Beneficiation of Low-Grade Bauxite: A Case Study of Lateritic Bauxite of India

P. G. Bhukte, G. T. Daware, S. P. Masurkar, M. J. Chaddha, and Anupam Agnihotri

Abstract Lateritic bauxite are the products of intense subaerial weathering of alumina rich rocks. The resources of bauxite in India are in the order of 3850 million tones and occupy 5th position in World map. The occurrences of Laterite are widespread in various regions. The bauxite deposits/occurrences are, however, mainly located in the Eastern Ghat, Central India, West coast and Gujarat state. Bauxite deposits consist of four horizons namely Duricrust (Laterite), Bauxite, Saprolite (weathered) and parent rock. The base (parent) rock is responsible for the formation of bauxite profile and characteristics of bauxite ore varies depending on rock composition. JNARDDC has evaluated bauxite and laterite deposits of India from geology, mining, beneficiation and metallurgical point of view. The bauxite mines/deposits are associated with various low-grade materials and it remains unutilized at mine site due to their inferior composition. For utilization of these low-grade materials, quality of the same has to be improved. Keeping in view the improvement in quality of low-grade materials, beneficiation studies have been carried out at JNARDDC. The studies carried out on laterite (ferruginous, aluminous, siliceous) and low-grade bauxite indicated that the ore can be upgraded with relevance to reduction in iron oxide, silica and enrichment in alumina content. At present, India is importing raw materials required for non-metallurgical applications (refractory, abrasives and chemical, etc.). The beneficiation studies have shown great promise to be developed as a substitute for the applications requiring high-grade ores. This will have a significant effect on the life of bauxite mines as well as dwindling natural resources.

Keywords Bauxite · Laterite · Beneficiation

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1 Introduction

The bauxite is the principal ore for the production of alumina/aluminium. The bauxite deposits are formed by intense subaerial weathering of alumina rich rock. The chemical, mineralogical and physico-mechanical properties of these bauxite widely vary depending upon the parent rock composition, mode of origin, geomorphological position, duration and age of bauxite formation. About 80% resources of bauxite in the Country are gibbsitic in nature however, occurrences of Laterite and low-grade bauxite are widespread in various parts of the country. During the process of bauxitisation, laterite/bauxite profile formed which comprises usually four horizons resting on the parent rock [1, 2]. The laterite is uppermost part, consists of hard material and dominated by ferruginous, aluminous and siliceous minerals. The thickness of laterite in profile is usually 0.5–4 m and varies from deposit to deposit. Bauxite thickness varies from 0.5 to 14 m. A transition zone (saprolite, PLK) is formed below the bauxite zone and is composed of silica and alumina bearing minerals. In most of the bauxite deposits of India, the bauxite rests on saprolite zone. In general, the thickness of saprolite zone is from 0.5 to 10 m and largely varies from deposit to deposit [3]. During the exploration/ mining of bauxite deposits, the low-grade materials (laterite, low grade bauxite, saprolite, partially lateritised khondalite) is unutilized due to their inferior composition. The optimum use of Country's resources of unutilized raw material associated with bauxite mines requires proper technical data and information in order to establish their suitability for industrial uses. In present scenario, high quality bauxite, suitable for non-metallurgical industries are fast exhausting in the country. The research work carried out at JNARDDC will facilitate in improvement of the quality of low-grade ores (laterite and low-grade bauxite) by using various beneficiation techniques proposed here.

2 Waste Generated at Bauxite Mine

During the bauxite mining, various low-grade materials such as laterite, saprolite, low grade bauxite, PLK (Partially Lateritized Khondalite/parent rocks) are generated however, these are discarded off due to their inferior composition. These materials have characteristics of low alumina, high silica and iron oxide content. Due to this inferior quality, these materials could not be used for alumina production or other industrial applications hence, remain unutilized at mine site. During the mining, protection of forest cover, top soil, OB Laterite, etc. is important for the healthy environment and sustainable development of the region [4].

