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Granulometric Evaluation of Continental Bentonites and Kaolin for Ceramic Applications

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Abstract: Increasing demand for bentonite and kaolin usage in the ceramic industry engineered this study, which focused on understanding the granulometry of some selected continental clayey materials from Botswana, Mozambique, Pakistan, Senegal, South Africa and the United States of America. The Particle Size (PS), Particle Size Distribution (PSD), modal diameter and Specific Surface Area (SSA) of the clayey materials were determined. The results depicted that all samples had particles with Euhedral Spherical Diameter (ESD) which were $\leq$50 μm and also contained between 11.2 and 42.5 wt. % of $\leq$2 μm fraction of clayey material. The modal diameters ranged from 1 to 13 μm and the SSAs were between 4 and 19 $m^2 g^{-1}$. These values are in conformity with those obtained by other researchers and based on their granulometric characteristics; the clayey materials were found to be suitable for use in the ceramic industry.

Key words: Clay, composite clay body, modal diameter, particle size, particle size distribution, sand, silt, specific surface area

INTRODUCTION

Bentonitic and kaolinitic clay deposits are exploited for very wide varieties of industrial applications, one of which is in the ceramic industry (Patterson and Murray, 1983). These clays are used to make clay bodies, slips and glazes of different chemical and mineral compositions for ceramic applications. However, their usage in ceramic production is accompanied by significant problems at the different stages of product manufacturing: raw clay mining, processing, clay body formulation, drying, glazing, firing and cooling of finished product.

Problems associated with ceramic production must be avoided in order to have the desired end-product. Process-generated problems including black coring, blistering, bloating, bubbles, crawling, crazing, exploding, fracturing, peeling, pin holing, shivering and warping encountered in the production of ceramics can be traced back to the genetic history, mineral and chemical compositions as well as the physico-chemical properties of the raw clays.

The value of any clay mineral deposit is determined by its mineral genesis, types and amount of mineral and chemical impurities, Cation Exchange Capacitance (CEC) and granulometric characteristics (Cravero *et al.*, 2000; Patterson and Murray, 1983). Granulometric characteristics include Particle Size (PS), Particle Size Distribution (PSD), modal diameters and Specific Surface Area (SSA). In this study, we report our investigations on PS, PSD, modal diameters, specific surface areas and their effect on clay material applications in the ceramic industry.

MATERIALS AND METHODS

Samples: Samples analyzed in this study were from Botswana, Mozambique, Pakistan, Senegal, South Africa and United States of Africa (USA). Samples were simply coded MT and numbered from 1 to 17 as indicated in Table 1.

Analytical techniques: Granulometric analyzes which include PS, PSD, modal diameter and SSA measurements of samples of clayey materials were carried out employing both a mechanical shaker and a 1993 model Shimadzu SA-CP4 Particle Size Analyzer (PSA). The bentonite and kaolin samples were granulometrically characterized based on the principle of Stoke's law of sedimentation of individual spherical particles falling freely at a steady velocity under the influence of gravity, resisted only by the viscous drag of the medium (Gaspe *et al.*, 1994), expressed as:

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$$V = [2r^2(d_p\text{-}d_w)g]/9\eta \quad (1)$$

Where:

V	=	Rate of settling of particles (cm sec^{-1})
r	=	Radius of particles (cm)
d_p	=	Density of liquid medium (g cm^{-3})
d_w	=	Density of water (g cm^{-3})
η	=	Poise (g cm^{-1} sec)
g	=	Acceleration due to gravity (981 cm sec^{-2})

The mechanical/electrical shaker was set at 60 strokes per minute (spm) for effective shaking and the nest of sieves consisted of the following particle size ranges in µm: 180, 150, 125, 106 and 53. The < 53 µm size fraction of clay samples were analyzed using the 1993 model Shimadzu SA-CP4 automatic Particle Size Analyzer (PSA). The analyzer was set at 240 revolutions per minute (rpm) for effective segregation of particles. The SSA and PS were automatically measured by the PSA.

