

EVALUATION OF KATTHA BAUXITES FOR INDUSTRIAL UTILIZATION

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Abstract. Attempts have been made to evaluate twenty representative bauxite samples of the Kattha area and their chemical, mineralogical and physical properties such as bulk density, shrinkage after firing, thermal expansion and pyrometric cone equivalent were determined. Silica and alumina contents of bauxites vary from 7.5 to 42% and 37.6 to 75.45% respectively. Most of the samples are rich in boehmite while a few contain considerable amount of kaolinite. The bauxites may be utilized for the production of alumina and aluminous chemicals, low and high grade refractories, high alumina cement, abrasives and in the purification of oils, waxes and petroleum.

Large deposits of bauxites and bauxitic clays are available in Kattha area, which is situated a few miles north of Kattha village and about 16 miles north of Khushab, District Sargodha. The bauxites are generally monohydrated (boehmite) in character, but appreciable amount of kaolinite is also found associated in some bauxites. This deposit is the best source of bauxites in the country and the tonnage is estimated to be in the range of 60 millions.¹

The objective of the present studies is to evaluate the bauxite resources for the important industrial utilization so that import could be cut short and thus Pakistan's independent self-reliant economy could be established by using potential resources of the domestic raw-materials.

Industrial Utilization. Alum, alumina, aluminous chemicals and aluminium metal are the products which find utility in many other important industries such as paper, textile, water purification, refractories, aluminous products and for making pharmaceuticals and alloys. Bayer's and acid processes are generally practised for the production of the above-mentioned aluminous products. Both the above processes may be utilized for the extraction of alumina from the ore after certain modifications.

High alumina refractories intended for use at high temperature are manufactured by precalcining the bauxite and are employed in industries such as iron and steel, cement, glass and ceramics. These basic industries are significant and are directly related to the economy of the country.

Abrasives are the back-bone of many other industries. Artificially prepared abrasives such as electrocorundum (pure alumina) and regular electrocorundum (impure alumina) are used in industries such as grinding wheels (rubbing bricks, honning sticks), paper and belts, which are further utilized in iron and steel and many other important industries as well. The abrasives are manufactured by the calcination and fusion cast processes.

High alumina cement is an important refractory material used in producing high alumina products such as tubes, muffles and kiln furniture etc. This is also used at various places where severe high temperature repairs are needed. Fusion of available bauxites with domestic limestone can be carried out to produce this cement.

These available bauxites can be commercially exploited for the production of alum, alumina, aluminous chemicals, low and high grade refractories, abrasives, high alumina cement and in the purification of mineral and vegetable oils and in the petroleum refining.

Experimental

Chemical Analysis. Bauxite samples were analysed according to standard methods (Table 1).²

Petrographic Studies. Some representative bauxite samples fired at 1300 and 1500°C were made into thin sections³ and examined petrographically.

Differential Thermal Analysis. All the samples were ground to -100 mesh, dried at 65°C for 15 hr and then subjected to the DTA technique raising the temperature of the furnace at a constant rate of 10°C/min.⁴ The results are shown in Figs. 1, 2 and 3.

X-Ray Powder Diffraction. Sample No. 6 and 21 were subjected to X-ray powder diffraction technique using a 10-cm camera and Ni-filtered CuK α radiation with 40 kV and current of 21 mA. The d values and their intensities obtained were compared with the standard⁵ d values of the bauxite minerals (Table 2)

Specific Gravity. The specific gravity of the raw and fired bauxite samples was determined by the conventional method (Table 3).

Acid Solubility. Bauxite sample Nos. 2, 6, 8, 13, 14, 15, 17 and 18 were ground to pass -120 mesh sieve and digested with 1:1 H₂SO₄ for 60 min to see their solubility for the production of alumina, aluminium metal and aluminous chemicals.

