dehydroxylation Loss%, And the Total Loss % in Weight for Nine Representative Borehole Samples after Thermo-Gravimetric (TG) Analysis.

Sample No.	Dehydration loss %	Dehydroxylation loss %	Total loss %
TA2	2.5	8.5	11.0
TA4	3.5	10.0	13.5
TA18	1.0	11.5	12.5
TA44	2.5	13.5	16.0
TA50	4.0	13.0	17.0
TA53	3.5	11.5	15.0
TA56	2.25	13.75	16.0
TA57	2.5	13.0	15.5
TA58	3.0	12.0	15.0

Table (5): Comparison between the Hiswa Kaolinite and the Watts Blake Bearne Co. (WBB) Specifications (Sanblend 75) of Commercial Kaolinite for the Sanitaryware Industry.

Specification of WBB's Sanblend 75 for Sanitaryware Industry. (Hanson, 1996).			
Composition	**%**	**Property**	**%**
SiO_2	52.4	L.O.I	11.9
Al_2O_3	30.5	+125μm	0.2
Fe_2O_3	1.0	-10μm	97
TiO_2	1.2	-5μm	79
CaO	0.2		
MgO	0.3		
K_2O	2.2		
Na_2O	0.3		

Hiswa Kaolinite*		
Composition & Properties (%)	**Kaolin A1 (Ex.3-OF)**	**Kaolin A2 (Ex.2-OF)**
SiO_2	51.73	50.80
Al_2O_3	30.10	29.00
Fe_2O_3	1.39	1.63
TiO_2	1.01	1.08
CaO	0.03	0.03
MgO	0.16	0.18
K_2O	1.66	1.70
Na_2O	0.07	0.26
L.O.I	13.74	13.70
+125μm	0.0	0.0
-10μm	98.6	99.7
-5μm	77.5	86.2

* After hydrocyclone separation.

Table (6): Comparison between the Typical Chemical Composition and the Technical Properties of Clay Materials used for Ceramic Tiles.

Typical chemical composition and technological properties (%) of clay materials used for ceramic tiles from different countries.		**Chemical Composition and Technological Properties (%) of Hiswa clay deposits- Jordan (Kaolin A1, A2, A3).**
Chemical Composition (wt. %)*		
SiO_2	44.90-70	52.32-58.73
Al_2O_3	19.61-32.0	19.25-27.66
Fe_2O_3	0.5-8.6	1.80-9.15
TiO_2	0-1.4	0.83-1.12
CaO	0-1.0	0.06-0.15
MgO	0.05-1.96	0.15-0.16
K_2O	0.05-1.98	1.39-1.59
Na_2O	0-1.0	0.08-0.09
SO_3	0.12-0.80	0.31-0.83
L.O.I	7.5-13.60	9.36-13.92

Technological Properties (wt. %)				
Plastic Limit (wt. %)	16-26	Kaolin A1	Kaolin A2	Kaolin A3
		23.51	23.56	18.09
Liquid Limit (wt. %)	23-42	40.32	41.48	30.05
Plastic Index (wt. %)	9-26	16.81	17.92	11.96
Brightness	21.60-84.43**	19.02-74.46		
Water absorption***				
~ 1050°C	17.87	16.6-23.3		
~ 1250°C	4 ± 3	7.4-8.8		
Firing Shrinkage***				
~ 1050°C	4.4	0.8-2.18		
~ 1250°C	11.4	8.3-14.4		

***** Michailidis and Tsirambides, 1986; Ozdemir and Sezer, 1987; Loughbrough, 1993; Cravero *et al.*, 1997; Ligas *et al.*, 1997; Kabre *et al.*, 1998 Dondi, 1999.

****** Fentaw and Mengistu, 1998.

******* Galan *et al.*, 1996; Fentaw and Mengistu, 1998.

Table (7): Results of Oil Absorption; Oil Absorption Increases with the Decrease of Particle Size.

Size (micron)	Oil absorption (g/100g)		
	Kaolin A1	**Kaolin A2**	**Kaolin A3**
-425	29.76	27.44	21.81
-63	40.92	37.44	28.83
-15	45.57	43.71	35.34
Average	**38.75**	**36.12**	**28.66**
	34.51		

Table (8): Results of Bulk Density; the Bulk Density Decreases with the Decrease of The Particle Size.

