100 % Utilization of Bauxite Residue in Cement Plants: Hindalco Experience

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Abstract

Bauxite Residue (BR) is the major challenge towards the sustainability of primary aluminium industries. For several decades, researchers across the globe had been investigating for finding a viable solution to this perennial problem. Despite all these efforts, BR utilization is only 2-3 % of the total annual generation of about 173 Mt. Most of these applications are for road construction and landfills, construction applications, adsorbent / catalyst manufacture, iron and steel making and cement industry.

Principles of circular economy has brought a paradigm shift in managing various industrial wastes and by-products. To bring about a transformational change in the aluminium industry, Hindalco has tried to align itself with sustainable ways of operations. Reuse of the material in cement industry showed the greatest promise for immediate solution.

Towards this objective, preparation of BR must be given a top priority. To reduce the moisture content and improve handleability of the residue, pressure filtration technology has been adopted by all refineries at Hindalco. This has reduced the moisture content to ~ 20 to 25 % consistently. Based on the successful laboratory and plant scale demonstration, Hindalco had collaborated with top cement industries in the country for large-scale utilization of bauxite residue. We closely worked with many stake holders in overcoming the challenges associated with storage, handling, and transportation of the materials. In FY 20-21 (financial year 2020-2021), we could supply the material to more than 40 cement plants achieving BR utilization of ~ 62 %. Also, three of our sites had achieved 100 % BR utilization during the reporting period, which has resulted in Hindalco emerging as the world leader in the successful utilization of BR in cement. Hindalco's journey towards 100 % utilization of BR in cement production, challenges faced, and key learning have been discussed in the paper.

Key Words: Bauxite residue, Alumina, Aluminium, Circular economy, Laterites

1. Introduction

Globally, about 173 Mt of Bauxite Residue (BR) is generated each year and current inventory is approximately to the tune of about 3 Gt [1]. CAPEX and OPEX cost of disposal are typically below 4-8 US$/t. The amount of BR produced by an alumina plant or refinery is primarily dependent on the sources of the bauxite and secondarily on the extraction conditions used by the plant. In the extreme cases, this can vary from 0.3 to as high as 2.5 t of residue per tonne of alumina produced, though typically it lies between 0.7 and 2 t of residue per t of alumina produced. The most important factors are aluminium content of the bauxite, the type of aluminium oxide/hydroxide present (e.g., gibbsite, boehmite or diaspore) and reactive silica component present and the temperature and pressure conditions used for the extraction. Most of these factors are dictated by the nature and form of the alumina present, the local cost for energy, and the cost and distance the bauxite ore needs to be transported.

Principles of circular economy has brought a paradigm shift in managing various industrial wastes and by-products. To bring about a transformational change in the aluminium industry, Hindalco has tried to align itself with sustainable ways of operations. Reuse of the material in cement industry showed the greatest promise for immediate solution. High Fe_2O_3 and Al_2O_3 content in BR is useful to produce cement clinker. This application has the advantage of avoiding mining of virgin laterite ores leading to improved resource efficiency. Considering that 4 billion tons of raw material are required for the annual 2.8 Gt of cement production globally, it results that ~ 120 Mt of BR can be consumed in a year if it is used at ~ 3 wt% in the raw mix[2].

2. Characteristics of Bauxite Residue

BR is mainly composed of iron oxides, titanium oxide, silicon oxide and un-dissolved alumina together with a wide range of other oxides which will vary according to the country of origin of the bauxite. The high concentration of iron compounds in the bauxite residue gives the by-product its characteristic red color, and hence its common name ‘red mud. A typical chemical and mineralogical composition of BR from India is shown in Table 1.

Table 1. Composition of bauxite residue from India.

BR Analysis	
Fe_2O_3, %	35-65
TiO_2, %	9-15
SiO_2, %	5-11
Al_2O_3, %	17-19
Na_2O, %	3-07
Moisture, %	22-25
Phase Analysis of Iron	
Hematite, %	40-50
Goethite, %	50-60
Particle Size	
d_{50}, micron	2.7-3.0
Mineralogical Phases , %	
Hematite, Goethite	60
Boehmite, Gibbsite	15
Sodalite, quartz	8
Rutile, anatase	7
Tri Calcium Aluminate	7
Trace elements	3

BR is a very fine material in terms of particle size distribution; typically, > 90 % by volume is below 75 µm. The specific surface (BET) is around 10 m^2/g. Various phases present include sodalite from reaction of R. SiO_2 (reactive silica) and quartz attack (in case of a high temperature digestion) as well as cancrinite by addition with lime. Depending upon the process used and the bauxite quality, BR may contain trace quantities of oxalate and other organic sources along with water of crystallization.

