Utilization of bauxite waste as a fine aggregate material for concrete roads: a critical review

A. M. Alamsyah[1], Pratikso[1], *R.* Mudiyono[1], *A.* Wahyudi Biantoro[2*]

[1]Civil Engineering Department, Sultan Agung Islamic University, Semarang, Indonesia
[2]Civil Engineering Department, Universitas Mercu Buana, Jakarta, Indonesia

Abstract. Bauxite tailings are an abundant waste product with no economic value. This research uses a critical review to describe the potential of bauxite tailings as a substitute for fine aggregate in concrete mixtures for road construction. There are differences in the Composition of the bauxite tailings used in the concrete mix, which will influence the results of testing the compressive strength and elasticity of the resulting concrete. This result used 30% and 70% bauxite tailings composition to replace fine aggregate in the concrete mix. Various studies on red mud substitute concrete show differences in mechanical properties and durability compared to Ordinary Portland Cement (OPC) concrete. Using up to 20% red mud by weight of cement improves adhesion and pressure quality in mortar compared to ordinary cement mortar. However, replacing more than 20% of cement with red mud reduces concrete's compressive strength and stiffness, and more than 15% substitution lowers stress and bond-breaking quality. Thus, the analysis results show a tendency to use red mud as a cement substitute in concrete, with the best compressive strength and solid mass stiffness of concrete in the range of 15 – 20%.

1 INTRODUCTION

Bauxite stone can be used for various purposes, one of which is as a concrete mixture. Concrete is a function of its constituent materials: hydraulic cement (Portland Cement), coarse aggregate, fine aggregate, water, and additional materials. Concrete can be defined as a collection of mechanical and chemical interactions of the materials that form it. Concrete, widely used as a building material, is obtained by mixing Portland cement, water, and aggregate. When this mixture is poured into a mold and left, it hardens like rock. Hardening is caused by a chemical reaction between water and cement, which occurs over a long time.

Concrete is a building material widely used by people today because it can withstand large loads. The load is supported by the homogeneity of the materials that make up the concrete, namely cement, water, fillers, and other materials that are used in the form of reinforcement or additives. The filler material here is aggregate, which fills 50 - 70% of the concrete volume, so the aggregate's properties can influence the concrete's strength [1].

The use of red mud in concrete has been identified, and only fundamental issues have been addressed. Research regarding red mud concrete for structural application is scanty. A

* Corresponding author: agung_wahyudi@mercubuana.ac.id

detailed experimental investigation is required on the development of red mud concrete with an accelerator, retarder, and viscosity-modifying admixture individually, as well as an evaluation of the different properties of concrete [2]. Red mud is a solid waste produced during the bauxite refining of alumina. In recent years, environmental problems caused by the accumulation of red mud have become increasingly serious [3].

In road construction, several layers function as road pavement. The road's layers consist not only of asphalt but also of concrete, often called last on (asphalt concrete)—utilization of last on to maintain the life of the road so that it lasts longer. The last one has various mixtures, including coarse aggregate and fine aggregate. This aggregate can be sand or small gravel of a predetermined size. This research will discuss using bauxite waste as a substitute for fine aggregate in road concrete mixtures.

High silica and alumina levels are needed in geopolymer concrete to replace Portland cement in concrete [4]. Bauxite is a raw material used to make aluminum. Mined bauxite must be washed first to minimize dirt and increase levels. The waste resulting from bauxite washing is called bauxite waste or red mud (bauxite tailings) [3].

When using a sand mixture for bricks, based on SNI 03-0349-1989, the average compressive strength of solid bricks is a minimum of 25 kg/cm2, with normal bricks having a strength of 38.5 kg/cm2. So bricks with variations in the bauxite waste mixture of 25% of the fine aggregate (sand) requirement will obtain an average compressive strength value of 36.7 kg/cm2 and 50% with an average compressive strength value of 28.5 kg/cm2 can still be used. Or meet standards [6].