Size (micron)	Bulk Density (g/cm^3)		
	Kaolin A1	**Kaolin A2**	**Kaolin A3**
-2000	1.21	1.25	1.33
-425	0.85	0.83	1.18
-63	0.71	0.67	0.63
-15	0.66	0.63	0.69

Table (9): Comparison between Hiswa Kaolinite and the Jordan Specifications (Js 433:1985 And Js 771:1991) Of Commercial Kaolinite Used As Fillers and Extenders Materials for Paints, And British Standard (Bs 1795) For China Clay Extenders in Paint

Chemical Composition	$Al_2O_3.2SiO_2.2H_2O$					
Kaolinite Type	Commercial Kaolinite			Hiswa Kaolinite*		
	Grade A	Grade B	Grade C	Kaolin A1	Kaolin A2	Kaolin A3
Retained Size% (max.)						
125μm	0.0	0.0	0.0	0.0	0.0	0.0
65μm	0.0	0.0	0.0	0.0	0.0	0.0

45µm	0.50	0.10	0.05	0.0	0.0	0.0
Passing Size% (min.)						
20µm	90.0	95.0	99.5	100	100	100
10µm	70.0	80.0	90.0	99.9	99.7	98.9
2µm	15.0	35.0	70.0	41.5	40.1	38.2
Volatile matter at 105°C (maximum wt. %)	2.0	2.0	2.0	1.10	1.01	0.60
LOI (wt. %)	10-14	10-14	10-14	13.92	12.41	9.36
Soluble matter in water (maximum wt. %)	0.5	0.5	0.5	0.35	0.31	0.51
pH	4.5- 9.5			5.30-6.50		
Oil absorption (g/100g)	30-60	30-60	30-60	29.76-45.57	27.44 - 43.71	21.81-35.34
Bulk density (g/cm^3)	0.67-1.82			0.66-1.21	0.63 - 1.25	0.69-1.33
Carbonate content (maximum wt. %)	<1.0	<1.0	<1.0	0.06	0.08	0.15
Lead (Pb) content (maximum wt. %)	0.03 %	0.03 %	0.03 %	43ppm	46ppm	149 ppm

* After hydrocyclone separations. Jordan specifications (JS 433:1985 and JS 771:1991) and (BS 1795) British Standards (1795) in Toon, 1985.

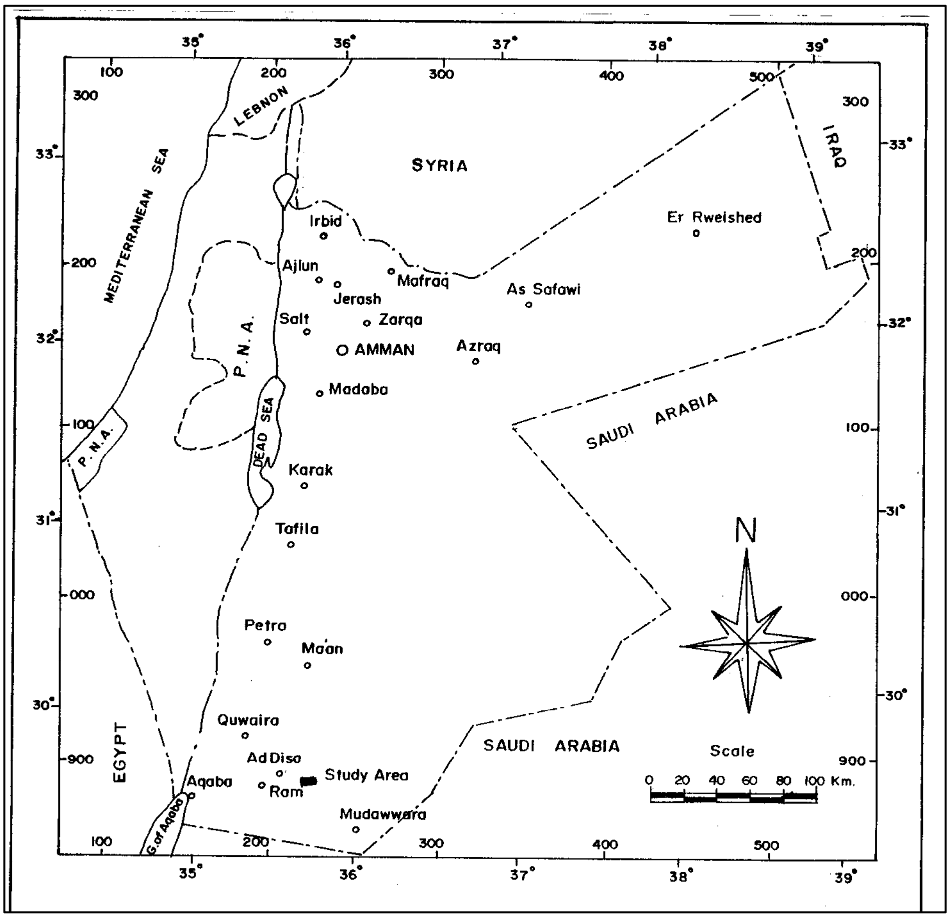

Figure 1. Location Map of the Study Area.

