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The Physical Properties and Geochemical of Clay from the Bestari Jaya, Kuala Selangor, Selangor, Malaysia for Potential Usage

M. R. Umor, A. Hussin and N. Muda

***Abstract* — The study emphasis on physical properties and geochemical of the clays from Bestari Jaya area to determine its suitability for any commercial application. Nine samples collected from six boreholes as representative of white and dark clay in the study area. All samples examined through the optical properties test and physical properties such as moisture, specific gravity, Atterberg limit and particle size distributions. The geochemical and mineralogical conducted using XRF and XRD analysis. The clays from Bestari Jaya considered of having variation in the brightness from medium to high brightness as shown by Delta L value (51.32-73.49%). The moisture content ranges between 34.50-81.03%. The plasticity index (PI) and plasticity limit (PL) values found in ranges of 18-32% with an average of 22.22%, and 32-46% with an average of 37.11% respectively. The plasticity limit and index reveals that the Bestari Jaya clays can be classify as kaolinite clays that are suitable for pottery and brick making. The specific gravity ranges between 2.49 – 2.70 with an average of 2.61. The average value is similar to the value of pure china clay (2.6). The SiO_2 content in Bestari Jaya clays is between 37.49 – 69.96 wt% and Al_2O_3 is between 18.92 – 33.02 wt%. While the L.O.I values are between 8.71-16.04%. Kaolinite as the dominant mineral phases in all clay samples with composition ranges from 65-97.7% and an average of 73.12%. Apart of that, quartz in ranges of 5.3 – 20.6%, identified in almost all samples. Muscovite, hematite and magnetite occur as accessory minerals. Referring to standard and result obtained on representative sample, the Bestari Jaya clays potentially used in the production of smaller tiles for unexclusive pedestrian traffic. The presence of significance amount of heavy metals makes it unsuitable to use in the pharmaceutical or paper industry.**

***Index Terms* — Clay, Bestari Jaya, Geochemical, Physical Properties.**

I. Introduction

Clay is a naturally occurring material composed of layered structures of fine-grained minerals which exhibit the property of plasticity at appropriate water content but becomes permanently hard when fired [1], [2]. The clay distribution in Malaysia mostly situated in North Peninsular Malaysia such as in Perak. Its usage is famously related with the production of its traditional ceramic product known as ‘labu sayong’ [3]. Clays deposit in Sayong, Perak and Mukah in Sarawak contains kaolinite and quartz as dominant minerals with the presence of other elements [4], [5]. Clay minerals have specific physicochemical characteristics. The qualitative and quantitative mineralogical composition, as well as the particle size distribution, are the main factors controlling the physicochemical properties of a particular clay.

This paper presents results of analysis of clay samples collected from selected borehole in the clay quarry area at the Bestari Jaya, Kuala Selangor, Selangor Malaysia. It is anticipating that this study will provide the clays characteristics in detail which need to critically measure for any future commercial application. The similar method used in this paper as stated on [6].

II. General Geology

Pre-Quaternary rocks and alluvial deposits geologically overlie the area of Bestari Jaya. The pre-Quaternary rock classified as shale, schist and phyllite, whereas the alluvial deposits composed mainly of Holocene and Pleistocene sediments [7]. The Simpang Formation is the older sediment of Pleistocene age, whereas the younger unit of Holocene age are known as the Beruas Formation and the Gula Formation [8]. In other area, The Simpang Formation is namely as Old Alluvium, whereas the Beruas Formation is called as the Young Formation [9].

[10] introduced the term of Simpang Formation to describe a unit of gravel, sand, silt, and clay overlying bedrock in the Taiping area, with thickness varying from a few metres to more than 50 metres from east to the west. The thickness of overlying unit can be determine using the seismic method and electrical resistivity [11], [12]. [7] restricted the Simpang Formation to clay, silt, sand, gravel and peat deposited in a terrestrial environment before the most recent major low sea level. [13] used the Beruas Formation to describe fluviatile-estuarine-lacustrine deposits consisting of clay, sandy clay, sandy gravel, silt and peat in the Beruas area, Perak.

This unit overlies the Simpang Formation, filling channels and depressions, as well as overlying bedrock in some places. [7] restricted the Beruas Formation to clay, silt, sand, gravel and peat deposited in a terrestrial environment before the most recent major low sea level between 15,000 and 18,000 years BP. [10] introduced the Gula Formation to describe a sequence of mainly grey to green-grey marine to estuarine clay, with subordinate sand occurring in the Taiping area. The formation is distinguished from the Beruas Formation and Simpang Formation by its lithology. The sediment of green-grey colour, presence of marine fossils and low heavy mineral content [8].