3 Transforming Unutilized Materials (Mine Waste) into Resource

The mining sector is one of the important sectors that contribute to the national economy. The increasing demand for metal and minerals from various industry are expected to drive the market and the Asia Pacific region is projected to lead the mining waste management market. In World scenario China, Australia, Kazakhstan and India are the main countries contributing to the mining waste management market [5]. Keeping in view the optimum use of Country's resources of unutilized raw material associated with bauxite mines requires proper data and information in order to establish their suitability for industrial uses. In present scenario, day by day the resources which are suitable for non-metallurgical industries are exhausting and country is importing the high-grade bauxite. The National Mineral Policy (NMP-2019) has emphasized utilization of small group of deposits along with mineral wealth. The occurrences and isolated deposits of bauxite and laterite are scattered all over the Country and available for economic extraction of mineral values.

4 Scenario of Bauxite Deposits

The world production of bauxite estimated at 327 million tones. Australia continued to be the major producer and accounted for about 28% share in total production, followed by China (24%), Guinea (20%), Brazil (9%), India (7%) and Indonesia, Jamaica (3%) [6–9].

Country	Australia	China	Guinea	Brazil	India	Indonesia	Jamaica
Production (M.T)	96.00	79.00	66.18	29.00	23.68	11.00	10.10

In India consumption of non-metallurgical grade bauxite is about 8%. Cement sector is contributed about 40% followed by refractory, chemical, steel, ferro alloys, abrasive, etc. Gujarat State is the main supplier of abrasive and refractory grade bauxite. In current scenario, the proved reserves of high-grade bauxite, suitable for non-metallurgical industries (refractory, abrasive, chemical) are limited however, the large resources of metallurgical grade gibbsitic bauxite is available in east coast region. The high alumina, low iron and titania bauxite occur only in parts of Gujarat, Chhattisgarh, Maharashtra, Jharkhand and with scattered and scanty deposits in part of eastern and western region. Gujarat state is well known for high alumina bauxite suitable for non-metallurgical applications however, most of the deposits are already exhausted. Some of the high-grade bauxite deposits located in Central India are not accessible due to forest and tribal problems. On the other hand, vast good quality bauxite reserves located in eastern Ghat and coastal region, suitable for metallurgical industry, are mostly lying unused. The scarcity of high-grade bauxite in the Country can partly be resolved by making available these deposits for non-metallurgical industries and also encourage existing mines, to separate out value-added high-grade ore [10].

5 Beneficiation

The objective is to reduce iron oxide and silica content and enrichment of alumina in low grade ore for improvement in the quality.

5.1 Sampling and Characterization

For the present study, the representative samples of laterite and low-grade bauxite were collected from bauxite deposits located in West coast and east coast deposits of India. In west coast (Maharashtra) deposits, the thickness of bauxite is 2.5 m (avg). It is pisolitic in nature and contains moderate to high alumina as well as low silica [11, 12]. The weathered rock zone (saprolite) is placed below the bauxite zone which is soft in nature and cream, white, grey in colour. The laterite (overburden) occurs above the bauxite zone and it is hard, massive in nature with red, pink, and grey in colour (Fig. 1a).

The samples were crushed to −25 mm size by Jaw crusher. For the characterization studies, −74 μ size samples have been prepared by universal mill/ bond mill and thoroughly mixed using homogenizer. The representative sample was drawn by coning and quartering procedure. The chemical and mineralogical analysis of samples has been done by wet chemical method and XRD with XDB software respectively. Laterite is characterized by high iron oxide (20–45%), silica (6–15%) and low alumina (25–35%) content however, low grade bauxite is characterized by quite low alumina, low iron oxide as compared to laterite. Mineralogical analysis by XRD shows that laterite and low-grade bauxite is characterized by hematite, goethite, kaolinite and gibbsite minerals. The petrology studies indicate that laterite is pisolitic and iron minerals exhibit colloform texture. The gibbsites are cryptocrystalline and pseudomorph after plagioclase feldspars (Fig. 1b, c). The morphology studies indicated that laterite contains undeveloped crystals of gibbsite and in some laterites, it is hexagonal in shape (Fig. 1d). Our studies reveal that in most of the laterite deposits, the gibbsite is not well developed due to partial bauxitization [13]. It is observed that habit of minerals, crystal shape, etc. are not prominent in low grade ores as compared to bauxite ore [14].