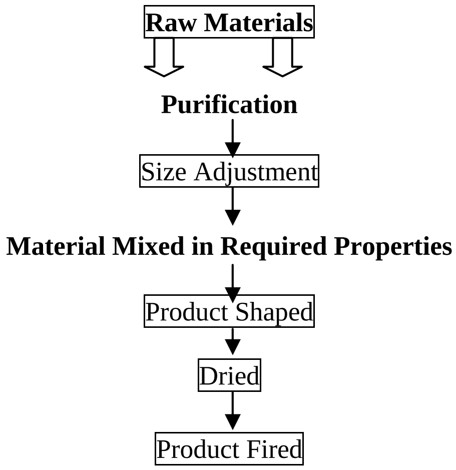

Figure 2. Generalized Diagram Of The Major Processes Of Manufacturing The Ceramic Products.

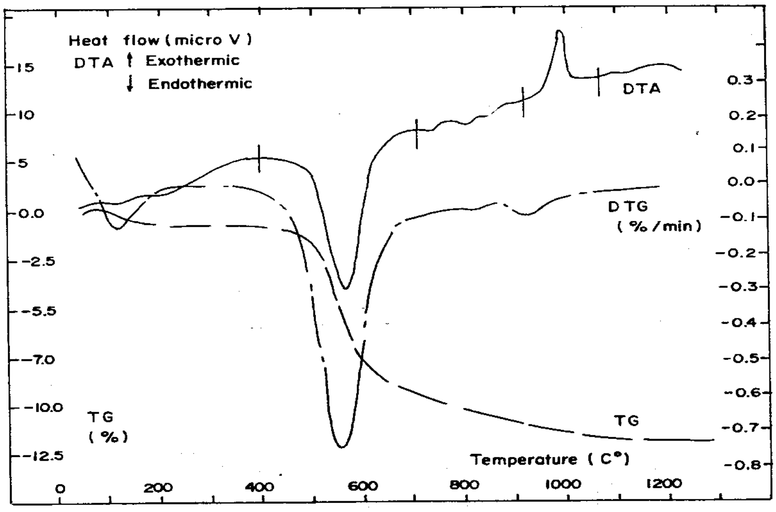

Figure 3. Typical Thermal Curves (DTA, TG, DTA) for Hiswa Kaolinite (Heating Rate 10°C/min.).

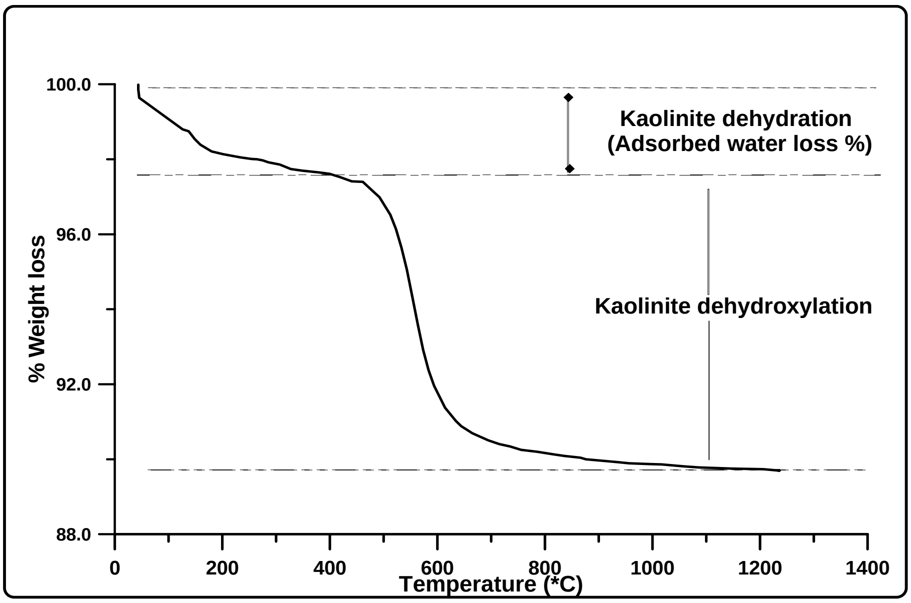

Figure 4. Thermo-Gravimetric (TG) Curve of a Kaolinite from Hiswa Clay Deposit.