RESULTS

Particle size (PS) and particle size distribution (PSD): The textural classification utilized in this study is as follows: ≤ 2 µm is clay, > 2 µm ≤ 50 µm is silt and > 50 µm ≤ 100 µm is sand (Jackson, 1956; Tan, 1998). A summary of the textural classification of the samples is given in Table 2. The results revealed that all samples had particles with Euhedral Spherical Diameter (ESD), which were ≤ 50 µm. 0 wt. % of particles of sample MT1 were texturally classified as sand, 88.3 wt. % were silt and 11.7 wt. % were clay (Table 2). The sample consisted of 43.5 wt. % being ≤ 10 µm and its cumulative frequency distribution curve is given in Fig. 1. Sample MT2 constituted texturally of 0 wt. % sand, 82.9 wt. % silt and 17.1 wt. % clay (Table 2). The sample consisted of 46.3 wt. % of particles being ≤ 10 µm in which 17.1 wt. % is ≤ 2 µm and its cumulative frequency distribution curve is reported in Fig. 1.

Sample MT3 consisted of 0 wt. % sand, 57.5 wt. % silt and 42.5 wt. % clay. Approximately 71.2 wt. % of the sample consisted of particles being ≤ 10 µm in which 42.5 wt. % was ≤ 2 µm and its cumulative frequency distribution curve is reported in Fig. 1. Sample MT4 comprised of 0 wt. % of particles being classified as sand, 88.8 wt. % silt and 11.2 wt. % clay (Table 2). The cumulative frequency curve is reported in Fig. 1. The cumulative frequency distribution curve of sample MT5 is given in Fig. 1. From Table 2, sample MT5 was texturally 0 wt. % sand, 88.0 wt. % silt and 12 wt. % clay. Sample MT10 consisted texturally of 0 wt. % sand, 88.6 wt. % silt and 11.4 wt. % clay (Table 2) and its cumulative frequency

Table 1: Sources, identification and codes of clay samples

Sample code	Sample identification
MT1	Bentonite from Mozambique
MT2	Bentonite MD 100#
MT3	Bentonite 3%
MT4	Bentonite HV 100#
MT5	Topi clay
MT10	Sample 5
MT11	Sample 6
MT12	Sample 7
MT13	Sample 8
MT14	Sample 9
MT15	Sample 10
MT16	Makoro kaolin
MT17	Kgwakgwe kaolin

Table 2: Particle weight percent in relation to textural classification of samples

Sample No.	Sand (>50 ≤ 100 µm)	Silt (>2 ≤ 50 µm)	Clay (≤ 2 µm)
MT1	0	88.3	11.7
MT2	0	82.9	17.1
MT3	0	57.5	42.5
MT4	0	88.8	11.2
MT5	0	88.0	12.0
MT10	0	88.6	11.4
MT11	0	87.8	12.2
MT12	0	80.0	20.0
MT13	0	71.2	28.8
MT14	0	82.3	12.7
MT15	0	68.3	31.7
MT16	0	89.3	11.7
MT17	0	83.1	16.9

distribution curve of the particles are depicted in Fig. 1. The cumulative frequency distribution curve of sample MT11 is plotted in Fig. 1. Sample MT11 constituted of 0 wt. % sand, 87.8 wt. % silt and 17.2 wt. % clay.

Sample MT12 consisted of 0 wt. % sand, 80 wt. % silt and 20 wt. % clay (Table 2). Approximately 75.7 wt. % of particles contained in sample MT12 were ≤ 10 µm and the cumulative frequency distribution curve is represented in Fig. 1. Sample MT13 was texturally composed of 0 wt. % sand, 71.2 wt. % silt and 28.8 wt. % clay. The sample comprised 87.7 wt. % of particles being ≤ 10 µm and its cumulative frequency distribution curve is plotted as Fig. 1. Sample MT14 consisted of 0 wt. % sand, 82.3 wt. % silt and 12.7 wt. % clay as indicated in Table 2. Approximately 61.9 wt. % of particles in sample MT14 were ≤ 10 µm and its cumulative frequency distribution curve plotted as Fig. 1.