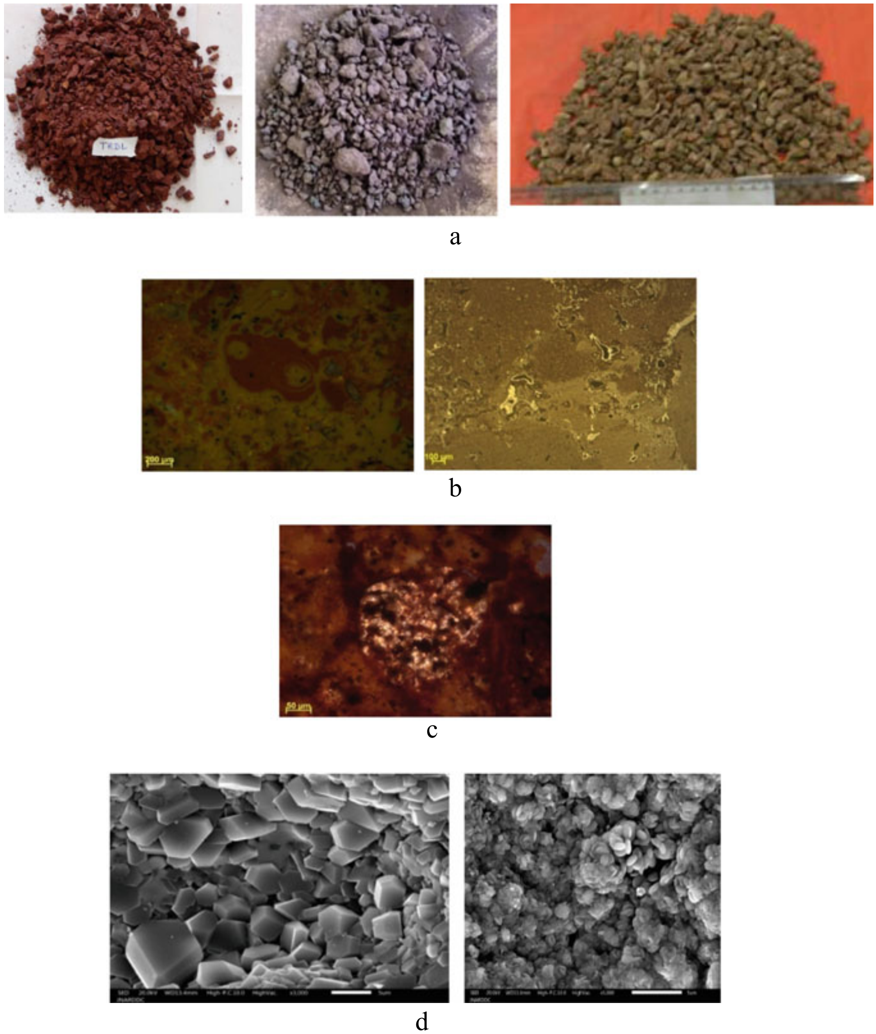

Fig. 1 **a**. Physical appearance of Laterite samples, **b**. Pisolitic texture with iron phase in Laterite, **c**. Gibbsite phase (cryptocrystalline) in low grade bauxite, **d**. Morphology of low-grade bauxite and Laterite by SEM

5.2 Beneficiation/Upgradation Studies on Laterite and Low-Grade Bauxite

The abundant resources of low-grade bauxite and laterite are characterized by high iron oxide, silica and low alumina content which restrict their use in metallurgical as well as non-metallurgical applications. Thus, any beneficiation process which can reduce silica (mainly in reactive form such as kaolinite) and iron content in bauxite and laterite, are important from processing point of view. The studies have been done by organizations/industry on beneficiation on low grade bauxite mainly for removal of impurities such as iron oxide, silica [15]. JNARDDC has done extensive studies on bauxite and laterite of various origin. Keeping in view to reduction in iron, silica and increase in alumina content, various physical beneficiation techniques such as screening, sieving, magnetic separation and hydrocyclone were adopted. The results of beneficiation studies showed that iron and silica content can be reduced from low grade bauxite and laterite [16]. The salient features and results obtained in physical beneficiation studies carried out on laterite and bauxite are given below.