Porosity and Bulk Density. Bauxite powder (-100 mesh) moistened with dextrin solution in water was pressed into pellets by a hand press. The pellets were dried, fired at 1200, 1400 and 1500°C and their porosity and bulk density were determined by standard methods (Table 3).⁶

Shrinkage and Change in Colour after Firing. Bauxite powder (-100 mesh) was mixed with dextrin solution and rods 4 in long and $\frac{1}{4}$ in radius were prepared in plaster of Paris moulds. The rods were dried and successively fired at 1200, 1300, 1400 and 1500°C and their linear shrinkage was measured (Table 3). The change in colour of the fired products was also recorded (Table 4).

Pyrometric Cone Equivalent. The pyrometric cone equivalent of bauxite samples was determined by standard method.⁷ Oxygen was introduced into the furnace when it had attained the maximum temperature (Table 1).

Thermal Expansion. The linear thermal expansion of the bauxite rods 4 in long and $\frac{1}{8}$ in dia was determined at 1000°C by using standard⁸ horizontal British-made dilatometer (Table 1).

Results and Discussion

The chemical composition of the bauxite samples varies considerably (Table 1). Sample Nos. 1-3, 13, 13A, 14, 15, 21, 22, 22B, 23 and 25 are good bauxites having alumina and silica in the range of 60-75 and 7.50-19.26% respectively. Sample Nos. 6, 11, 12, 18 and 24 are medium grade bauxites containing 44.57-56.15% alumina and 14.20% silica while sample Nos. 8, 16 and 17 are simply bauxitic clays as they contain only 37.62-40.24% alumina and 19.2-40.6% silica. Iron is in the range of 1-1.60% in eleven sample Nos. 2, 8, 13, 13A, 14, 15, 21, 22, 22B, 23 and 25. Three bauxites bearing Nos. 1, 3 and 6 have acceptable iron contents from 2 to 3% while samples 11, 12, 16, 17, 18 and 24 have exceptionally higher iron contents in the range of 4.28-8.75%. Titanium is found to be between 1-3% while calcium and magnesium contents are very low in all the samples. Sample Nos. 17 and 18 also contain 1.98-2.2% Na₂O, 0.15-0.28% K₂O and 6.17-6.86% SO₃ while sample No. 3 has only 0.41% alkalis and 0.62% SO₃.

According to Mackenzie⁹ boehmite, gibbsite and dickite give a single endothermic peak between 510-580°C, 260-380°C and 650-700°C respectively. The endothermic peak at 530-560°C and another smaller exothermic peak at 920-960°C are characteristics of kaolinite. As the important endothermic reactions for both boehmite and kaolinite are in the similar temperature range, sometimes a single peak represents the presence of both the minerals in some mixtures while two separate and distinct peaks are observed for these two minerals in others.⁹

The experimental DTA curves (Figs. 1, 2 and 3) show that sample Nos. 12, 13, 13A, 14, 21 and 22 contain the mineral boehmite only. The occurrence of a sharp endothermic peak between 530-600°C and a small exothermic peak between 930-960°C in sample Nos. 1, 2, 3, 6, 8, 11, 16, 23, 24 and 25 show the presence of kaolinite in addition to boehmite. The endothermic reaction at 730, 740 and 770°C in sample Nos. 3, 17 and 18 respectively show the presence of natroalunite as well.¹⁰ This fact is supported by the presence of Na₂O and SO₃ contents in these samples (Table 1). The endotherms at 530 and 655°C in sample No. 15 show the presence of boehmite with a very small amount of dickite. A small endothermic peak in the range of 260-310°C in sample Nos. 1, 11, 18 and 24 also shows the presence of a small amount of gibbsite.