From the particle size distribution curve shown in Fig. 1, sample MT15 comprised of 80 wt. % of particles being ≤ 10 µm, of which 12.7 wt. % were texturally classified as clay size particles. The PSD curve for sample MT16 is given in Fig. 1. Sample MT16 was constituted of 0 wt. % of particles texturally classified as sand, 89.3 wt. % silt and 11.7 wt. % clay. Approximately 41.9 wt. % of the particles in sample MT16 were ≤ 10 µm, in which 11.7 wt. % of them were ≤ 2 μm. From Fig. 1 and Table 2, 83.1 wt. % of particles contained in sample MT17 were texturally classified as sand and 16.9 wt. % as clay.

Modal diameters of particles: The modal diameters of bulk clay samples were between 1 and 13 μm. From the results obtained for PSD, the samples were grouped into

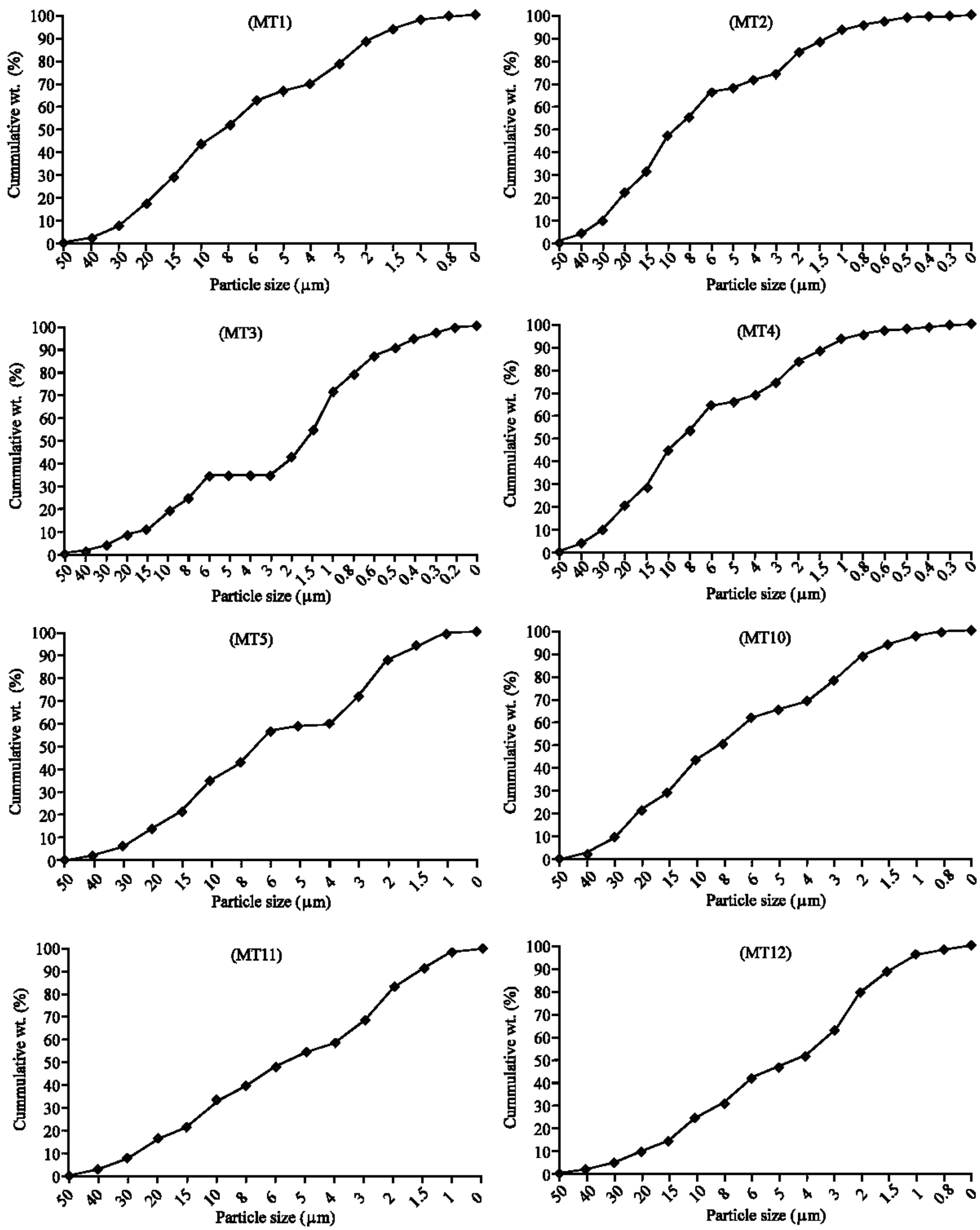