3. BR Utilisation - Key Application Areas

Utilization of BR is about 2-3 % of the total annual generation globally[3]. The major areas for utilization of BR are presented in Figure 1 . As can be seen from the figure, cement industry is the main player for utilization of BR.

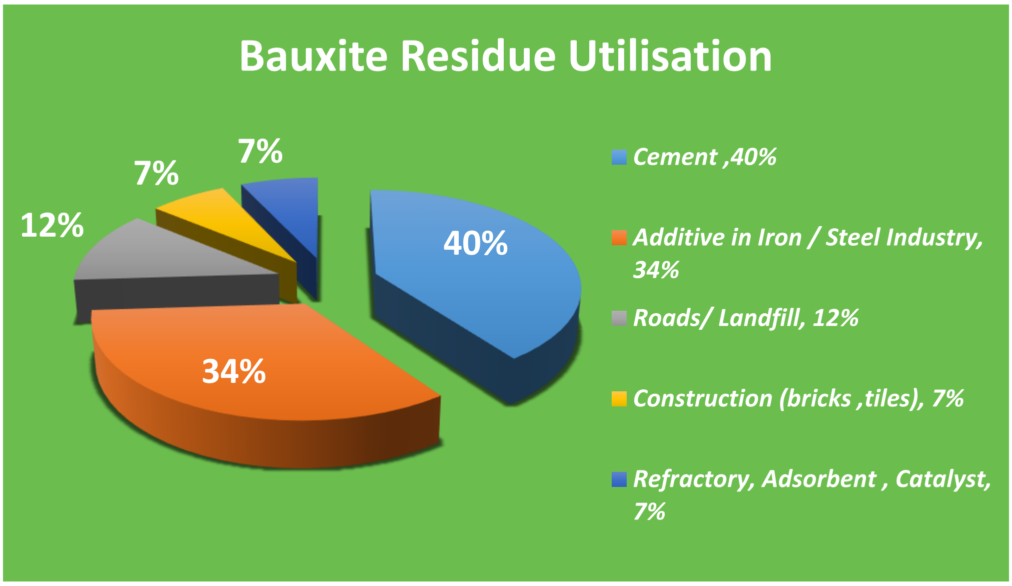

Figure 1. Major utilisation areas of BR.

4. Use of Bauxite Residue in Cement Production

BR with high Fe and low Na content, vicinity to cement companies producing high volumes of cement and possibility to deliver BR filter-cake with low surface moisture < 25 %, which allows cake handling via established technology, are seen as very promising factors for utilization of bauxite residue. A comparison of the major ingredients presents in Portland cement as against the analysis of BR generated from alumina refineries is presented in Table 2.

Table 2. Composition of portland cement raw mix v/s BR.

Ingredient	% In cement	% In BR
CaO	60-65	-
SiO_2	18-25	5.0-11.0
Al_2O_3	4-8	17-19
Mg	<5	-
Fe_2O_3	2-6	35-65
$CaSO_4$	3-5	-
SO_3	1.8-3.5	
$Na_2O + K_2O$	0-1	3-7

A typical comparison of the composition of cement and BR shows that SiO_2, Al_2O_3, and Fe_2O_3, which are the major constituents of BR are also present in cement. Addition of 0.5-3 wt% of BR in clinker raw mix is a realistic figure and the same may vary with the quality of BR to be added, composition of other raw materials feed to kiln and the economics of using BR over other raw materials like laterite.

5. Value Creation from Bauxite Residue

Cement industries traditionally use laterite, lithomarge, subeconomic grade bauxite or iron ore to fulfil the requirement of iron oxide, alumina, and silica. The presence of iron oxide, alumina and silica in the BR provides the potential to use it in the clinker raw mix. It leads to conservation of minerals like laterite, subeconomic grade bauxite and iron ores. Apart from this, there is a need to crush the traditional raw materials mentioned above due to their larger size, which can be saved by using bauxite residue, saving the crushing cost.