The X-ray powder diffraction results are presented in Table 2. The d values obtained for sample Nos. 6 and 21 were compared with the standard d values of boehmite, kaolinite, dickite, diaspore and gibbsite. It may be found that the intensity of line 7.20 is

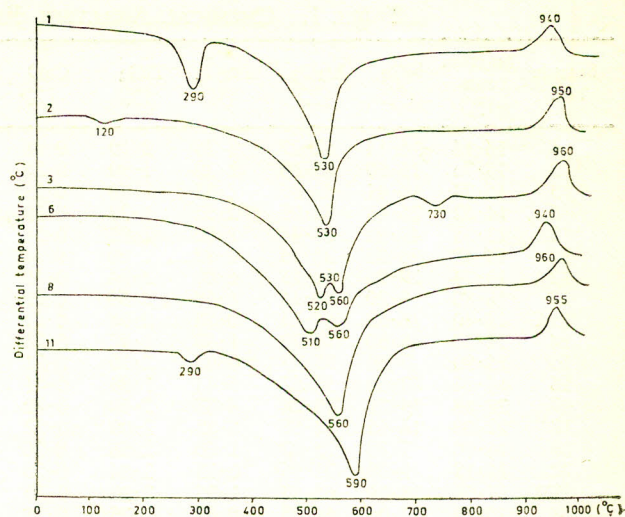


Fig. 1. Increasing temperature.

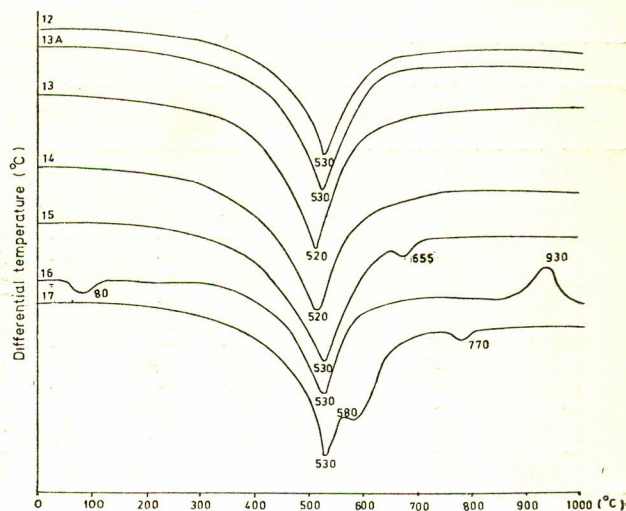


Fig. 2. Increasing temperature.

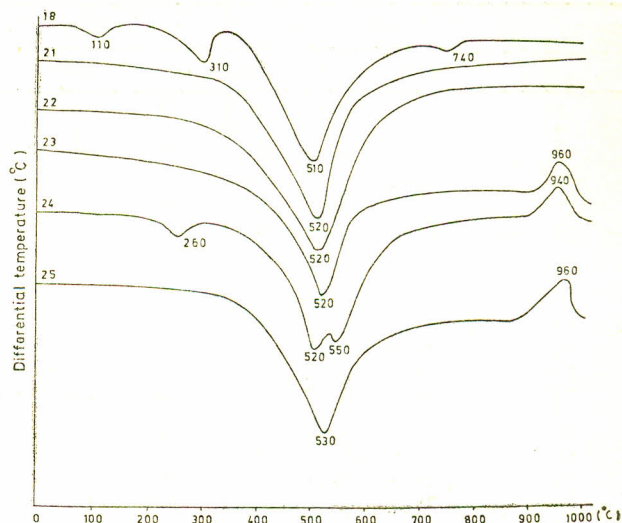


Fig. 3. Increasing temperature.

TABLE 1. CHEMICAL ANALYSES, REFRACTORINESS AND THERMAL EXPANSION.