Fig. 1: Continued

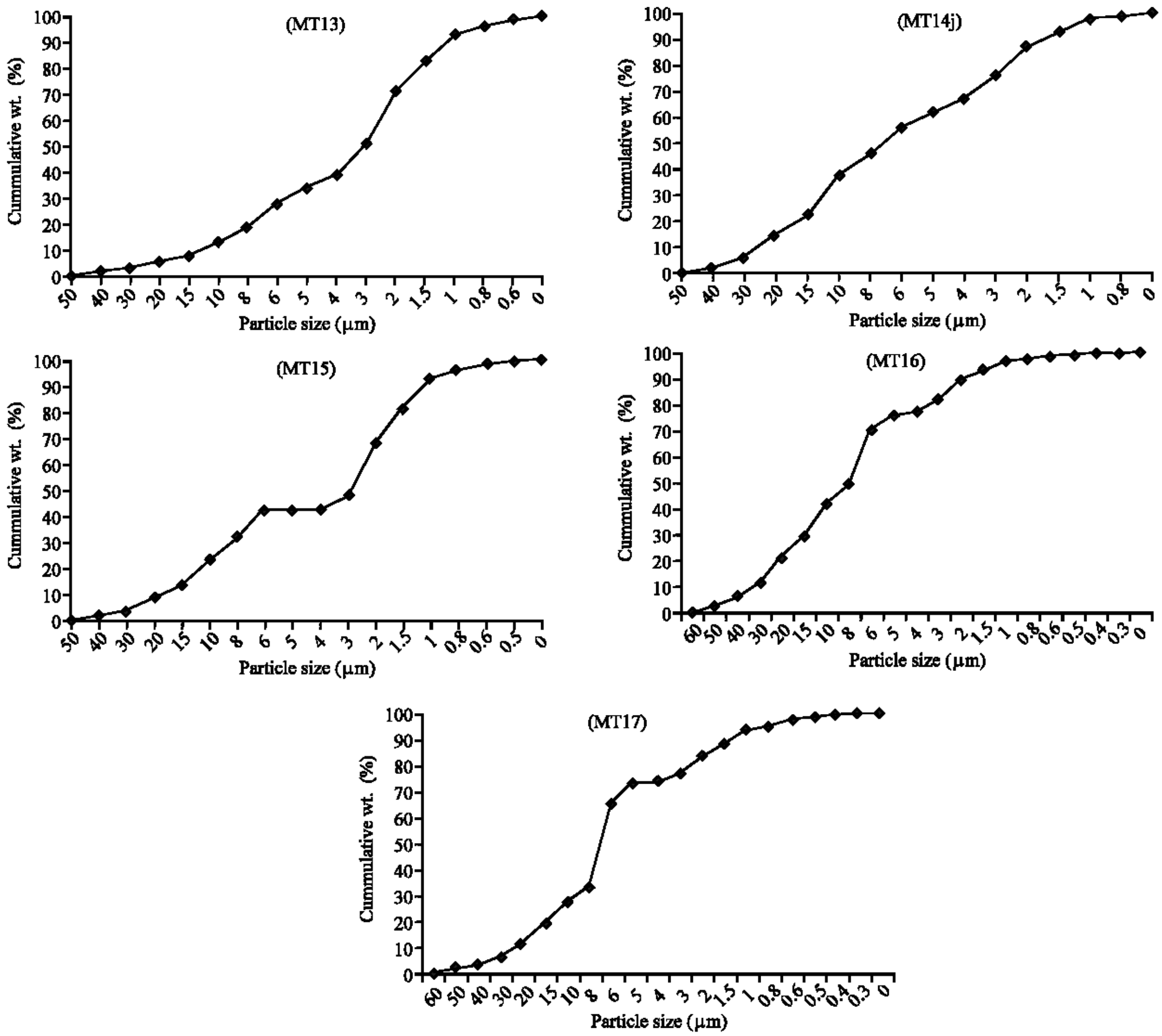

Fig. 1: Cumulative frequency distribution curve of samples of clayey materials

two classes based on their modal diameters as observed in Fig. 2. The first class of samples were those with high modal diameters and high cumulative wt. % at which the modal diameters occurred. Samples MT1, MT2, MT4, MT10 and MT14 had their modal diameters occurring between 11 and 13 µm and with corresponding cumulative wt. % between 45 and 70 wt. %.

The second class of samples consisted of those with low modal diameters and low cumulative wt. % and these were MT3, MT5, MT11, MT12, MT13 and MT15. The modal diameters of these samples occurred between 1 and 3 µm and they had corresponding cumulative wt. % within the range of 20 and 40 wt. %. No samples had its modal diameter within the range of 4 and 10 µm.

