An Overview of Bauxite Residue Utilisation

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Abstract

Bauxite residue is a solid waste generated during the production of alumina from bauxite. The disposal of this waste is a global challenge due to its potential environmental impact. If not well managed, its high alkalinity is a potential source of contamination of water, land and air in close proximity of the disposal site. Extensive work is carried out by researchers worldwide on value addition and fruitful utilization of bauxite residue. Some of the opportunities for utilization include adsorbents for the removal of heavy metals, dyes, phosphate, nitrate and fluoride; preparation of catalysts; recovery of iron, titanium and other trace metals; production of radio opaque materials; production of construction bricks; wood substitutes; cement; geo-polymers; development of coatings and pigments. This paper examines the details of bauxite residue utilization with the ultimate aim of solving the challenges of disposal and environmental impact.

Keywords: Bauxite residue utilization; wood substitutes; coatings and pigments; radio opaque material;geo-polymers

1. Introduction

Aluminium is a light weight,high strength structural material. Bauxite is the most economically important aluminium ore due to the presence of its high alumina content. Bauxite is a lateritic rock and contains mainly gibbsite, boehmite and diaspore. Bauxite also includes the iron oxides, goethite, hematite and small amounts of titanium, silica and other minerals and other impurities in minor or trace amounts. Bauxite usually contains the clay mineral kaolinite and has a density ranging from 2 600 to 3 500 kg/m^3. Bauxite colour varies from whitish to pink to reddish brown depending on the iron content in the bauxite[1]. Globally, estimated bauxite resources are 55 to 75 billion tonnes, located in Africa (33 %), Oceania (24 %), South America and Caribbean (22 %), Asia (15 %) and elsewhere (6 %). India is self-sufficient in bauxite and has 3 billion tonnes of bauxite reserves out of global reserve of 65 billion tonnes. This places the country 5th in rank in the world [2].Bauxite is classified based on ore type. These are mineralogically different and their occurrence in different countries is given in Table 1.

Table 1. Bauxite ore type indifferent countries [3].

Gibbsitic	Boehmitic	Diasporic
Australia, Brazil, Guyana, India(Eastern Coast),Indonesia, Jamaica, Malaysia, Sierra Leone, Suriname, Venezuela.	Australia, Guinea, Hungary, USSR, Yogoslavia, India (Central part.)	China, Greece, Guinea, Romania, Turkey

Aluminium production involves three stages: bauxite mining, followed by the refining of bauxite to alumina, usually in the Bayer process and smelting of alumina to aluminium by the Hall-Heroult process. Alumina can also be produced from bauxite under alkaline conditions using the lime sinter process [4], Deville Pechiney process(sodium carbonate) [5] and using the Serpeck process at high temperature in a reducing environment in presence of coke and nitrogen [6].The Bayer process[7] is the most economic and prevalent method employed for extraction of alumina from bauxite, where it contains sufficient Al_2O_3 content. Bauxite of higher silica content is not suitable for the Bayer process and is more economically processed by the sintering process. Waste generated from the sintering process is generally brown in colour, contains higher solid contents and lower quantities of Fe_2O_3 and Na_2O.

2. Bauxite Residue (Redmud)

In the Bayer process, the insoluble residue obtained after digestion of bauxite with sodium hydroxide at elevated temperature and pressure to extract alumina is known as red mud, or bauxite residue. Annual production of smelter and chemical grade alumina in 2015 was about 115 million tonnes produced using the Bayer process. The global average for the production of bauxite residue per tonne of alumina varies from 1 to 1.5 tonnes, so it is estimated that about 150 million tonnes of bauxite residue is produced annually. Bauxite residue has been called by different names by various companies. These are registered trademarks and reported in many publication and reports [8, 9]. Bauxite residue seems a more suitable name as some of the muds are brown rather than red and some diasporic derived residues are blackish. Despite this variation in colour, the name “red mud” remains more commonly used in North America and Europe [8, 9].

From an ecological viewpoint, whether it is red or brown mud is unimportant, both require appropriate waste and environmental management. The key risk with residue is the high alkali content, where pH values in fresh residue usually exceed 13. There is a risk of this alkalinity percolating into groundwater, in case of heavy rain and where appropriate monitoring and control measures are not in place. There is a risk of dam collapses (Hungarian alumina refinery, Ajka in 2010) and during the dry period of the year, dusting of the alkaline material may cause issues for local communities [10].