The study area is representing by clay, silt and clayey sand of the Beruas Formation. The colour is white to yellowish and dark brownish (Fig. 1).

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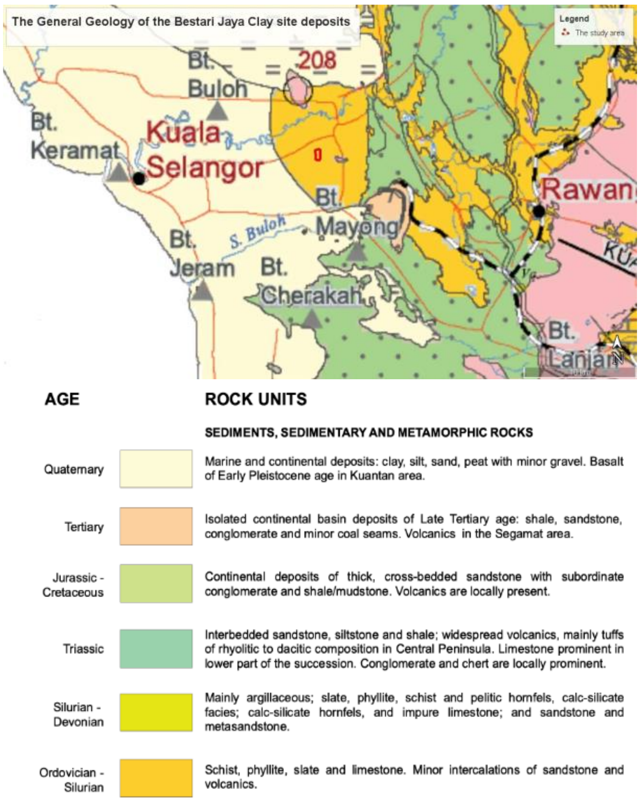

Fig 1. The general geology of the study area.

III. Material And Methodology

There are 23 borehole conducted in exploration for mining clay. The representative clay sample for laboratory evaluation was selected from 6 different boreholes. The sample namely as BJ1 until BJ9 at the maximum depth of 22–24 m. At certain area, excavation of clay already done, and clay stored at shed yard. In this study, 9 clay sample from selected boreholes has been analyzed for physical, chemical, and mineralogical properties. The clays are ball clays, appeared mostly greyish, whitish with yellow stained and dark brownish (Table 1).

The samples need to dry at room temperature and then were crushed using ceramic mortar grinder. The crushing powder then being sieve. Only the particles passed < 63 micro-m sieve size used for analysis. The clay then divided into portion for physical analysis and chemical analysis.

The chemical composition measured as oxides using 2 g of dried and homogenized powder samples. The machine conducted the test is a Bruker S8 Tiger wavelength-dispersive X-Ray Fluorescence (WD-XRF) spectrometer equipped with a Rh anticathode at the Centre of Research and Innovation Management (CRIM), National University of Malaysia. More than 30 commercially certified reference materials of similar matrix (sedimentary rocks, river, lake and marine sediments, sands and soils) used in the calibration. The determination of Loss On Ignition (L.O.I) using the same powdered samples by heated to 1000 °C for one hour.

X-ray diffraction (XRD) patterns determine using Bruker diffractometer Model D8 Advance operating with Cu Kα radiation (Kα 0.15406 nm). The analysis conduct by generated the power of 40 kV and 20 mA. The measurement carried out at 0.02° min-1 for 2θ values between 3 and 80 degree at the Centre of Research and Innovation Management (CRIM), National University of Malaysia. The optical properties such as brightness or whiteness of the Bestari Jaya clays were measured by colour spectrophotometer.