5.3 Screening/Sieving

After exploration of ore, sampling of ore (sorting, braking, and screening) is important stage at mine site as well as in laboratory. Screening and sieving tests on laterite and bauxite samples from different geological origin have been carried out at JNARDDC laboratory. The clay agglomerates on the bauxite surface create lot of problems in the processing of ore. In general, its concentration in the ore is decreased by washing the ore followed by screening in which the agglomerates are detached and are removed with the action of water [17, 18]. The wet sieving has been carried out on western Ghat (Maharashtra) laterite. The sample crushed to required size (30 mm) and screened into 13 fractions namely +16, −16+11, −11+8, −8+4, −4+2, −2+1, −1+0.5, −0.5+0.25, −0.25+0.149, −0.149+0.074, −0.074+0.063, −0.063+0.045 and +0.045 mm by Anlysette vibrating screen for half an hour. The result clearly indicate that Al_2O_3 enriched above +2 mm size fraction and it increase proportional to the grain size. However, silica and iron oxide content gets enriched below −0.5 mm by wet sieving [19, 20]. The dry as well as wet sieving has been carried out on ferruginous bauxite (Panchpatmali mine). The ten different fractions clearly indicate that Al_2O_3 enriched above +2 mm size fraction and it increases proportional to the grain size. However, silica and iron content get enriched below –0.5 mm in dry screening though by wet sieving the same gets enriched below –0.063 mm (Fig. 2) [21]. The screening and sieving trials on laterite and bauxite samples of various geological origin indicated that iron content enriched in fine fractions however, increase in Al_2O_3 % particularly in coarse and middle fractions. It indicates that selective mining of a deposit can improves the overall quality of grade (ROM). The authors are in opinion that bauxite mines/deposits can be evaluated and ranked according to parameters such as bauxite resources, characteristics, present mining capacity, etc. however, quality of run of mine (ROM) and beneficiated ore are the major parameters [22]. Now a days, the said techniques are being adopted by mine owners located in Central India.

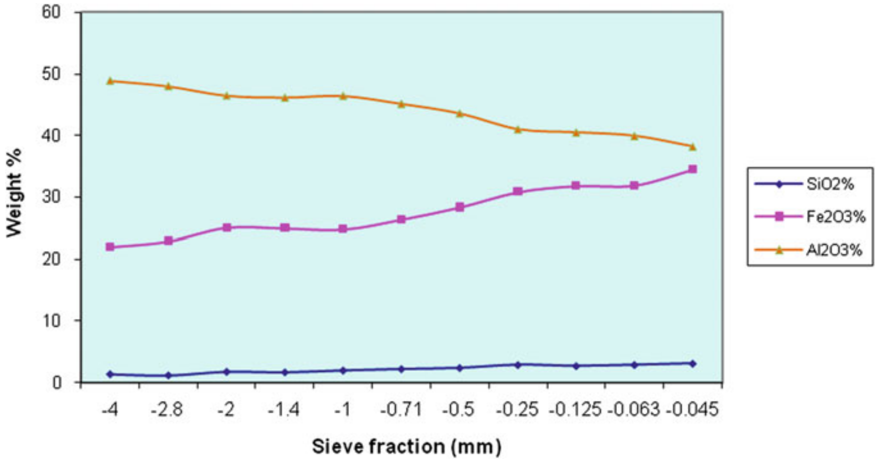

Fig. 2 Wet sieving of bauxite (East coast-Panchpatmali-Odisha)

5.4 De-Ironing Studies by Wet High Intensity Magnetic Separator (WHIMS)

One of the impurities in low grade ores associated with bauxite mine is high iron oxide content. The presence of high Fe_2O_3 content in ore would impact on generation of bauxite residue during alumina production. The non-metallurgical industries (refractory, abrasive, chemical) also require very less iron oxide content ($Fe_2O_3 <$ 3%). Keeping in view the reduction of iron oxide content, tests were carried out by using wet high intensity magnetic separator (WHIMS). The trials have been done on laterite and bauxite samples with various size such as −297, –149, −74 and −44 μ and different magnetic intensity (5000 to 19,800 gauss) with 20 and 30% solids. It is observed that as magnetic intensity increases, alumina content in the non-magnetic fraction increases and iron decreases with varying recovery of ore (non-magnetic fraction).