3. Environmental Consequences and Bauxite Residue Management

Bauxite residue produced from alumina refineries is a significant environmental risk for the surrounding environment including soil, vegetation and aquatic life, if not properly managed. The appropriate environmental management and/or utilization of bauxite waste are a major universal concern and preoccupation. The quantity and characteristics of the residue makes the task of safe disposal and utilisation more complex.

Safe storage of such large quantity of residue leads to the increase in production costs of aluminium by 2-5%. Residue storage also occupies large useful land tracts. The design and construction of such residue disposal facilities has varied considerably over the years with disposal practices generally dependent on nature of the immediate environment [11]. It is reported that conventional disposal methods involve the construction of clay lined dams or dykes, into which residue slurry is pumped and allowed to consolidate and dry naturally [12].

A good quantum of research and development work is being carried out all over the world in evolving a solution for the safe storage and utilization of bauxite residue. The current trend in residue storage is the increasing use of dry stacking as the preferred technology and further development in this area is being done to optimize the technology. Partial neutralisation using sea water is practiced at a number of Australian plants close to the sea; carbonation by using waste carbon dioxide from ammonia production has been adopted in Kwinana (Australia) and accelerated carbonation using intensive farming methods (Aughinish, Ireland), shows considerable benefits. Many of these approaches to disposal and management like alkali neutralisation using acid, CO_2 treatment, seawater neutralisation, bioleaching and sintering processes to fix leachables, stockpiling of bauxite residue alongwith their implications are discussed in detail elsewhere [3, 8].

Filtration using drum filters and plate and frame filter presses to recover caustic soda produce a lower moisture. This trend opens up benefits in terms of reuse with less than 28% moisture content and lower soda there by reducing transportation cost. Alunorte(Brazil), Distomon (Greece),Gardanne, Kwinana, Seydisehir(Turkey) and many plants in China have already adopted or are planning to adopt plate and frame filter presses [8].

The tragic incidence of Ajka alumina refinery in Hungary in October 2010 is still in the memory of the industry and the wider community. The producers and the organization such as the European Aluminium Association and International Aluminium Institute (IAI) have worked in collaboration to support improved solutions and publish best practice guidelines for treatment and storage of bauxite residue in a safer way with lower caustic and higher solid content [13].

4. Characteristics of Bauxite Residue

Bauxite residue is fine grained material. Typical values for particle size distribution are 90 weight % below 75 micrometers. The specific surface area is between 10 and 30m^2/g, depending on the degree of bauxite grinding.

4.1 Chemical and mineralogical characteristics of bauxite residue

Bauxite residue 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 gives the by-product its characteristic red colour, hence its common name is 'red mud'. A typical chemical composition is shown in Table 2 and mineralogical composition in Table 3. The variation in chemical composition between bauxite residues worldwide is high.

Table 2. Typical range of chemical compositions for bauxite residue.

Constituents	**Typical range (wt%)**		
	A [8]	B [13]	C [3]
Fe_2O_3	05 - 60	20 - 40	30 - 60
Al_2O_3	05 - 30	10 - 20	10 - 20
TiO_2	0.3 - 15	4 - 20	Trace - 25
CaO	02 - 14	0 - 14	2 - 8
SiO_2	03 - 50	5 - 30	3 - 50
Na_2O	01 - 10	2 - 08	2 - 10

Table 3.Typical range of mineralogical compositions for bauxite residue [13].

Constituents	**Range wt %**
Sodalite ($3Na_2O.3Al_2O_3.6SiO_2.Na_2SO_4$)	4 - 40
Goethite (FeOOH)	10 – 30
Hematite (Fe_2O_3)	10 - 30
Magnetite (Fe_3O_4)	0 - 08
Silica (SiO_2) crystalline and amorphous	3 - 20
Calcium aluminate ($3CaO.Al_2O_3.6H_2O$)	2 - 20
Boehmite (AlOOH)	0 - 20
Titanium Dioxide (TiO_2) anatase and rutile	2 - 15
Muscovite ($K_2O.3Al_2O_3.\ 6SiO_2.2H_2O$)	0 - 15
Calcite ($CaCO_3$)	2 - 20
Kaolinite ($Al_2O_3.\ 2SiO_2.2H_2O$)	0 -05
Gibbsite (Al(OH)3)	0 - 05
Perovskite ($CaTiO_3$)	0 - 12
Cancrinite ($Na6[Al6Si_6O_{24}].2CaCO_3$)	0 – 50
Diaspore (AlOOH)	0-05

A range of other components are present at trace levels in the bauxite, including metal oxides such as those of arsenic, beryllium, cadmium, chromium, copper, gallium, lead, manganese, mercury, nickel, potassium, thorium, uranium, vanadium, zinc and a wide range of rare earths.