TABLE I: The List of Samples

No sample	Borehole with depth (m)	Field name	Colour
BJ1	BH 7 (12.0 – 14.0)	Silty CLAY	Light gray fined
BJ2	BH 8 (19.5 – 21.5)	Sandy Clayey SILT	Yellowish stained
BJ3	BH 12 (15.0 - 17.0)	Silty SAND	Whitish clay
BJ4	BH 13 (3.0 - 5.0)	Sandy CLAY	Whitish clay
BJ5	BH 13 (11.0 - 13.0)	Sandy SILT	Yellowish
BJ6	BH 15 (13.0 - 15.0)	Sandy Silty CLAY	Dark brownish
BJ7	BH 23 (5.0 - 7.0)	Sandy CLAY	Yellow-whitish
BJ8	BH 23 (10.0 - 12.0)	Sandy SILT	Yellow-whitish
BJ9	BH 23 (22.0 - 24.0)	Silty SAND	Yellow silty clay

IV. Results

A. Colour

Commercially valuable clays combine of desirable colour light, and it suitably of fine particle size. It has been known that relationships exist between soil colour, physical properties and chemical characteristics of soil [14], [15]. Different elements and compounds of those elements exhibit different colours. The sufficient concentrations present can influence the overall colour of a clay sample. Pure kaolin clays occur in nature as finely divided particulate dispersion of white colour. Its impurities of ferruginous oxides minerals such as rutile, siderite, pyrite, mica and tourmaline often between 0.5–3.0 %. These minerals contain iron. If the concentration of these mineral is above threshold, the colour could be unacceptable and eventually would be affected its technological performance.

Brightness represents the % of reflectance of light. Table 2 simplified the findings of colour values for the investigated clays. The term Delta L is a measure of lightness/darkness and varies from 100 for perfect white to 0 for absolute black. The red/green color is indicated by Delta a. The more positive its value, greater is the reddishness and negative value indicating greenishness.

TABLE 2: The brightness of clay Bestari Jaya

Sample No	Delta L	Delta a	Delta b	Total
Standard	68.67	1.5	18.39	88.56
BJ1	62.37	2.09	17.88	82.34
BJ2	53.19	2.23	12.76	68.18
BJ3	73.49	1.68	15.81	90.98
BJ4	66.96	1.25	13.55	81.76
BJ5	51.32	2.72	13.4	67.44
BJ6	62.41	3.2	19.34	84.95
BJ7	65.26	1.61	16.75	83.62
BJ8	59.75	2.54	14.07	76.36
BJ9	53.09	2.99	14.39	70.47

Note: Delta L - Whiteness, Delta a - Red and Green, Delta b - Yellow and Blue.

Similarly, the yellow shade is represented by Delta b, positive value for yellow and negative for bluishness. The color in clays is essentially due to the higher carbon content (grey), iron oxide (pink) and iron oxyhydroxide (cream). Generally, the clays from Bestari Jaya considered of having variation in the brightness from medium to high brightness as shown by Delta L value (51.32-73.49%).

Only one sample which is BJ3 considered of having high brightness. The L value for this particular sample detected as 73.49%. The higher L value in this sample indicates the minimum presence of carbon or others colouring matters. The brightness of other tested samples of Bestari Jaya clays ranges from 51.32–73.49 %.

The presence of iron and titanium will decrease of brightness [16]. The high iron content will cause the red pigmentation of brick when calcined at 1100 °C. The absence of carbonate minerals will induce the formation of Fe_2O_3 because the presence of carbonate will cause the Fe element present in the matrix trapped in the calcium silicate structure [17].

Brightness in excess of 80% would be required for clays to be used in paper filling or paper coating. The relatively high values of yellowness in Bestari Jaya clays, spanning the range from 12.76 to 18.39%, renders it unsuitable industries, especially the paper industry. Hence bleaching, froth flotation could be improvised the brightness of this resources.

B. Physical Properties

Some values of the basic physical properties of these clays for site in Bestari Jaya are given in Table 3. The physical properties of clays include the percentage of moisture content, specific gravity, plasticity (Atterberg limit) and clays fraction proportion. The Atterberg limits are a basic analysis to determine the interaction of water contents of a fine-grained soil: its shrinkage limit, plastic limit, and liquid limit.

The moisture content of the representative samples found to be in ranges of 34.50-81.03%. The results proved that the higher moisture contents related with higher clays fraction. Whereas the lower moisture content significantly related with samples dominant with sand fraction.

TABLE 3: THE RESULT OF PHYSICAL PROPERTIES OF CLAY BESTARI JAYA

Sample No.	Moisture (%)	Specific gravity	Liquid Limit (L.L) (%)	Plastic Limit (P.L) (%)	Plastic Index (P.I) (%)	Sand (%)	Silt (%)	Clay (%)
BJ1	55.16	2.49	71	46	25	3	41	56
BJ2	42.85	2.66	52	32	20	25	49	26
BJ3	36.14	2.6	50	32	18	49	28	23
BJ4	36.67	2.6	61	39	22	40	20	35
BJ5	54.99	2.5	63	40	23	15	42	43
BJ6	81.03	2.69	73	41	32	7	43	50
BJ7	47.22	2.58	55	34	21	30	42	28
BJ8	34.64	2.7	57	38	19	45	40	15
BJ9	34.5	2.66	50	32	20	50	37	13
Min	34.5	2.49	50	32	18	3	20	13
Max	81.03	2.7	73	46	32	50	49	56
Aver.	47.02	2.61	59.11	37.11	22.22	29.33	38.00	32.11