The de-ironing tests were carried out on ferruginous laterite of western Ghats (Maharashtra) and eastern Ghats deposit by WHIMS on 10000 gauss magnetic intensity and various micron size sample. The eastern Ghats laterite is aluminous in nature and contains quite high alumina and low iron oxide compared to Western Ghats laterite. The results indicate 10–18% reduction in iron oxide and 10–15% enrichment in alumina content in non-magnetic fraction of western Ghat laterite however, eastern Ghat laterite shows considerable reduction in iron oxide (10–25%) as well as increase in alumina content by using same magnetic intensity and feed size (Fig. 3). The recovery of ore after processing in western Ghat laterite (weight % of non-magnetic fraction) is 35% however, in case of eastern Ghat sample, the recovery is 47%. It is observed that with the same magnetic intensity and laterite size, the two kinds of laterite deposit show significant difference in ore and alumina recovery as

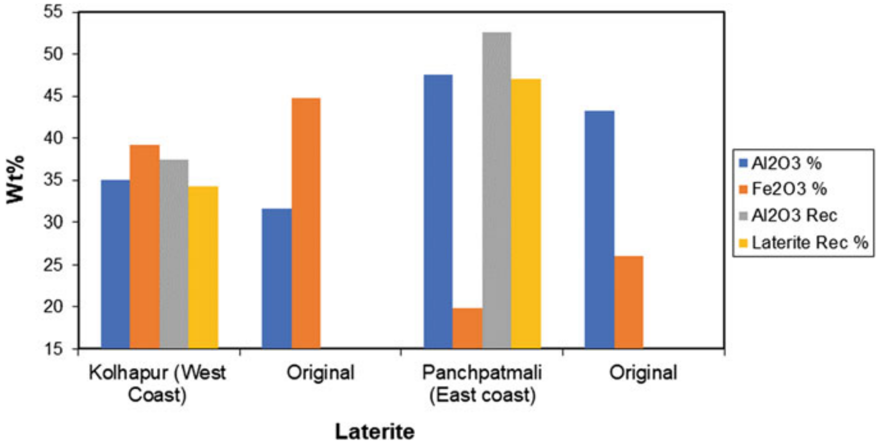

Fig. 3 De-ironing by WHIMS of laterite with 10000 gauss intensity and grain size (−297+149 μ)

well as reduction in iron content [23, 24]. The studies indicated that in beneficiation process (physical separation), magnetic intensity, grain size and ore characteristics of laterite play an important role.

5.5 Beneficiation of Blended Bauxite by WHIMS

An attempt has been done at JNARDDC to beneficiate various grades of overburden laterite (Panchpatmali deposit) such as ferruginous dark grey laterite, pink laterite, grey laterite and yellow laterite. The chemical composition of laterite and bauxite samples is given in (Table 1). The blended beneficiation experiments carried out at following parameters:

Sample composition :80% process bauxite and 20% ferruginous dark grey laterite
Magnetic intensity :6000, 7000 and 8000 gauss
Bauxite size :297 μ

Table 1 Chemical analysis of process bauxite, laterite and blended bauxite

Constituents (%)	Process bauxite	Ferruginous dark grey laterite	Blended bauxite
Al_2O_3	46.22	33.59	43.49
Fe_2O_3	23.10	39.14	27.28
SiO_2	3.13	4.43	3.48
TiO_2	1.90	2.04	2.11
LOI	24.70	19.25	22.47

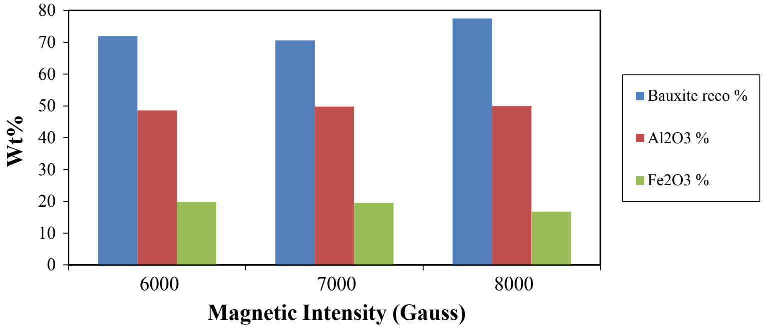

Fig. 4 De ironing of blended ore by WHIMS (−297 μ)