Non-metallic elements that usually occur in the bauxite residue are phosphorus and sulfur. A variety of organic compounds can also be present, these are derived from organic matter in the bauxite and include carbohydrates, alcohols, phenols, and the sodium salts of polybasic and hydoxyacids such as humic, fulvic, succinic, acetic or oxalic acids. In addition, small quantities of some of the sodium compounds introduced with the sodium hydroxide used in the extraction process will remain depending on the dewatering and washing systems used.

5. Utilisation of Bauxite Residue

The key to a solution for the disposal challenge is the comprehensive development of utilization technologies. Bayer himself in 1892 proposed the potential for iron recovery and filed a patent. Since the 1950s, researchers have carried out projects exploring possible utilization of bauxite residue, keeping in mind the physical and chemical characteristics. Over the years, extensive work has been done by researchers worldwide to develop various economic ways for utilizing residue. The various applications reported include civil and building construction(cement, brick, aggregate, geopolymer, wood substitutes);chemical applications (catalysts or adsorbents, ceramics, coatings, plastics and pigments); metallurgical applications (recovery of major metals, steel making, recovery of minor or trace metals); application in pollution control (waste-water treatment,waste-gas treatment, soil improvement, etc.).The main application areas have been described in the present research paper.

5.1 Recovery of elemental components

Bauxite residue contains components like Fe_2O_3,Al_2O_3, SiO_2, CaO, Na_20 and K_2O. It also contains Li_20,V_2O_5,TiO_2 and ZrO_2. Elements like Ga, Sc, Nb, Li, V, Rb, Ti and Zr are valuable and an abundant secondary resources. Recovery of metals, especially rare earth elements from bauxite residue have attracted great interest. Due to the high iron content in bauxite residue, extensive research into the recovery of iron from Bayer process bauxite residue has been carried out by scientists all over the world.

The processes for recycling of iron from residue can be divided into roasting magnetic recovery, reductive smelting, direct magnetic separation, and the leaching extraction method, according to the different methods for iron separation. Researchers in Russia, Hungary, America and Japan have carried out iron production experiments from red mud. Researchers from the University of Central South have made steel directly with iron recovered from bauxite residue [14]. The Chinese Metallurgical Research Institute has enhanced the iron recovery rate to 86 % through making a sponge by red mud-magnetic separation technology. Sun et al. [15] researched the magnetic separation of iron from Bayer residue and determined the process parameters for the magnetic roasting-magnetic separation method to recover concentrated iron ore.

Considering the high aluminum and sodium content in residue, only by recovering them, full use of these resources can be made. Zhong et al. [16] recovered Al_2O_3 and Na_2Ofromresidue by the Sub-Molten Salt Method, with a one-way Al_2O_3 recovery rate of 88 %. After alumina recovery, the residue undergoes sodium recovery treatment using NaOHsolution, recycling Na_2O from residue. Zheng et al. [17] discussed an aluminum and sodium recovery process of a soda lime method after adding silicon slag into residue. Under the optimum conditions, the recovery of aluminum and sodium is up to 95 %, with residue Na_2O content of less than 1 % after treatment, meeting the requirements for cement raw materials.

5.2 Production of building or construction materials

5.2.1 Cement production

Work on using bauxite residue in Portland cement has been underway for over 75 years. The aluminium and iron content are useful substitutes for cement raw materials to achieve normal strength and setting characteristics, although the presence of sodium ions can be a problem. The chromium content of the bauxite residue, even though low, can be an issue if too high a proportion is used. Iron rich, special setting cements with improved strength (when compared to Portland cement) have been made with levels of up to 50 % bauxite residue from Renukoot, India together with bauxite and gypsum [13].

Substantial quantities of the bauxite residue from the AdG alumina plant in Distomon, Greece formerly disposed of in the sea, are now consumed by the local cement industry. Dry Fly ash is mainly composed of SiO_2 and Al_2O_3, and can be used to absorb the water in residue and improve the reactive silica content of cement. Scientists have conducted studies into the production of cement using bauxite residue, fly ash, lime and gypsum as raw materials. The use of bauxite residue based cement not only reduces the energy consumption of cement production but also improves the early strength of cement and resistance to sulfate attack [18].