Cement plants majorly use coal, pet-coke, or combination of both as a fuel in kilns. Pet-coke has a higher GCV (Gross Calorific Value) (6.5 to 9 GJ/kg) compared to coal GCV (3.5-5.5 GJ/kg). Due to this reason, pet-coke is economically more viable to be used as a fuel across cement plants. However, pet-coke causes high % SO_2 emissions compared to coal due to the presence of high sulphur content in it. Higher sulphur content increases circulation of volatiles and potentially causes plugging in pre-heaters. Presence of alkali in BR may prevent the pre-heater plugging and cement plant can use more quantity of pet-coke for improving its cost competitiveness.

Role of BR characteristics on cement production could be summarized as follows:

Na_2O content in BR:

Na_2O content in BR has many advantages:

- It acts as a flux and helps to achieve lower levels of free CaO in the clinker.
- The strength of the clinker and grindability are improved due to the presence of Na_2O.
- For the cement industries using pet coke (having 6-8 % sulphur) as fuel, the Na_2O content in BR helps to capture the sulphur gases moving out of the calciner.

Moisture in BR:

- High surface moisture in BR is not desirable. Difficulty in loading/unloading and high transportation cost are the key issues associated with high moisture.
- Most of the modern refineries have adopted pressure filtration leading to reduction in moisture content in BR. The cement industry would prefer 15-20 % moisture in BR.

TiO_2 content in BR:

- Presence of TiO_2 in BR acts as a catalyst and helps in reducing the calcination temperature and thereby, lower energy consumption.

Fe_2O_3 content in BR:

- Presence of higher Fe_2O_3 content in BR helps in reducing cooler jamming by preventing burning issues. It is limited to the above amount for smooth operation of the cement kiln.

Fineness of BR:

- Fineness of BR helps in grinding cost reduction. For higher amount of BR, granulation is one of the potential solutions.

6. Hindalco's Experience on BR Use in Cement

Hindalco's approach towards BR management is based on 5R + 1 S approach wherein 5R's are **R**educe, **R**edesign, **R**ecover, **R**ecycle/Reuse & **R**ehabilitation & 1 **S** is **S**torage. Various projects have been initiated under the 5R + 1S approach, which are at different levels of maturity based on their potential impact on utilization of BR and the cost of implementation.

BR sale to cement plants comes under the head of **R**ecycle/Reuse approach and is a matured technology and has a high potential impact.

All the refineries of Hindalco have been working on successful collaboration with different cement industries in and around the geographical location to enhance the sale of BR to cement industries.

Hindalco has been the leader in successfully implementing the technology for use of BR in cement plants. Close collaboration with cement plants through regular site visits and technical interactions with the help of various research laboratories, institutes and in-house innovation centre have been instrumental in developing a circular economy model for the successful use of BR generation to cement plants. Hindalco has become a world leader in the utilization of bauxite residue and has created a benchmark for the alumina industry across the world. Hindalco is the world's first company to achieve 100 % red mud utilization across three of its refineries, namely Belagavi, Muri and Renukoot.

7. Hindalco Belagavi – Experience

As early as 2010, Hindalco Belagavi Refinery initiated a process through discussion with cement plants for using Bauxite Residue for Cement manufacturing, as a replacement of laterite, lithomarge & some part of subeconomic grade bauxite. Based on this discussion and further developments, around 10-12 cement plants in Karnataka and Andhra Pradesh started using BR in their production process successfully.

Systematic trials were undertaken for establishing the use of BR in cement plants. As a typical case study, the studies conducted in one of the cement plants for replacing laterite ore with BR is discussed below. The compositions of the laterite ore and the BR used during the trials are shown in Table 3.

Table 3. Laterite and BR qualities.