Plasticity modifies the shape of a clay–water mass in non-elastic, non-reversible fashion. The most significant parameters to measure the plastic state of clay are the liquid limit (LL), plastic limit (PL) and the plasticity index (PI). LL is the water content of clays at which flow just begins when jarred in a specific manner. PL is the minimum water content at which the clay can just be roll by hand into 3-mm-thick unscrambled threads.

Values measured for Bestari Jaya clays are compare to those known for kaolinite in different places. The Attenberg limits results obtained from the liquid limit (L.L) and hence plasticity value derived. The plasticity index (PI) for Bestari Jaya clays were found in ranges of 18-32% with an average of 22.22%. Plastic limit (PL) value for Bestari Jaya clays are from 32-46% with an average of 37.11%.

Comparing the liquid limit and plasticity index of the Bestari Jaya clays with standard workability chart by [18], the Bestari Jaya clays considered of has good plasticity (high), which could be related to good kaolinite crystallinity (Figure 2).

The clay is classified as a high plasticity. The results of plastic and liquid limits tests plotted on the plasticity chart shows that they occur roughly parallel to with situated just below the "A" line. This narrow linear relationship suggest that all sample of clays have a broadly similar mineralogical composition and particle size range.

An increment of plastic limit and plasticity index is correlated with increasing of finer fractions, which itself is linked to larger specific surface. All tested samples are virtually plastic and non-samples give plasticity indices of below 10. Plasticity of Bestari Jaya clays can be increasing by removal of non-clay components such as quartz grains.

In terms of the clay workability, the Bestari Jaya clays are predict of potentially having acceptable or optimum molding properties fields and its can find use in bricks, pipes, tiles and pottery (Figure 3). The plasticity of sample will increase with the increasing of fine particles especially kaolinite minerals [19]. At the other hand, the increasing of silica content will also be reducing the plasticity. Plasticity is inversely proportional to the grain size whereas the specific surface area (coarse grain) will reduce the amount of water absorbed [20].

The Bestari Jaya clays considered as a good plasticity (medium-high), which could be relate to higher Cation

Exchange Capacity (CEC) and good kaolinite crystallinity. The plasticity limit and index reveal that the Bestari Jaya clays could be category as kaolinite clays that are suitable for pottery and brick making. The specific gravity of the Bestari Jaya clay is in ranges between 2.49 – 2.70 with an average of 2.61. The average value is similar to the value of pure china clay (2.6).

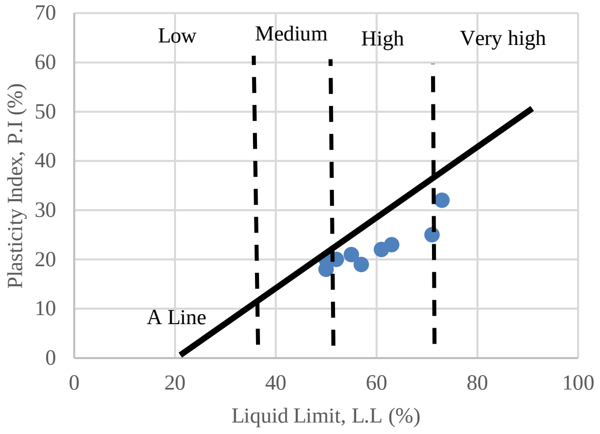

Fig. 2. The liquid limit (LL) index vs plasticity index (PI).

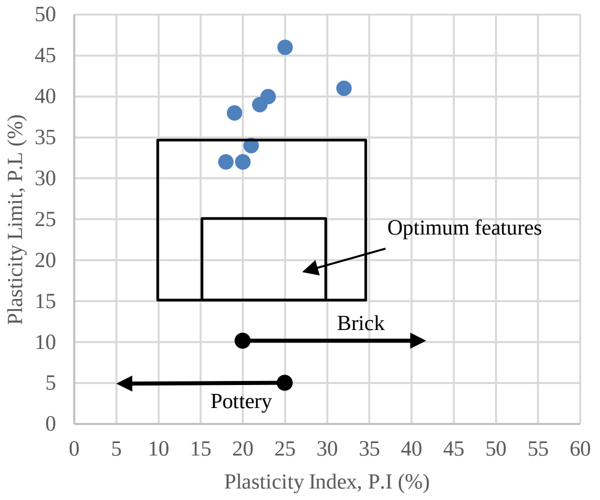

Fig. 3. The plasticity index (PI) vs plasticity limit (PL).