Ekrem Kalkan [19] studied using red mud as a cement stabilizer. In 1980, Barsherike [20] studied the possibility of producing cement with bauxite residue as a raw material component of Portland cement, and successfully prepared cement complying with the relevant standards. Vangelatos [21] studied the preparation of ordinary Portland cement from residue, lime and freestone, and demonstrated that the 28-day compressive strength of the cement strength can reach 63MPa. In China, research was completed on the production of sulfo-aluminate cement from residue in 1955 [22]. Pan et al. [23] studied slag and bauxite residue activated by a composite solid alkaline activator and developed alkali slag bauxite residue cement. Liang [24] and Zhong [25] prepared cement-bauxite residue concrete. The compressive and flexural strength of this kind of concrete is close to or even higher than that of ordinary concrete, meeting the requirement of cement concrete used for pavement materials.

5.2.2 Clay based products

The use of bauxite residue and flyash for the production of heavy clay products are explored by Central Building Research Institute, Roorkee, India(26).Ekrem [19] studied the potential use of bauxite residue for the preparation of stabilisation material and results showed that residue and cement–residue materials can be successfully used for the stabilisation of clay liners in geotechnical applications. Study on the exploitation of bauxite residue as a clay additive for the ceramic industry [27] was carried out at National Institute of Technology, Rourkela, Orissa, India. A study carried out by Pontikes et al. [28, 29] was aimed at using bauxite residue in the heavy clay industry in which the plasticity of clay mixtures with bauxite residue and polymer addition was evaluated.

5.2.3 Brick

Mixtures with clay, shale, sand, and fly ash have been proposed and evaluated for brick manufacture by various teams of workers and has been undertaken using bauxite residue from Jamaica, Sardinia, Hungary, and Korea. Xing [30], Yang [31], Zhang [32], Nevin et al. [33] separately reported the production of non-steam-cured and non-fired brick, fly ash brick, black pellet decorative brick and ceramic glazed tiles. For instance, non-steam-cured and non-fired brick is developed by using industrial residues as raw materials, by adding cement and lime as binder and by pressing and natural curing technology. The Institute of Shandong Aluminum Company and the Institute of the Chinese Great Wall Aluminum Company separately achieved the production process of non-steam-cured and non-fired brick using bauxite residue and fly ash as raw materials.

Formulations made with both inorganic and organic binders have been successfully manufactured: inorganic binders used include quicklime, limestone, cement, and gypsum; and organic ones have included polyvinyl acetate (PVA) and polymethyl methacrylate (PMMA).

In the mid-1990s, a project to build a sports pavilion using bricks made from bauxite residue was set up by the Jamaican Bauxite Institute and the Jamaican Building Research Institute using bauxite residue. Bricks made by a silicate bonded system and bauxite residue pozzolanic cement gave good characteristics and the building is still in use today [13].

5.2.4 Aerated concrete and light weight aggregate

Aerated concrete is a light porous building material that has great characteristics such as thermal insulation, fire resistance and seismic resistance and is made from calcareous and siliceous materials. Bauxite residue aerated concrete, developed by using cement (15 %), lime(12 % -15 %), residue (35 % - 40%) and silica sand (33 % - 35 %) has the compressive strength and bulk density which complies with Chinese standards on the strength of concrete blocks [34]. Lightweight aggregates have also been manufactured by incorporating foaming agents into the mixes normally with fly ash. Meanwhile, roof tiles have been manufactured in Turkey from bauxite residue from the Seydisehir alumina plant [35].

5.2.5 Pigment application

The high iron content and finely divided state of the red mud has attracted an interest as a pigment in a wide variety of materials. Additions to bricks of a few percent of high iron oxide bauxite residue (2 – 5 %), have been made to reduce the cost of the raw materials and provide a uniform red colouration to the bricks. Small additions to tiles were at one stage moderately significant, but the demand for these tiles, once widely used for windows sills and floors has now shrunk considerably. Bauxite residue has been used as a pigment in plastics, in particular PVC for waste water pipes. A plant was operated in Larne, Northern Ireland for many years utilising the kilns after the Bayer plant closed to manufacture a pigment for the tile, paint, and plastic industries [13].