Two classes of samples as shown in Fig. 3 were distinguished based on the modal diameters of samples in relation to the cumulative wt. % of the ≤ 2 µm. The first class of samples were those with high modal diameters. Samples MT1, MT2, MT4, MT10 and MT14 had their modal diameters occurring between 12 and 14 µm and with

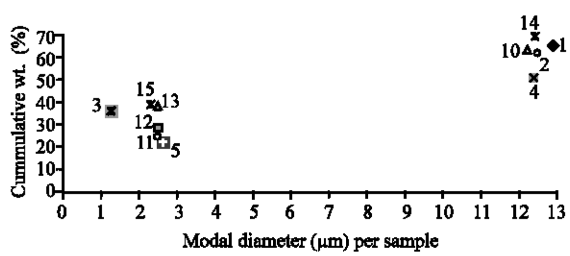

Fig. 2: Comparison of modal diameter and cumulative wt. % of bulk clay samples

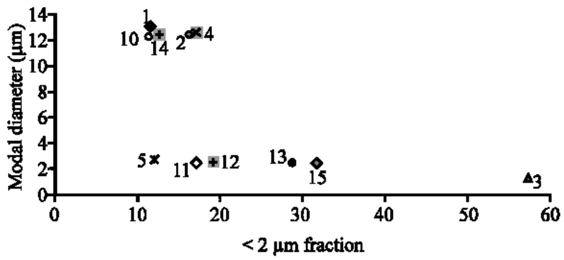

Fig. 3: Comparison of modal diameter and cumulative wt. % of the ≤ 2 μm fraction of clay samples

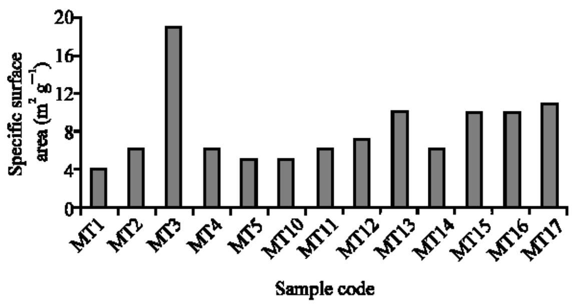

Fig. 4: Specific surface area of samples of clayey materials

corresponding cumulative wt. % of the ≤ 2 μm fraction within the rage of 10 and 20 wt. %.