Sample No.	Ignition loss (%)	SiO ₂ (%)	Al ₂ O ₃ (%)	Fe ₂ O ₃ (%)	TiO ₂ (%)	CaO (%)	MgO (%)	Na ₂ O (%)	K ₂ O (%)	SO ₃ (%)	Refractoriness (°C)	Thermal expansion % at 1000°C
1	16.14	16.14	62.27	2.76	2.10	0.41	Tr	—	—	—	1700	0.569
2	13.76	16.90	65.80	1.30	1.90	0.26	0.12	—	—	—	1780	0.637
3	15.24	19.44	59.85	2.35	1.80	0.23	Tr	0.35	0.15	0.62	1680	0.656
6	14.62	26.48	54.05	2.52	1.33	0.39	0.08	—	—	—	1700	0.606
8	13.38	41.93	39.48	1.60	2.92	0.54	0.10	—	—	—	1650	0.498
11	14.48	30.01	48.35	4.85	2.00	0.41	Tr	—	—	—	1680	—
12	13.74	20.06	56.15	6.80	3.04	0.19	Tr	—	—	—	1700	0.610
13	16.80	9.20	69.15	1.50	2.90	0.22	Tr	—	—	—	1760	—
13A	14.40	16.52	66.14	0.78	2.08	0.21	0.10	—	—	—	1780	0.643
14	14.50	8.60	73.70	1.40	2.42	0.28	0.05	—	—	—	1815	—
15	13.90	7.50	75.45	0.65	2.10	0.21	Tr	—	—	—	1830	—
16	14.14	40.60	37.62	5.43	1.60	0.41	0.32	—	—	—	1610	—
17	24.58	19.21	40.24	4.37	2.60	0.40	0.10	2.20	0.15	6.86	1500	—
18	22.00	14.15	44.57	8.75	2.00	0.22	0.05	—	—	—	1530	—
21	14.00	7.80	73.02	1.00	2.88	0.30	Tr	—	—	—	1800	—
22	14.18	9.70	71.96	0.75	3.04	0.20	0.21	—	—	—	1800	0.675
22B	14.50	13.00	67.87	1.35	2.98	0.20	0.80	—	—	—	1780	—
23	15.70	17.00	64.38	0.87	1.75	0.21	Tr	—	—	—	1760	—
24	17.22	24.16	21.37	4.28	2.10	0.44	0.11	—	—	—	1680	—
25	16.00	19.26	60.84	1.36	2.30	0.12	Tr	—	—	—	1750	—

Tr, traces

TABLE 2. X-RAY DIFFRACTION DATA.

Sample No. 6		Sample No. 21		Boehmite		Kaolin		Dickite		Diaspore		Gibbsite	
d Values	Intensity	d Values	Intensity	d Values	Intensity	d Values	Intensity	d Values	Intensity	d Values	Intensity	d Values	Intensity
7.20	M	7.25	VW	—	—	7.25	S	7.25	VVS	—	—	—	—
6.15	M	6.15	S	6.12	VS	—	—	—	—	—	—	—	—
4.48	W	—	—	—	—	4.48	M	4.44	M	4.7	VW	4.85	VS
4.21	W	—	—	—	—	4.23	M	4.17	M	—	—	4.37	S
3.59	M	3.56	W	—	—	3.59	S	3.6	VVS	—	VS	—	—
3.17	W	3.17	S	3.16	S	—	—	—	—	3.21	VW	3.19	VW
2.501	W	2.501	W	—	—	2.501	M	—	—	—	—	2.46	S
2.344	M	2.35	S	2.355	S	2.344	M	—	—	—	—	—	—
2.298	VW	—	—	—	—	2.298	W	—	—	2.31	S	—	—
1.989	VW	1.989	W	1.977	W	1.993	W	—	—	2.13	M	2.29	VW
1.895	VW	1.895	VW	—	—	1.895	VW	—	—	—	—	1.917	W
—	—	1.866	S	1.859	S	—	—	—	—	—	—	—	—
1.852	VW	1.852	S	1.845	S	—	—	—	—	—	—	—	—
—	—	1.774	W	1.766	W	—	—	1.801	M	1.71	M	1.80	M
1.669	VW	1.666	M	1.660	M	1.669	W	1.6556	W	1.635	S	1.75	M

M, medium; W, weak; VW, very weak; S, strong; VS, very strong; VVS, very much strong.