Bauxite quantity :50 gm
Slurry solids :30%

The tests carried out at different magnetic intensities indicate that quality of beneficiated bauxite as well as loss increases as magnetic intensity increases. However, bauxite quality in terms of alumina content is observed to be more or less same at 7000 and 8000 gauss magnetic intensity. The iron reduced in the range of 17–20% from original 27% and alumina enriched up to 50% (Fig. 4). The chemical and quantitative mineralogical composition of beneficiated bauxite (product) is presented in Tables 2 and 3 respectively. The results show that alumina loss increases with the increase in the magnetic intensities for all bauxite. The same trend is also observed with losses for iron, titania and silica bearing minerals. Not much change in losses is observed if the bauxite is ground to a finer size of 149 μ at 7000 and 8000 gauss magnetic intensity. Based on the experiments it is observed that magnetic intensity of 7000 gauss seems to be optimum for beneficiation of blended bauxite. Below 297 μ is satisfactory for beneficiation as well as for processing of the beneficiated bauxite for alumina production [25].

Table 2 Chemical composition of beneficiated product (bauxite)

Constituents (%)	Beneficiated product 1	Beneficiated product 2
Al_2O_3	49.42	48.06
Fe_2O_3	19.05	19.36
SiO_2	3.57	3.99
TiO_2	1.48	1.52
LOI	26.00	25.77

Table 3 Quantitative Mineralogical composition of beneficiated bauxite

Phases (in %)	Beneficiated product 1	Beneficiated product 2
Alumina as		
Gibbsite	44.12	43.46
Boehmite	0.85	0.42
Alumo-goethite	1.27	0.95
Kaolinite	2.76	2.76
Total	49.00	47.60
Silica as		
Kaolinite	3.26	3.26
Quartz	–	0.50
Total	3.26	3.76
Titania as		
Anatase	1.00	1.00
Rutile	–	–
Total	1.00	1.00
Iron as		
Hematite	8.00	10.00
Alumo-goethite	11.24	8.43
Siderite	–	0.34
Total	19.24	18.78

5.6 Separation Studies by Hydrocyclone Test Rig

The high amount of silica and iron oxide are the main impurities in low grade materials. For separation of impurities and upgradation of low-grade ores, study has been taken up on laterite and low-grade bauxite by using hydrocyclone test rig. The laterite sample (−297+149, −149+105 and −105+74 µ size) has been prepared for the present study. The experiments were conducted on various parameters such as solid %, pressure (psi), size of sample (micron), vortex finder (mm) and apex (mm). The results show significant enrichment of alumina (32–34%) from original 27% and reduction in iron oxide (30–24%) content from original 38% (Fig. 5). The overall recovery of laterite is in the range of 40–50%. The trials also show encouraging results with respect to reduction in SiO_2 content (9–11%) [16, 26].

5.7 Leaching Studies

The eastern Ghats and coast (Odisha & Andhra Pradesh) comprises more than 2000 million tons of metallurgical grade gibbsitic bauxite. It is characterized by

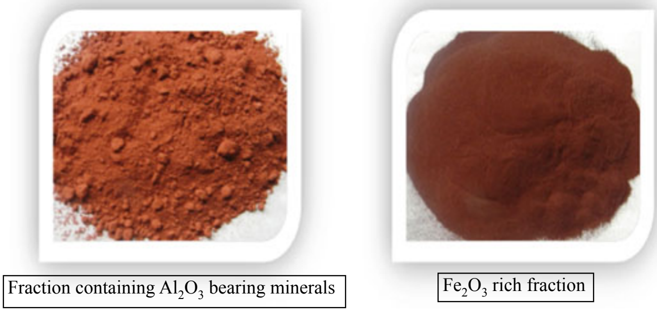

Fig. 5 Fractions of Laterite after physical beneficiation

moderate alumina, low silica and titania however, it contains high iron oxide. For non-metallurgical applications, it is necessary to bring down Fe_2O_3 content in bauxite. Keeping this in view, an attempt has been made to produce value added non-metallurgical bauxite by de-ironing of eastern ghat ferruginous bauxite (by acid leaching).

