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Characterization of Nigeria Kaolin as Raw Material for the Ceramic Industry

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Introduction

Kaolin has attracted the interest of many researchers due to its physical and chemical properties, thus being considered as one of the most studied industrial rocks. Kaolinite [$Al_2Si_2O_5(OH)_4$] is the most common mineral of the rock, followed by halloysite, dickite and nacrite. Kaolin deposits can be classified as either primary, formed due to in situ hydrothermal alteration or weathering of granitic rocks, or secondary, formed by the erosion and re-deposition of primary deposits (Prasad et al., 1991). Kaolin can be used in a wide range of industrial applications including ceramics. These products are dinnerware, sanitaryware, tile, porcelain, pottery and also refractory items (Murray, 2006). Each application relies on a specific set of properties; thus, kaolin characteristics can strongly affect the quality of the product. (Papoulis, 2003). According to the ceramic industry classification, kaolin products are distinguished into low and high quality products, on the basis of the purity of raw material, as well as the particle size distribution of the clay (Bloodworth et al., 1993).

In the present work, kaolin from Oza-Nogogo area, southern Nigeria was studied for the first time, in order to assess the suitability of this raw material for the ceramic industry. The evaluation of its industrial usage potential was based on a particular set of requirements defined by Bloodworth et al. (1993).

Geological Setting

The kaolin occurrences of Oza-Nogogo area belong to Oligocene-Miocene Ogwashi-Asaba Formation (Reyment, 1965); they outcrop along with coarse sandstone, light to brown clays and interbedded lignite layers (Akpokodje et al., 1991). The Ogwashi-Asaba Formation consists of sediments deposited during the third and last cycle of Niger Delta Basin (Schluter, 2006). The kaolin occurrences are characterized as sedimentary kaolin, with very high kaolinite content and subordinate amounts of quartz (Emofurieta and Salami, 1988).

Materials and Methods

Twenty samples were collected from four outcrops in Iduneha, Ewan, Uvbe and Ewebi, exposed by streams, hand dug pits and quarries. X-Ray diffraction (Bruker D8 Advance) with Cu-Kα radiation (λ = 1.5418 Å) and Nickel filter was applied to determine the mineral content in the raw samples. Scanning Electron Microscopy (SEM) was performed using an InspectTM F50 of FEI, in order to study the texture and the individual anomalies of the crystal structure of kaolinite. The particle size distribution of the kaolin samples was determined via Mastersizer 2000 of Malvern Instruments. Due to the underestimation of the clay fraction with the Laser Scattering Method, the results were converted applying Di Stefano's et al. (2010) equations. Both brightness and whiteness were measured between 380 to 780 nm, by using a Carry 100 UV-Vis spectrophotometer of Varian, controlled by Cary WinUV software. The nitrogen sorption-desorption isotherms for the samples degassed at 200°C for 2 h, were obtained at 77 K, using Nova 2200e Surface area and Pore size analyzer of Quantachrome. Specific surface area was determined from Brunauer-Emmett-Teller (BET) isotherms, whereas pore volume and diameter were identified via Barrett-Joyner-Halenda (BJH) method. Atterberg limit tests were performed for the determination of the liquid limit (LL) and the plastic limit (PL). The plasticity Index (PI) was calculated from the arithmetic difference of the LL and PL values as derived from Casagrande apparatus.

Results

According to the results obtained by X-Ray diffraction, the kaolinite content is very high (up to 89%), while quartz is the main impurity usually not exceeding 10%. Other secondary minerals, in only a small number of samples and in trace amounts, are dolomite, anatase, illite and iron oxides.

The results of six representative kaolin samples are given in Table 1. The grain size distribution shows that the kaolinized samples of Iduneha, Uvbe and Ewebi display high contents of fine clay fraction (<2 μm), with average values of 51%, 54% and 46%, respectively, whereas kaolin sample of Ewan reveal the least clay content (41%). The aforementioned results can also be confirmed by SEM analysis. Representative SEM image is given in Fig 1. Pseudo-hexahedral crystals of kaolinite dominate in the kaolinized samples, whilst its particle size appears to be <2 μm. In addition, intense orientation is observed, which is a feature of sedimentary kaolin deposits.