Figure (5): The Sanitaryware Article:
a) Before firing; b) After firing without glazing; c) After firing with glazing materials.

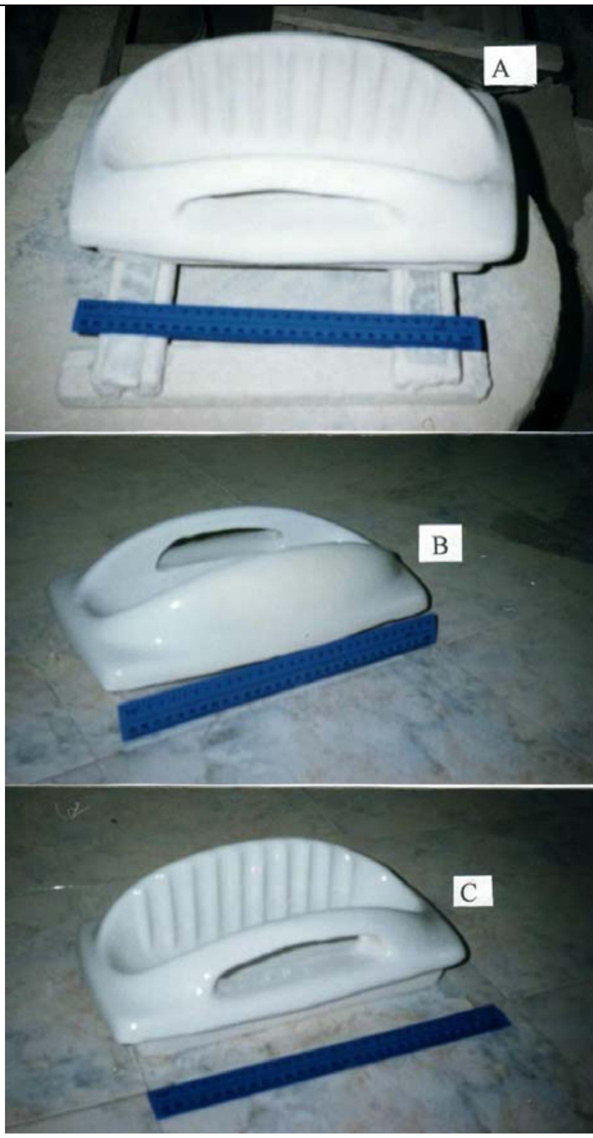

Figure (6): The Sanitaryware Article:
a) Before firing; b) After firing without glazing; c) After firing with glazing materials.

The Figures (5 and 6: B&C) Show a smooth vetrified body of the sanitaryware article without defects. the obtained color of the body is grey. no deformation has occurred.