TABLE 3

Sample No.	Specific gravity			Shrinkage (%)				Bulk density (g/ml)			Porosity		
	Raw	1200°C	1500°C	1200°C	1300°C	1400°C	1500°C	1200°C	1400°C	1500°C	1200°C	1400°C	1500°C
1	2.82	3.21	2.70	6	8	10	15	1.72	1.89	2.01	38.5	32.5	29.8
2	2.80	3.19	3.56	7	9	10	13	1.80	1.92	2.0	36.5	34.1	32.0
3	2.80	3.18	3.00	6	7	8	10	1.92	2.03	2.10	32.5	28.4	24.3
6	2.70	3.01	3.20	8	9	12	13	1.88	2.10	2.18	29.3	24.4	22.1
8	2.62	2.89	3.25	6	10	12	18	1.93	2.08	2.20	27.2	22.2	20.8
11	2.72	3.00	2.78	12	13	—	—	1.99	2.25	2.28	25.4	21.1	19.2
12	2.73	3.01	2.96	14	15	—	—	1.98	2.12	2.16	26.3	22.5	21.0
13	2.82	3.20	3.81	6	8	9	11	1.77	1.85	2.01	42.1	37.8	34.6
13A	2.83	3.19	3.76	7	8	10	11	1.81	1.94	2.10	39.0	35.0	32.4
14	2.99	3.48	3.84	8	9	11	12	1.70	1.79	2.00	43.2	39.7	35.6
15	3.00	3.49	3.86	6	8	9	11	1.70	1.76	2.10	44.3	41.3	37.4
16	2.62	2.89	2.71	12	14	—	—	—	—	—	—	—	—
17	2.71	3.02	2.89	13	14	—	—	1.98	2.17	2.20	26.9	23.9	22.1
18	2.72	3.00	2.80	—	—	—	—	—	—	—	—	—	—
21	2.99	3.59	3.84	6	7	9	10	1.72	1.78	2.00	45.0	40.4	36.9
22	2.88	3.31	3.88	6	8	9	12	1.73	1.80	2.10	42.5	38.8	36.2
22B	2.81	3.20	3.59	7	8	10	12	1.79	1.84	2.01	39.2	35.65	32.8
23	2.80	3.19	3.51	7	8	9	13	1.75	1.91	2.00	39.2	34.0	32.0
24	2.72	3.01	2.79	13	16	—	—	1.97	2.12	2.18	26.9	23.8	22.10
25	2.80	3.20	3.23	6	8	9	15	1.88	1.97	2.01	32.4	28.8	24.3

medium in No. 6 but it is very weak in line 7.25 in No. 21. Line 7.25 is fairly strong in kaolinite but is very strong in dickite. Another reflection line 3.59 gives medium, weak, strong and very strong intensity in Nos. 6, 21 and pure kaolinite and dickite samples respectively. It may be concluded from here that sample No. 6 containing about 57% clay should have given at least half the intensity of the pure dickite. So the bauxite samples contain kaolinite and not dickite as was also confirmed earlier by Faruqi¹¹ and Chohan *et al.*¹²

Pure boehmite has a very strong intensity at line 6.12 and strong intensities at lines, 3.16, 2.355 and 1.845. The intensity of the corresponding lines is strong in No. 21 while it is from medium to very weak in No. 6. This shows that sample No. 21 contains a large amount of boehmite while sample No. 6 contains a small amount of this mineral. Diaspore and gibbsite are found only in very small amounts.