5.2.6 Wood substitutes

The appropriate utilisation of bauxite residue in making value added products, especially in development of bauxite residue polymer composites with an objective of “waste to wealth” is emphasised here for its optimum socio-techno-economic and environmental benefits. Polymer matrix composites developed by the CSIR-Advanced Materials Processes and Research Institute, India using bauxite residue from NALCO, India as a filler and natural fibre in reinforcement materials and can be used as a partial timber substitute. This becomes beneficial from two stand points, namely environmental protection through the meaningful use of bauxite residue and the development of value-added innovative products using naturally available plant fibres [36, 37]. This composite is equipped with better physical, chemical, mechanical, weathering and fire retardant properties than the conventional materials including wood and other wood substitute materials [38 - 40].

The developed composite materials can be used for many applications like flooring tiles, partitioning, false ceilings, roofing, panels, pre-fabricated housing, sheds and shelters. The salient features are; stronger than wood, weather and corrosion resistant, durable, termite fungus, rot and rodent resistant, fire retardant, self-extinguishing and cost effective. Scope and potential of bauxite residue-natural fibre reinforced composites is in engineering applications like building materials, railways and automobiles. A technology enabling centre has been established at CSIR-Advanced materials and processes research institute, India for up-scaling and training entrepreneurs.

6. Road Construction

When dewatered, compacted and mixed with a suitable binder, bauxite residue makes a good road building material and has been used to construct haul roads on bauxite residue areas for very many years. In the south of France, bauxite residue has been used in the construction of several roads and platforms. Some 25 000 cubic metres of Red Sand® from Alcoa were used in construction of the Perth to BunburyHighway which opened in 2009. High-grade road base material using residue from the sintering process is promising, and may lead to large-scale consumption of bauxite residue [41, 42].

7. Mining

Yang et.al. [43] have studied the properties, preparation and pump pressure transmission process of bauxite residue paste backfill material. Based on this study, a new technology named "pumped red mud paste cemented filling mining" has been developed by the Institute of Changsha Mining Research, in cooperation with the Shandong Aluminum Company. They mixed bauxite residue, fly ash, lime and water in appropriate ratios and then pumped the mixture into the mine to prevent ground subsidence during bauxite mining. This technology is a new use of bauxite residue cemented filling can effectively reduce the filling costs, increase the safety factor for workers and increase the comprehensive benefits of mining [44].

8. Geo-polymers

Geopolymer is a term covering a class of synthetic aluminosilicate materials with potential use in a number of areas, essentially as a replacement for Portland cement and for advanced high-tech composites and ceramic applications. The geo-polymerisation process involves a chemical reaction between bauxite residue and an alkali metal silicate solution under highly alkaline conditions. The product of this reaction is an amorphous to semi-crystalline polymeric structure, which binds the individual particles of residue, transforming the initial granular material to a compact and strong one. The potential use of residue for synthesis of inorganic polymeric materials through a geo-polymerisation process was studied for use in the construction sector as artificial structural elements such as massive bricks [45]. Bauxite Residue was reacted with fly ash and sodium silicate via geo-polymerisation reaction to get bauxite residue geo-polymers which are a viable cementations material that can be used in roadway constructions. Giannopoulou et al. [46] studied the geo-polymerisation of bauxite residue and the slag generated in the ferronickel production, to develop inorganic polymeric materials with advanced mechanical and physical properties.

9. Soil Amelioration

Addition of bauxite residue to acidic and sandy soils can be beneficial in many ways and considerable work in this area has been undertaken in Western Australia by Alcoa. Bauxite residue at a level of over 250t/ha was added to sandy soil together with 5 % gypsum. The soil additions improved water retention and nutrient utilisation. Greatly increased ammonium and phosphorus retention were found showing how the use of fertiliser could be reduced. Concerns were raised with respect to leachability of heavy metals and radionuclides from the bauxite residue, and a considerable amount of work was carried out to determine whether this was a problem. All the research studies indicated that there was no problem in leachability of heavy metals or radioactivity [13].

10. Radiation Shielding Materials

Materials have been developed by CSIR- Advanced materials and processes research institute, India using processed bauxite residue with a barium compound by a ceramic processing route using phosphate bonding. The shielding materials are characterized for their X-ray attenuation properties. These materials have been evaluated and compared with conventional shielding materials like concrete and lead. Compared to concrete, the half value thickness of the bauxite red mud based shielding materials is significantly less for X-ray photons. Further, the work confirmed the presence of celsian, bafertiste and iron titanium oxide as the major shielding phases. The compressive and impact strength showed that the materials developed meets the standard specifications recommended for radiation shielding concrete and ceramic tiles. This study has showed great potential for utilization of bauxite residue in making X-Ray shielding materials [47].