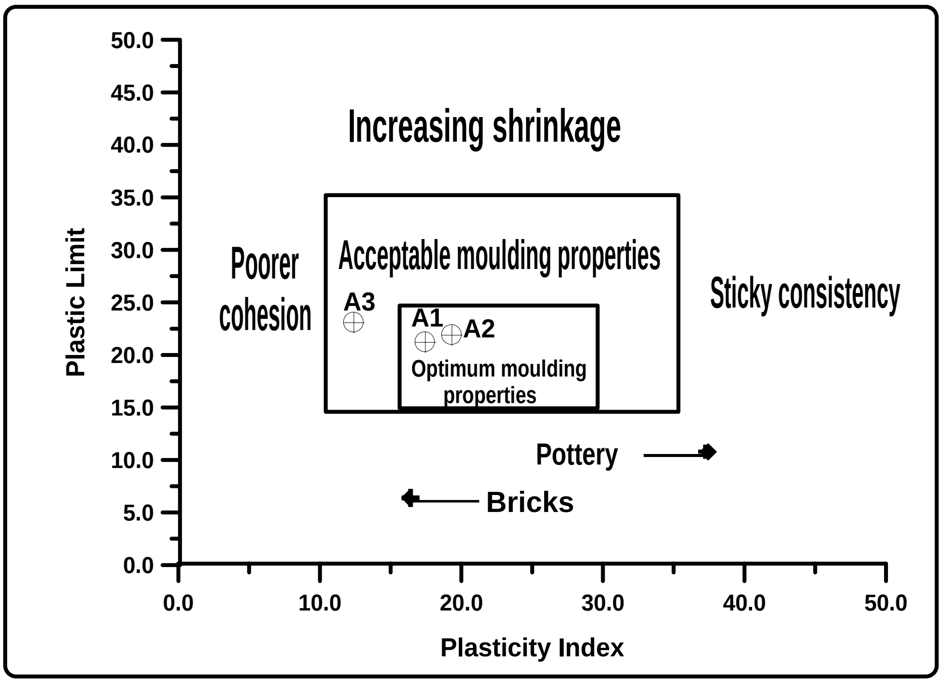

Figure (7): Clay workability chart (After Bain and Highly, 1978 in Saqqa *et al.*, 1995; Cravero *et al.*, 1997; Dondi, 1999). Samples (Kaolin A1 and Kaolin A2) fall within the region of optimum molding properties, and (Kaolin A3) falls within the region of acceptable molding properties.

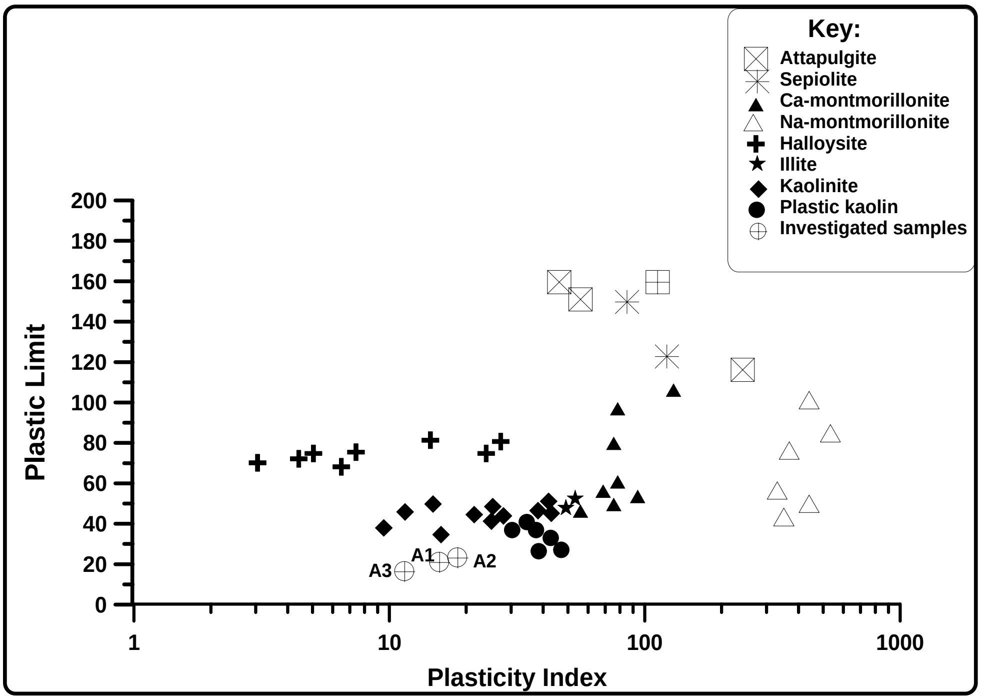

Figure (8): Clay identification chart (Bain, 1971). All samples (A1, A2, andA3) fall within the region of kaolinite.

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الصفات الحرارية والتطبيقات الصناعية لكاولين حصوة، جنوب الأردن

*طلال محمد المومني**

ملخـص

ركزت هذه الدراسة على الصفات الحرارية (التحليل الحراري التفاضلي، والتحليل الوزني الحراري، والتحليل الوزني الحراري التفاضلي)، والتطبيقات الصناعية لكاولين حصوة-جنوب الأردن في صناعة الجسم الخزفي للأدوات الصحية الخزفية والبلاط الخزفي، بوصفها مواد مالئة في صناعة الدهانات.

أشارت الخصائص الفيزيائية، والكيميائية، والمعدنية، والمواصفات التقنية والصناعية إلى أن توضعات حصوة الطينية متطابقة مع المواصفات القياسية. ودلت التجارب الصناعية على إمكانية استخدام توضعات حصوة الطينية – جنوب الأردن في صناعة الجسم الخزفي للأدوات الصحية الخزفية والبلاط الخزفي، كمواد مالئة في صناعة الدهانات.

كما أشارت نتائج منحنيات التحليل الحراري لعينات ممثلة من توضعات حصوة الطينية – جنوب الأردن إلى وجود نوعيات متوسطة التبلور وجيدة التبلور من الكاولينايت.

الكلمـات الدالـة: الصفات الحرارية، الخزف، المواد المالئة، الدهانات، حصوة، كاولين، الأردن.

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