Both kaolin samples of Iduneha and Uvbe show high brightness, exceeding 91%. Similar results are presented for whiteness, with the exception of sample L1/IDH/01, for which the color was not as white as it was in the other samples, due to its Fe_2O_3 content. The values for specific surface area of Iduneha kaolin, are higher (10.603-13.636 m^2/g) than the kaolin from Uvbe and Ewebi. The total pore volume of the samples is significantly small (0.03-0.08 cm^3/g) and the pore diameter ranges between 3.6-5 nm. High values of 32.3 nm and 33.3 nm were observed in the samples L1/IDH/04 and L5/UVB/01, respectively. The Plasticity Index is unusually high and is related to the forming conditions.

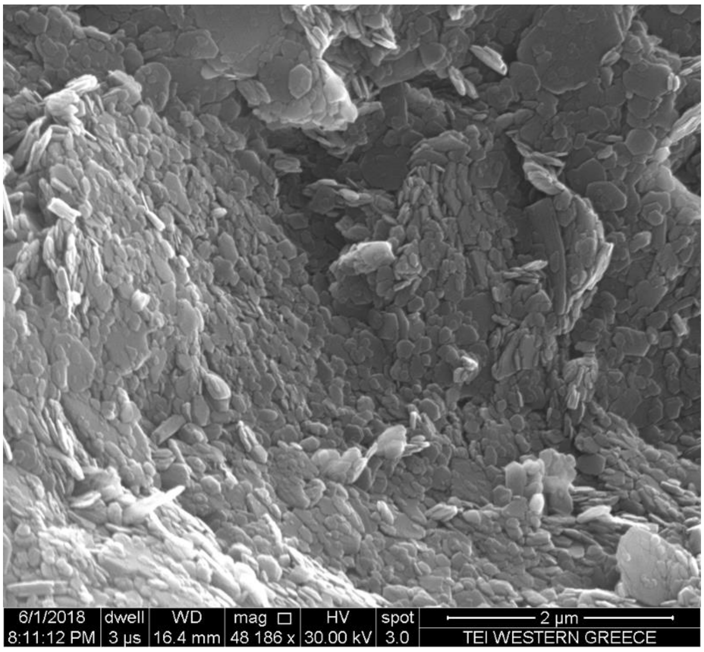

Figure 1. SEM image of a representative kaolin sample from Iduneha, showing hexahedral crystals of kaolinite.

Table 1. Results of physical properties of kaolin samples of Iduneha, Uvbe and Ewebi locations.

Location	Sample name	Grain size <2 µm	Brightness (%)	Whiteness (%)	SSA[1] (m^2/g)	Pore diameter (nm)	Pore volume (cm^3/g)	LL[2] (%)	PL[3] (%)	PI[4] (%)
Iduneha	L1/IDH/01	53	91.1	78.6	13.64	3.64	0.062	71.33	39.08	32.25
Iduneha	L1/IDH/04	43	94	85.4	12.59	33.25	0.078	98.31	44.29	54.02
Iduneha	L2/IDH/01	56	97.1	92.7	10.6	3.65	0.065	69.89	36.02	33.87
Uvbe	L5/UVB/01	50	-	-	9.39	32.27	0.05	-	-	-
Uvbe	L7/UVB/01	63	95.3	88.3	-	-	-	64.49	43.84	20.65
Ewebi	L9/EWE/01	40	-	-	9.29	3.61	0.062	53.86	41.29	12.57

1: Specific surface area, 2: Liquid limit, 3: Plasticity limit, 4: Plasticity Index

Conclusions

The kaolin samples obtained from the outcrops of Iduneha, Uvbe and Ewebi display similar properties. Taking into account the high content of kaolinite, the grain size being <2 µm, the high values of brightness and whiteness and the very light brown color, the kaolin of these areas meets the industrial set requirements for the manufacture of low-quality ceramics. Specifically, due to its surficial and thick strata, Iduneha is considered to have a significant economic interest. On the contrary, the Ewan occurrence is of inferior quality, and its exploitation could be an option only after beneficiation. However, for high-quality ceramic products, the studied kaolin samples fail to meet the industry's high standards.

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