C. *Particle size distribution*

The particle size distribution is the main factor for the industrial uses of clays. Coarse-particle clays differ from fine-particle clays that will reflect to a certain other physical and optical properties as well. The particle shape and size distribution also control brightness, slurry-viscosity, opacity, gloss, ceramic strength, shrinkage and the paper-filling and paper-coating properties such as the mechanical, optical and printing characteristics of paper sheets [21].

Results of sieve screening and hydrometer of the investigated clays are given in Table 3. Based on the particle size distribution, the samples can be divided into two facies of clayey bodies. The first facies are the fine clays with high content of clay and silt fraction (> 80%) and the second facies is sandy clays with clay and silt fraction contents ranging from 50 to 55%. In general. the particle size has a significant role on the on the plasticity characteristic of clay which is the smaller the particle size, then the better is the plasticity of the clay.

D. *Geochemical composition*

Chemical composition of clay is also an important factor in industrial clay usage because they influenced the properties of ceramic materials during calcination, Al_2O_3 content >30% would increase the refractory properties and mechanical strength [22].

The results of the chemical elements in bulk clays sample from Bestari Jaya are reported in Table 4. A theoretical composition of pure kaolinite normally composed with 46.55 wt% of SiO_2 and 39.49 wt% of Al_2O_3. The analysis shows the SiO_2 is most abundant (37.49-69.96 wt%) followed by Al_2O_3 (18.92-35.62 wt%). The Fe_2O_3 is quite high (0.74%-11.43%). The value of the K_2O, TiO_2, P_2O_5, MgO, MnO, CaO and Na_2O is relatively low which is less than 1.0 wt%. The L.O.I values are between 8.71-16.46 wt%.

The impurities in Bestari Jaya clays are related with accessory minerals. The presence of hematite justified the higher content of Fe in sample BJ6. The analysis also proved that the Bestari Jaya clay composed considerable amount impurities such as Fe (0.74-11.43%) and Ti (0.4-1.36%). These minor elements will affect the color of the clay even exist in small amounts because of their durability of heating at high temperature [23], [24]. The ranges of ratios for SiO_2/Al_2O_3 concentration are 1.14 -3.70 %, whereas 1.18 is the ideal SiO_2/Al_2O_3 ratio for commercial application. The concentration of silica and alumina contents agreed with the quartz and kaolinite in sample.

Estimation of trace elements/heavy metals in the investigated clays indicates the measurable quantities of P, Zn, Zr, Sr, Ba, Cr, Y and Th. Theoretically the accumulation of the trace elements is co-precipitated with the Fe-oxides or they are sorted much more strongly on the functional group of the oxides. The key to ceramic use is low Fe_2O_3 content and a good-fired brightness. The brightness values are within the range of the specifications but the raw Bestari Jaya clays seems to be unsuitable for ceramics as the chemical composition and grain size do not conform to the required range of 80–96% of clayey size.

E. *Mineralogical composition*

This mineralogical compositional analysis done by X-Ray diffraction method (XRD), which strongly indicates the presence of kaolinite as the dominant mineral phases in all of the investigated clay samples (Table 5). The analysis proved that the kaolinite composition ranges from 65-97.7% with an average of 73.12%.

Apart of that, quartz in ranges of 5.3–20.6% was identified in almost all samples except in sample BJ1 and BJ6. Muscovite, hematite, and magnetite occur as accessory minerals. Based on the mineralogical compositional ranges, the Bestari Jaya clays can be divided into fine kaolin (kaolinite >75%) and sandy clays (kaolinite in ranges of 50-65%).

The compositional materials of clay have linear effect on the properties of shrinkage and water absorption in sanitary ware manufacture. Clays with abundance kaolinite are the most preferred resource for industrial application. The presence of non-clays mineral such as an inert micaceous

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mineral, quartz and oxides would lead to the lower shrinkage value. The mineralogical variance also plays a big role in the absorption capacity of functional filler and extender prepared from clays.