Sample Nos. 1, 2, 11, 13A, 14, 15, 18, 21 and 22 were subjected to 1:1 H₂SO₄-treatment and the results obtained show that over 60% alumina is soluble while soluble iron content is only in the range of 0.50–1.0% with the exception of No. 18 which has up to 1.8% acid-soluble iron. Bayer's and acid processes are generally employed for the production of alumina and aluminium from bauxite. Both the processes may be employed here for this purpose according to the quality of bauxites. Acid process has got advantages over the Bayer's process in that poor bauxites and even clays¹³ may be used as a source for the production of alum, alumina and many important aluminous chemicals.

The specific gravity data (Table 3) show that the specific gravity of the bauxite samples fired at 1100°C varies from 3.01 to 3.59. Further firing of the samples at 1500°C, however, results in a decrease in the specific gravity of a few samples while it increases in most of the samples. Since the specific gravity of mullite is less than alumina, the decrease in specific gravity of sample Nos. 3, 11, 12, 16–18 and 24 having higher iron contents and samples Nos. 17 and 18 having 2.21–2.35% alkalis as well may be attributed to the formation of mullite at a considerably lower temperature. The increase in the specific gravity of the remaining samples containing high alumina is due to sintering. Mullite will also be formed in the rest of bauxites when fired at higher temperatures.

The low shrinkage, low porosity and high bulk density are the desirable ceramic properties of bauxite. It may be observed from Table 3 that sample Nos. 2, 13, 13A, 14, 21, 22, 22B, 23 containing high alumina and low silica and iron contents have low shrinkage, low bulk density and high porosity, whereas it is otherwise in bauxite numbering 1, 3, 6, 8, 11, 12, 16–18 and 24 with low alumina and high silica and iron contents at the same temperature. The lowest shrinkage and porosity of the bauxites after firing at 1400°C are 8–9 and 21% respectively, and the highest bulk density is 2.25 g/ml. After firing at 1500°C, the shrinkage and bulk density increase to 10% and 2.28 g/ml respectively while porosity reduces to 19.2%. Some high alumina bauxites with low iron contents have high porosity and low bulk density even at

TABLE 4. COLOUR OF THE BAUXITE SAMPLES.

Sample	Original	Samples fired (°C)		
		1000	1300	1500
1	Light yellow	Light brown	Brown	Dark brown
2	Light grey	Pinkish white	Dirty white	White
3	Light yellow	Yellow	Brown	Brown
6	Light brown	Brown	Dark brown	Very dark brown
8	Greyish white	Light yellowish	White	White
11	Light brown	Biscuit	Brown	Dark brown
12	Reddish brown	Brown	Dark brown	Black
13	Pinkish white	White	White	White
13A	Light grey	"	"	"
14	Pinkish white	Light cream	Cream	Cream
15	Cream	Pinkish white	White	White
16	Light brown	Brown	Dark brown	Black
17	Reddish brown	"	"	"
18	Light brown	"	"	"
21	Light grey	Dirty white	White	White
22B	Light pink	"	"	"
24	Yellowish cream	Biscuit	Light cream	Dark brown
25	Cream	Dirty white	White	Yellowish white

1500°C. These samples may be fired at some appropriately higher temperature after adding some mineralisers such as iron oxide, sodium fluoride, sodium silicate, sodium triphosphate, phosphoric acid which act as a flux without producing the adverse effect on the properties of the material.

The change in colour of the bauxite samples fired to various temperatures up to 1500°C is given in Table 4. It is clear from this table that sample Nos. 1, 6, 11, 16, 17 and 24 have undergone a great change in colour from light brown, through brown to dark brown and in some cases to black (Nos. 12, 16–18). Sample Nos. 2, 13, 13A, 14, 15, 21, 22, 22B, 23 and 25 are suitable specially for producing high temperature goods where colour is also important.

It may be seen from Table 1 that the highest refractoriness (pyrometric cone equivalent) is 1830°C and the lowest is 1520°C. Sample Nos. 1, 2, 6, 12, 13, 13A, 14, 15, 21, 22, 22B, 23 and 25 have refractoriness between 1700 and 1830°C and samples 3, 8, 16 and 24 have refractoriness between 1610 and 1680°C. Sample Nos. 17 and 18 which contain large amounts of iron (4–8.75%) and more than 2% alkalis have as low refractoriness as 1500–1530°C. With the exception of sample Nos. 17 and 18 the rest of the bauxites may be utilized in the manufacture of high grade and medium grade refractories.