The second class of samples had low modal diameters compared to the first class. The samples, which were MT5, MT11, MT12, MT13 and MT15, had their modal diameters occurring between ≤1 and 2.5 μm and they had corresponding cumulative wt. % within the range of 10 and 33 wt. %. Sample MT3 was noted to have both the lowest modal diameter (1.4 μm) and the highest cumulative wt. % of the ≤ 2 μm fraction (58 wt. %).

Specific surface area of particles: The Specific Surface Area (SSA) of samples obtained ranged from 4 to 19 m^2 g^{-1} and the results are given in Fig. 4. Based on values obtained for SSAs of samples analyzed, they could be subdivided into three classes. Samples with low specific surface areas also had low cumulative wt. % of the ≤ 2 μm fraction as demonstrated in Fig. 5. The first class of samples were MT13 and MT15, which had SSAs of 10 $m^2 g^{-1}$ and their cumulative wt. % of the ≤ 2 μm fraction were 35 and 40 μm, respectively. The second class were samples MT1, MT5, MT10 and MT14 having SSAs between 4 and 6 m^2 g^{-1}. The third class were samples MT2, MT4, MT11 and MT12 and they had SSAs between 6 and 8 $m^2 g^{-1}$. The SSA of sample MT10 was 10 m^2 g^{-1} and sample MT17 had a SSA of 11 m^2 g^{-1}. The SSA for sample MT3 was 19 $m^2 g^{-1}$ and its cumulative wt. % of the ≤ 2 μm fraction was 59 μm.

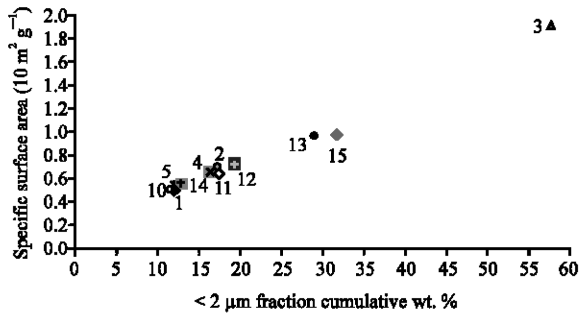

Fig. 5: Comparison of specific surface area and cumulative wt. % of the ≤ 2 μm fraction of samples of the clayey materials

DISCUSSION

The PSD of argillaceous sediments is an important property, affecting the ceramic strength of any clayey material (Murray, 1986). Jackson (1956) divided the grain particles of sediments into three main classes based on sizes: sand (50-1000 μm), silt (> 2-50 μm) and clay (< 2 μm) (Tan, 1998). This division of particles is indicative of the texture of the clayey material. Of the studied samples, based on the textural classification by Jackson (1956), none had a sand component as most of the particles ranged from 0.02 to 50 μm (Table 2, Fig. 1). The samples analyzed depicted the clays to be classified as clayey silts based on the ternary diagram represented as Fig. 6, of PSD devised by Shepard (1954) and applied by Strazzera *et al.* (1997) and Dondi *et al.* (1992), to Tertiary clays from southern Sardina, Italy that are widely used in ceramic industry. The particles of clayey material suitable for ceramic applications are classified as silty clay, clayey silt (Dondi *et al.*, 1992; Parras *et al.*, 1996), except for samples MT5 and MT10 as indicated in Fig. 6, which had their texture consisting of silt. This information is relevant to the degree of heat flow and water absorption capacity of clayey material.

The studied clay samples were functionally distributed using the grain size classification according to Winkler's scheme as applied to clays from southern Italy (Dondi *et al.*, 1992). Figure 7 gives the allocation of the clays studied in their various fields of applications: common bricks, vertically perforated bricks, roofing tiles and masonry bricks and hollow products. Based on the classification of clayey materials according to Winkler's scheme, as reflected in Fig. 7, samples MT5, MT10, MT11 and MT16 are suitable for the fabrication of common bricks; samples MT1, MT2 MT4, MT12, MT13, MT14, MT15 and MT17 could be used for the making of vertically perforated bricks and sample MT3 may have to be ameliorated to be utilized for any brick fabrication.