	Laterite, %	BR, %
Moisture	11.9	21.2
SiO_2	22.3	17.1
Al_2O_3	18.9	17.4
Fe_2O_3	41.0	36.5
CaO	0.10	0.7
MgO	0.20	0.7
TiO_2	2.20	7.3
K_2O	0.30	0.7
Na_2O	0.00	6.4
LOI	14.7	12.4

BR was fed along with limestone, from where it was fed into the pre-heater for clinkering. The percentage of BR was targeted at approximately 1.5 %. In this study, emission of various pollutants, such as, SO_2, NOx, CO (CO or CO_2?) etc., were monitored during the trials. Consistency in clinker quality parameters were maintained during the trials, as shown in Table 4. There had been no change in the oxides in clinker and the ratios such as LSF (Lime saturation factor), SM (silica modulus) and AM (alumina modulus) remained unchanged. Percentages of the various phases like C_3S, C_2S, C_3A and C_4AF are also similar in all the cases. Liquid content is also the same when laterite is used.

Table 4. Clinker quality with and without bauxite residue.

Clinker Analysis	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	Cl	P_2O_5	LSF	SM	AM	F/CaO	C_3S	C_2S	C_3A	C_3AF
With BR	20.6	5.30	4.90	63.4	1.10	0.25	0.21	1.32	0.02	0.30	93.0	2.00	1.06	1.75	49.1	22.1	5.80	14.9
Without BR	21.0	5.25	4.94	63.8	1.10	0.25	0.18	1.15	0.00	0.30	92.6	2.10	1.06	2.74	48.5	23.5	5.50	15.0

The key conclusions drawn from these trials:

- BR can be used in as raw material in clinker raw mix, preserving natural resources like laterite, lithomarge etc.
- No deterioration in quality of clinker or cement observed from the use.
- No size reduction required for the BR before feeding into the kiln. It leads to huge savings in cost and energy for cement industries.
- Presence of soda in BR (around 8 %) prevented the preheater plugging.

Over the years, Hindalco Belagavi has been instrumental in successfully scaling up the technology for use of BR use in cement plants and is now catering to the cement manufacturers in and around Karnataka and Andhra Pradesh thereby achieving ~ 100 % utilization of BR generation.

8. Hindalco Renukoot – Experience

Renukoot Alumina Refinery generates 1.0-1.5 Mtpa BR requiring huge disposal volume i.e., ~ 8.25 lacs m^3 per annum. Currently existing BR dam capacity is on the verge of exhaustion therefore refinery is struggling for space creation in existing dams for its sustenance. Various areas are identified for BR utilization but most of them failed due to commercial viability[4].

Hindalco Renukoot approached Dalla cement factory (Ultratech Now) and convinced them for the collaborative project and conducted preliminary trial study of 5 days with BR as per the guidelines of Co-processing in Cement/Power/Steel issued by CPCB (Central Pollution Control Board). During Trial Kiln process parameters, stack emissions and product quality parameters were observed closely for the 5 days' trial period (one day without using BR, three days using the BR during trial run, one day after trial run without using BR). BR usage at Dalla cement proved to be a success, but it was catering for limited quantity of BR thus serving only small proportion of generated BR ~ 2.5 %.

For establishing the technical viability cross functional team constituted involving Alumina team along with cement industry veteran. The team visited several cement plants at Kymore, Satna, Maihar, Rohtas, Rewa, Bela and Siddhi, etc. For establishing the commercial viability, cost analysis was performed for current additives vis-à-vis to BR.

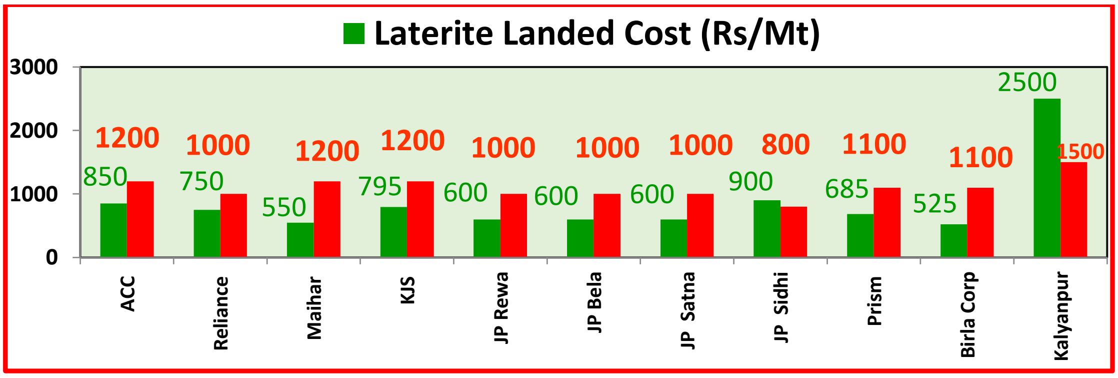

Figure 2. Cement plants wise transportation cost study table.