The thermal expansion results of the representative samples fired to 1000°C show (Table 1) a uniform linear expansion up to 1000°C which reveals the absence of free silica in the bauxites. It is clear from the results that most of the bauxites are suitable to be used for the manufacture of high grade refractories.

The samples fired to 1300 and 1500°C were studied under the microscope. It was observed that the samples fired to 1300°C did not show any significant

mineralogical change. However, sample Nos. 15, 18, 22B and 25 fired to 1500°C showed that a new phase of alumino-silicate (mullite) had developed. Less mullite and glass were seen to have developed in sample Nos. 15, 22B and 25 due to less iron content. However, sample No. 18 shows a large amount of mullite. This may be due to high iron content which has lowered the maturing temperature of the bauxite. The formation of mullite in sample No. 18 might have possibly started over 1200°C and completed between 1300–1350°C. The iron contents were found to have changed into magnetite.

Bauxites containing up to 10% silica and less than 3% iron are useful¹⁴ for the production of alum, alumina and aluminous chemicals. However, bauxites containing higher silica and iron contents can also be utilised provided that the silica and alumina ratio is more than 1:3. So, bauxites numbering 1–3, 13, 13A, 14, 15, 21, 22, 22B, 23 and 25 can be utilised for this purpose.

According to Bracewell¹⁵ bauxites containing 6–11% silica, less than 2.7% Fe₂O₃ and up to 3% TiO₂ are most desirable in the manufacture of refractories but bauxites containing at least 58% alumina and low iron contents are usually used for this purpose. Accordingly sample Nos. 2, 13, 13A, 14, 15, 21, 22, 22B, 23 and 25 can be used for manufacturing high temperature refractories.

High alumina cement normally contains from 30–70% of alumina. The method of manufacturing this cement depends upon the amount of iron present in bauxites. Usually bauxites containing 10% silica and up to 20–30% Fe₂O₃ may be used in the manufacture of this cement.¹⁵ On this basis sample Nos. 13–15, 21, 22 and 22B can be used for manufacturing this cement.

Gibbsitic and boehmitic bauxites containing not less than 55% Al₂O₃, less than 5% SiO₂, 6% Fe₂O₃ and 2–3% TiO₂ before calcination, should be used in the manufacture of abrasives but bauxites containing less than 50% Al₂O₃ and more than 10% SiO₂ or 15% Fe₂O₃ are often used. Hence sample Nos. 1, 2, 13, 13A, 14, 15, 21, 22, 22B, 23 and 25 can be used in this industry.

Low iron containing gibbsitic-bauxites partially calcined at 450°C are usually preferred to boehmitic bauxites in the purification of oils, waxes and petroleum. Though boehmitic bauxites are less effective than gibbsitic ones, their use cannot be denied because the gibbsitic bauxites are also finally converted into the useful crystalline form of alumina (γ-alumina) after passing through a monohydrated stage.¹⁵ So, sample Nos. 2, 13, 13A, 14, 15, 21, 22B, 22, 23 and 25 may be employed in this industry.

Conclusions

Most of the samples are good bauxites containing high per centage of alumina (60–75%) with the exception of a few which are poor grade bauxitic clays.

Mineralogically, most of the samples contain boehmite as the main mineral with a small amount of kaolinite. Some bauxites are rich in kaolinite and poor in boehmite.

Most of the investigated bauxites are suitable to be utilised in the production of alum, alumina, aluminous chemicals, high temperature refractories, high alumina cement and abrasives. They may also be used in the decolorisation of oils and waxes and petroleum refining after partial calcination at 450°C.

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