11. Environmental Applications

Interesting uses for bauxite residue are also in the environmental field. Some promising applications in water treatment include the removal of heavy metals and metalloid ions, inorganic anions such as nitrate, fluoride and phosphates, organics including dyes, phenolic compounds and bacteria [48 - 55]. Trials have been made using thermally activated seawater neutralised bauxite residue for the removal of arsenate, vanadate and molybdate [56 - 59]. Bauxite residue can be used to neutralize acid forming gases produced during coal combustion, absorption of SO_2 on bauxite residue and treatment of waste gas containing sulfur [60, 61].

12. Coagulant, Adsorbent and Catalyst, and other Applications

The attractive features of bauxite residue such as iron content in the form of ferric oxide, high surface area, sintering resistance and cost effectiveness makes it suitable for use as catalyst for hydrogenation, hydro de-chlorination, oxidation of hydrocarbon, conversion of waste oil and waste plastics to fuel, conversion of coal and oil production [62, 63].

US patent 4017425 describes a method developed for the use of bauxite residue as adsorbent, catalyst, ion exchanging substance and clarifying substance for waste gas and adsorption processes [64]. Novel applications of bauxite residue as a coagulant and adsorbent for water and gas treatment as well as catalyst for some industrial processes have been reviewed [65].Efforts were made to utilise bauxite residue for plasma spray wear resistant coatings on metal substrates, stainless steel, copper and aluminium [66 - 68]. A few references are also available to evaluate the use of bauxite residue in refuse tip capping, site restoration, lanthanides recovery and treatment of acid mine drainage [8].

13. Major Barriers/Risks

It is necessary to consider the barriers that have prevented the implementation of sound and economically viable processes/technologies. Some important risk factors to consider are composition based. Technical and community perceptions relate to soda, alkalinity, leaching of heavy metals and low levels of naturally occurring radioactive material(NORM). Leaching of heavy metals into the environment is a particular issue for any material that is used in building products, bricks, roads, in construction, soil capping, or soil amelioration. Solubility/extraction studies of components, aggregates or metal uptake in vegetation may be carried out to show that the bauxite residue will not be a problem in use. Most bauxites will contain low levels of radioactive elements termed NORMs, in particular ^{238}U and ^{232}Th and this is normally roughly double in the bauxite residue. A thorough understanding of the radioactivity issues is most important when considering any application.

The high pH is an issue from both a health and safety aspect and any adverse effects on a particular application product. The impact ranges from poor weather resistance in construction materials to high sodicity when used in soil amelioration. Both high sodium levels and high pH will be reduced when press filters are used. Carbonation using CO_2, intensive farming or acid neutralisation could also be considered. Based on a number of standard test criteria, material with a pH value above 12.5 is often considered as hazardous. Implementation of improved filtering operation, may reduce the pH to a level that avoids skin and eye irritation.

A high moisture level will increase transport costs, so it is beneficial for the bauxite residue to have as high solid content as possible. Additives such as starch have been used for dewatering, but from 1980, there has been a growing use of synthetic flocculants, although the use of plate and frame press filters (in combination with polymer based flocculation) is now being more widely adopted to reduce residue moisture content.

14. Conclusion

The comprehensive utilisation of bauxite residue generated in the process of industrial production of alumina is still a worldwide challenge. The current technologies and practices, the capacity for consumption and secondary utilisation are grossly insufficient to make an impression in the accumulation of bauxite residue inventories. Despite much work done over the last century, only some 2 - 3% of the bauxite residue produced annually is used in a productive manner. The largest future potential uses are as wood substitutes, geo-polymers, iron recovery, cement production, building materials, soil amelioration, landfill restoration and road construction materials.

It is to be noted that very large tonnages of equally hazardous industrial byproducts such as fly ash are routinely used in value-adding industrial applications. The same outcome should be possible for bauxite residue. The need is for bauxite residue producers, technology developers/providers, promoters, construction agencies, funding agencies, entrepreneurs, and users to work together for effective implementation of existing or new technologies and cater to the need, and fulfill the demand for sustainable development.

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