Therefore, road transport proved to be not desirable and hence it was thought to work upon economic transport medium i.e., railway/rake. Even though railway rake emerged as most cost-effective transportation medium, implementation of the idea was a great challenge as BR dam and railway lines were geographically very far apart. To address this challenge, Renukoot collaborated with Grasim chemicals to develop a unique solution for sparing the rake used for caustic unloading and developing an alternate solution for caustic unloading at refinery. However, there was another challenge in transportation of BR using rakes.

BOXN (Bogie Open High Sided Air Braked Wagon) rake was required for BR loading purpose however, existing infrastructure were designed for BTCS (Bogie Tanker Centre Side Discharge) rake. Modification was carried out in limited time of ~ 7 days to accommodate BOXN rake. To maintain the desired level of moisture in the ready for dispatch BR, the whole material was covered with tarpaulin to save it from heavy rain. Also, an arrangement was made to cover a very huge quantity (in a mountain form) in BR Dam # 3 for rainy season dispatch.

Through these innovations and through regular interaction and visits to cement plant along with Hindalco Industries Limited central team, Renukoot team was able to develop ~ 25 of customers for BR utilization as well increased the BR sale to cement plants substantially as shown in Figures 4 & 5. The plant has already achieved 100 % use of BR generated in the plant for cement making.

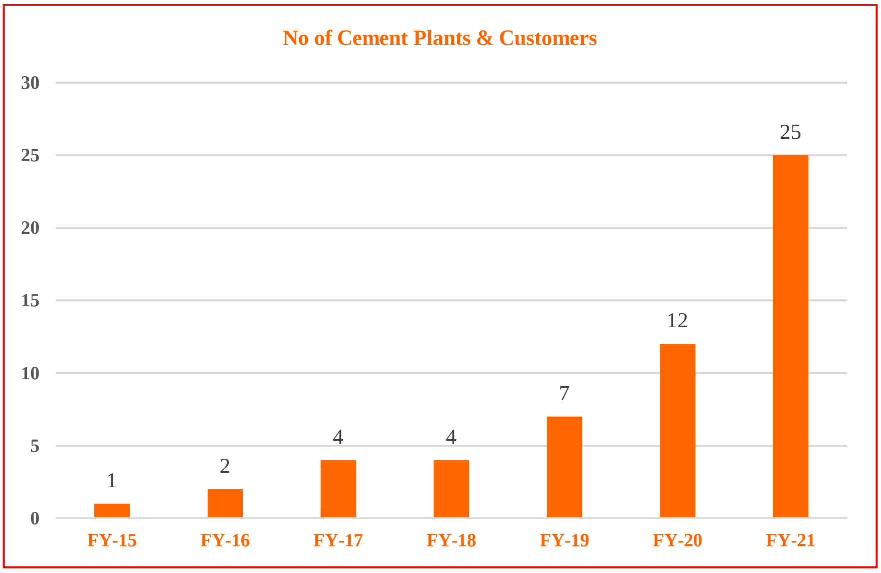

Figure 3. Number of cement customers developed by Renukoot.

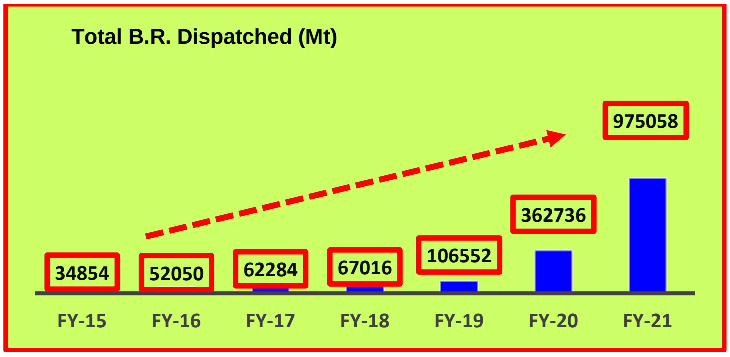

Figure 4. Amount of BR dispatched to cement plants.