TABLE 4: THE CHEMICAL COMPOSITION OF CLAY BESTARI JAYA

Sample	BJ1	BJ2	BJ3	BJ4	BJ5	BJ6	BJ7	BJ8	BJ9
Oxides (wt%)									
SiO_2	45.19	63.47	69.96	62.7	49.83	37.49	56.63	55.	60.52
TiO_2	1.36	0.98	0.4	1.06	1.16	1.22	0.65	0.71	0.59
Al_2O_3	35.65	21.35	18.92	22.66	32.45	33.02	28.1	26.9	23.27
Fe_2O_3 (t)	0.79	2.67	0.76	0.74	1.6	11.43	1.24	3.24	2.76
MnO	0.01	0.02	0.01	0.01	0.01	0.03	0.01	0.01	0.01
MgO	0.1	0.11	0.17	0.22	0.13	0.11	0.27	0.28	0.24
CaO	0.02	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.02
Na_2O	0.07	0.09	0.03	0.04	0.02	0.08	0.03	0.01	bdl
K_2O	0.01	0.02	0.5	0.27	0.27	0.02	1.04	1.43	1.28
P_2O_5	0.02	0.07	0.03	0.04	0.1	0.08	0.03	0.09	0.08
L.O.I	16.46	11.11	8.71	11.86	14.78	16.04	11.7	11.96	10.86
Total	99.68	99.93	99.52	99.63	100.37	99.54	99.62	99.65	99.63
SiO_2/Al_2O_3	1.27	2.97	3.70	2.77	1.54	1.14	2.02	2.04	2.60
Element (ppm)									
Ce	bdl	140	bdl	bdl	160	bdl	bdl	bdl	200
Cl	690	1040	190	180	80	1270	100	60	130
Cr	160	90	bdl	100	40	50	bdl	40	50
Cu	100	60	bdl	bdl	bdl	90	bdl	bdl	30
Ga	470	40	370	30	570	50	40	450	30
Nb	30	20	20	30	30	20	20	20	20
Ni	60	70	40	bdl	bdl	80	bdl	bdl	bdl
Pb	bdl	40	50	80	80	90	60	50	80
Rb	bdl	bdl	60	20	20	bdl	120	160	160
S	530	60	80	1730	90	300	70	90	60
Sr	10	10	20	40	50	bdl	30	20	30
Th	40	40	40	50	130	30	50	60	60
Tl	10	bdl	10	bdl	bdl	10	bdl	bdl	bdl
Y	bdl	20	10	20	10	20	20	20	20
Zn	30	60	10	30	20	150	10	bdl	10
Zr	350	210	140	710	440	290	210	240	160

TABLE 5: THE MINERAL COMPOSITION OF CLAY BESTARI JAYA

Sample	Minerals	%
BJ1	Kaolinite	97.7
	Anatase	2.3
BJ2	Kaolinite	81.2
	Quartz	18.8
BJ3	Kaolinite	80.5
	Muscovite	6.6
	Diaspore	6.5
	Quartz	6.4
BJ4	Kaolinite	84.4
	Quartz	15.6
BJ5	Kaolinite	94.7
	Quartz	5.3
BJ6	Kaolinite	91.4
	Hematite	6.9
	Magnetite	1.7
BJ7	Kaolinite	65.2
	Quartz	20.6
	Muscovite	14.2
BJ8	Kaolinite	70.4
	Muscovite	21.2
	Quartz	8.4
BJ9	Kaolinite	65
	Quartz	19
	Muscovite	16

V. CONCLUSION

Most of clay resources are used extensively in papermaking, ceramic, rubber, paint, plastic and pharmaceutical. However, the industrial use of clays is ruled by specific properties for each technological application. These properties depend on four important factors: (i) The geological conditions of the deposits, (ii) Clays mineralogical and geochemical composition, (iii) Clays crystal order, and (iv) Clays physical properties (colour and firing performance).

Based on the study, it can be concluded that the clay resources from the Bestari Jaya can be considered as inhomogeneous and suitably classified as medium grade raw material. The large range application of this resources for industrial use may potentially effective if adequate beneficiation advancement such as particle separation and chemical bleaching is commencing.

The investigation has confirmed that the clays from the studied area is kaolinite type with small amount of quartz, muscovite and localized concentration of impurities. The particle size of the Bestari Jaya clays not fall within the required range of paper coating specifications. Even the brightness value is detected within ranges of 51.32-73.49% which is below than paper coating requirements. The main mineralogical phases are kaolinite and the tested samples can categorized specifically into fine kaolin, sandy kaolin and quartzose sandy kaolin.

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