Leaching studies were carried out on ferruginous bauxite of Eastern ghat deposit with varying parameters like acid concentration, temperature, time and grain size. The bauxite is characterized by high iron oxide (Fe_2O_3−26%), alumina (Al_2O_3−44%). In general, with increase of concentration of HCl acid, the iron content reduces substantially with little loss of alumina. The various leaching tests show that iron reduction <3% can be achieved with 9–12% acid concentration at 95 °C (Table 4). It is observed that grain size of ore plays an important role during leaching studies. The maximum reduction in iron oxide content as well as enrichment of alumina achieved in −4 mm size fraction (Fig. 6). As a recovery of bauxite is concern, it is higher in −4 mm size followed by −11 mm. The test carried out with fraction of −11 mm, indicates higher recovery of ore however, insignificant reduction in iron oxide as well as increase in alumina content [21]. The experimental studies indicated that by using leaching technique non-metallurgical grade bauxite can be produced. In current scenario, India is importing high grade high alumina bauxite to fulfill the requirement for refractory industry [27].

From beneficiation studies it is observed that reduction of iron, silica content and enrichment of alumina inn low grade ore by using physical separation process. However, for substantial removal of iron and increase in alumina content, leaching process is effective. The specification required for bauxite used in metallurgical and

Table 4 Leaching by HCL

Constituent (%)	Original bauxite	De-ironed bauxite	Recovery of ore after leaching (%)
Al_2O_3	43–45	58–62	80–88
Fe_2O_3	25–26	5–2	–

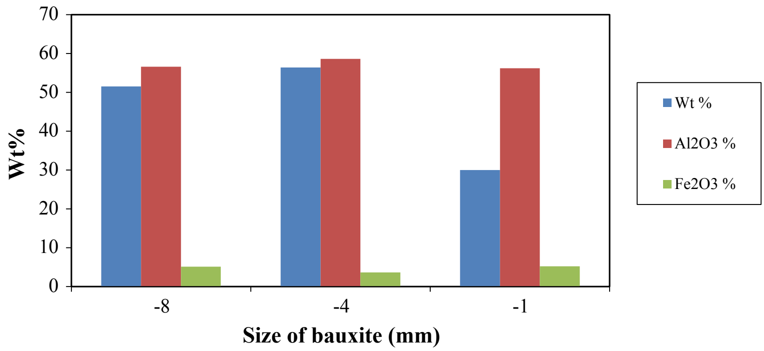

Fig. 6 Leaching (HCl) on various size of bauxite

Table 5 Specification of bauxite [28]

Grade	Major Oxides (%)			
	Al_2O_3	SiO_2	Fe_2O_3	TiO_2
Metallurgical	40–52	1.5–10	5–30	1–6
Abrasive	Min. 55	Max. 5	Max. 6	Min. 2.5
Chemical	Min. 55–58	Max. 5–12	Max. 2	0–6
Refractory	Min. 58–61	Max. 1.5–5.5	Max. 3	Max. 2.5
Low grade bauxite/Laterite after beneficiation (JNARDDC)	>58.00	<5.00	<3.00	<4.00

non-metallurgical industries is given in Table 5. By using beneficiation techniques, low grade ore can be used for non-metallurgical applications (refractive, abrasive, etc.).

6 Results and Discussion

Based on the beneficiation studies it is observed that silica and iron content enriched in fine fractions however, improvement of Al_2O_3% particularly in coarse and middle fractions. The studies on removal of impurities by WHIMS indicated reduction in iron oxide content and in this process, magnetic intensity, grain size and ore characteristics of laterite play an important role. The tests indicated that laterite can be blend with metallurgical grade bauxite for alumina production. The leaching by HCL showed that substantial reduction in iron oxide and enrichment in alumina content. By using this process, the ore required for non-metallurgical industries can be produced.

7 Summary

The quality of abundant resources of ferruginous, aluminous, siliceous laterite, low grade bauxite can be improved by using beneficiation techniques. Beneficiation studies indicated that iron oxide and silica can be significantly brought down with enrichment of alumina.

Bauxite for non-metallurgical industries meet very rigid physicochemical requirement and specifications particularly for constituents like alumina, iron oxide, titania, etc. compared to ore used for metallurgical industry. The laboratory beneficiation test results show that it is possible to produce high grade, high alumina bauxite by de-ironing, leaching process. The de-ironed laterite and low-grade bauxite may be a substitute material for high grade bauxite. After calcination, process de-ironed material can be use as calcined bauxite in refractory industry However, further detail studies are required to work out the technoeconomic of the process.

The unutilized/waste material associated with bauxite mine can be processed for value added products after beneficiation. The positive impact on cost anomaly as well as life of mine may appreciably increase by processing inferior material.

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