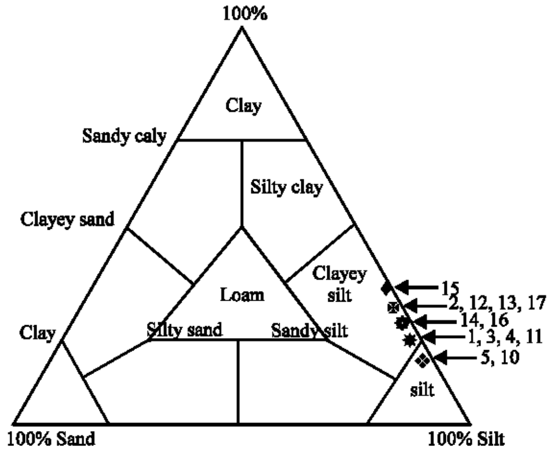

Fig. 6: Ternary diagram classification of clay samples based on sand-silt-clay ratios (Note that the numbers signify samples and are all preceded by MT) (Dondi *et al.*, 1992; Tan, 1998; Jackson, 1956)

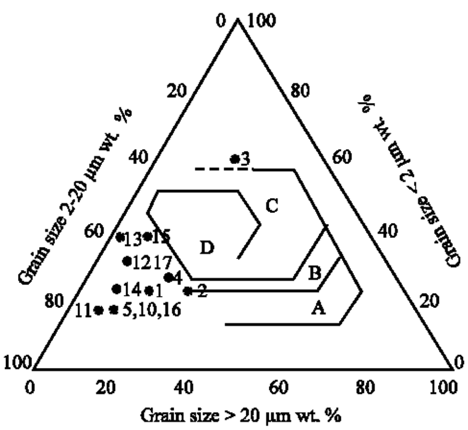

Fig. 7: Grain size classification of studied clays according to Winkler's scheme. Fields are characteristic for: (A) common bricks, (B) vertically perforated bricks, (C) roofing tiles and masonry bricks (D) hollow products. (Numbers are indicative of sample numbers and are preceded by MT). (Dondi *et al.*, 1992; Tan, 1998; Jackson, 1956)

Modal diameters of the samples analyzed were of two groups: 1-3 and 11-13 μm. Clays used in ceramics have modal diameters between 1 and 5 μm (Murray, 1986). The first group of samples qualifies for ceramic usage. Whereby modal diameters are high as in the second group of studied samples, the clays can be mixed with different clayey material; in which case the composite claybody will have reduced modal diameters, which can be accommodated in the ceramic industry.

The SSA of any clayey material is a variable used in the determination of clay suitability for ceramic applications. According to Kaolins (2000), the SSA of most commercial clays used for ceramics is 10 $m^2\ g^{-1}$. The studied samples had SSA values between 4 and 19 $m^2\ g^{-1}$. The SSA of clay particles has a linear relationship with the particle size. Clay particles are flat and are randomly oriented. Particle size and orientation affect the clay's drying shrinkage, which has a consequence on the finished product (Ceramic Terminology, 2001). Finer particles tend to increase the rate at which reactions occur in the kiln/furnace (Bloodworth *et al.*, 1993). Based on PS and PSD, modal diameters of samples and their SSAs, all the clay samples analyzed in this study were found to be suitable for ceramic applications.

CONCLUSION

The grain size of any clay definitely has a bearing on its viscosity, color, abrasiveness and ease of dispersion (Murray, 1999). Although the results obtained from granulometric analyses show that these clays are suitable to be used in the ceramic industry, there are other controlling factors such as the clay mineralogy and clay chemistry, which usually influence the quality of the finished product. In this regard, a beneficiation exercise may have to be carried out depending on the specific ceramic application designated for the clay material to be utilized.

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