9. Challenges of BR Use in Cement Plants in India

There are a few key challenges which need to be overcome for further enhancing the use of BR in cement:

Technical /Operational:

- Lower moisture (< 15 %) in BR is preferred. Pressure filtration and drying facilities may be required.
- Adequate storage facility will be needed for ensuring supply of dry material in rainy season.
- Lack of enough research for maximizing BR use (say, upto 20 % in raw mix) for cement making.

Commercial:

- Higher cost of transportation to cement plants.
- Achieving break even with laterite price.
- Rake availability for BR transport.

Statutory / Regulatory:

- Higher time taken for railway siding approvals.
- Preference of railways for coal and other raw materials over BR.
- Lack of guidelines or standard on use of BR in cement making.

10. Hindalco Muri – Experience

Muri Refinery generates 0.65-0.70 Mtpa bauxite residue. Muri had started exploring use of BR in cement industries in early 2013 with ACC Chaibasa plant. However, spillage of the residue in 2018-19 from its pond pushed the initiative to target 100 % evacuation of the material generated. A team of experts formed and started exploring the utilization in nearby Raipur/Orissa region which helped to develop market for its use. As compared to other cement regions in India, Raipur is more challenging looking the limestone chemistry, as in Raipur cluster cement units require low alkali material due to presence of alkali in limestone. Muri team along with Hindalco Corporate expert team had explored the use of BR in Dalmia Rajgangpur, Hirmi, Rawan and Chandrapur cluster cement units (UTCL Awarpur, Manikgarh, ACC Chanda & UTCL Balaji) which helped to utilize 100 % of the residue generated from 2019 onwards.

Muri has the challenge of meeting low moisture in BR as the unit supplies fresh material with 26-27 % moisture, whereas other refineries are supplying at 24-25 % moisture level from their old storage ponds. Many trials and kaizen (small improvements) were undertaken to improve moisture level and Muri could successfully achieve 23-24 % moisture during summer period.

For sustainability point of view, Muri plant must evacuate at least 65-70 % bauxite residue due to its CTO (Consent to Operate) criterion fulfillment. For achieving this a cross functional team along with Hindalco Corporate, external consultant & plant technical representatives were formed which helped to utilize maximum amount of the residue. Hindalco central marketing team along with plant technical representative had regularly visited the cement units to work towards customer centric approach, which helped in developing markets to utilize bauxite residue and thereby a sustainable solution for the plant.

11. Concluding Remarks

Bauxite Residue issue faced by primary aluminium industries could be addressed through a collaborative approach guided by the 5R+1S BR Management approach mentioned in the paper. The most promising route is the recycling or reuse of BR in cement making. BR can offer the cement sector, both industrially mature and promising alternative for replacement of laterite without any change in the cement quality. Addition of BR for OPC (Ordinary Portland Cement) grade cement production can take place to a level up to 3 wt%; depending upon the quality of BR used in the clinker raw mix. Increased adoption of pressure filtration will reduce both water and alkali content in BR and enable more of its usage in cement making. Along with the various technical challenges discussed, the proximity of cement plants, transportation logistics and statutory or regulatory compliances, overall economics, etc., are also to be considered for successful use of BR in cement making.

12. Future Scopes and Opportunities

Most of the minerals present in Bauxite Residue are of importance for achieving cement chemistry. Levels of Na, Ti, Fe in BR, along with Al/Fe ratio can determine maximum addition levels. The constituents, namely, Na and Fe have positive impact on cement production process in terms of efficiency of operation and cost of production. Use of BR in cement making will play an important role in the long-term sustainability of both aluminium and cement industries. The application will not only help in improving the Natural Resource efficiency but also improving environmental performance in terms of reducing SOx and green-house gas (GHG) emissions from these industries. Research opportunities are there in developing new type of cements with fast setting properties with increased used of BR and other industrial wastes and thereby, promoting circular economy in this industrial segment.

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