Bauxite tailings can be used as a concrete mixture to replace fine aggregate. Using bauxite tailings as a substitute for fine aggregate makes bauxite tailings have economic value [4]. This is proven in research, proving that bauxite tailings can be used as fine aggregates [5]. Bauxite processing waste can be used as an artificial aggregate to replace sand and gravel. Artificial aggregates will be evaluated for their physical properties so that they are better than natural aggregates, namely in the form of density and absorption of concrete, as well as mechanical properties in the form of compressive strength of concrete [1].

Research regarding the use of bauxite as a substitute for aggregate, both as coarse aggregate and fine aggregate, has been widely carried out. Bauxite is used as an aggregate substitute in concrete mixtures. Bauxite stone itself has the potential to be used as a replacement material for coarse aggregate. Bauxite stone has a high absorption capacity for water resulting in a lower slump value than normal concrete but still meets SNI requirements, so that working with fresh concrete is not difficult [6]. In several areas in Indonesia there is quite a lot of bauxite rock, but it is difficult to get sand as fine aggregate and gravel as a mixture of coarse aggregate. Therefore, it is very important to know the ability of bauxite materials and waste as coarse and fine aggregates in concrete mixtures, especially for areas with high bauxite reserves [7]. Bauxite waste can also be used as a substitute for sand in concrete production [8], and bauxite mining waste can also be used as a design mix material for asphalt concrete [9]. Bauxite waste helps make road pavement, increasing road durability [10].

Indonesia has the sixth largest bauxite reserves in the world with total bauxite reserves reaching 1,000,000 thousand tons m3. Large bauxite reserves have the potential to provide large foreign exchange earnings for Indonesia, but unfortunately this potential has not been utilized optimally. This is because the amount of bauxite processed into alumina is very minimal compared to the amount mined. For this reason, the government limits the amount of raw bauxite ore exported so that domestic producers process bauxite into alumina which has a higher.

Currently, the world price of bauxite ore reaches US$ 18 per ton, while the price of alumina reaches US$ 350 per ton. This comparison shows that if bauxite producers in Indonesia are willing to carry out the stages of processing bauxite into alumina, then the

bauxite will have a selling value that doubles. The following shows a comparison of the prices of bauxite and alumina products in Indonesia and in the world.

Table 1. Comparison of bauxite and alumina prices.

Ore Prices		**Price of alumina materials**		**Price of aluminum products**	
Indonesia	**World**	**Indonesia**	**World**	**Indonesia**	**World**
IDR 279,000 per ton	US$ 18 per ton	IDR 5,430.00 per ton	US$ 350 per ton	IDR 27,338.00 per ton	US$ 1,762 per ton

Based on Table 1, it is known that the price of bauxite in Indonesia is cheaper than abroad, so that bauxite production is often exported. Bauxite processing waste in the form of bauxite tailings or red mud has economic value when used as a substitute for fine aggregate or as a substitute for sand in concrete mixtures used for roads.

Concrete with a tailings composition of 70% has been used by PT Freeport Indonesia, one of which was used in the construction of employee residences as a building material. Tailings from bauxite mining PT. Various Mines on Bintan Island were made into paving blocks for construction in the mine site area and surrounding areas [11] . Natural fine aggregate from the Tayan area, West Kalimantan is commonly used as a material in national construction projects, including the construction of the Marunda port and the construction of the Batang PLTU. The tailings resulting from washing mining goods, including bauxite, become fine aggregate as a substitute for natural fine aggregate. The aim of this research is to determine the development and potential of bauxite waste as a substitute for fine aggregate in construction, especially in concrete road mixtures, based on its physical properties and to estimate the potential volume of material as a substitute for fine aggregate.

2 METHODS

This research uses the Systematic Literature Review (SLR) analysis method, a literature review method that is carried out systematically with the aim of collecting and critically analyzing data and findings from various other studies. Analysis starts from the most basic things and then moves on to more complex things. The process using this method requires several stages, and the results are expected to develop more detailed, accurate and complex knowledge by collecting journals that research the use of bauxite waste as a substitute for fine aggregate in concrete Composition for road materials. Bauxite waste is residue from washing residue from bauxite rock which is often not used in bauxite ore processing. This research uses journals related to the use of bauxite materials published during the last ten years.

A literature review was carried out on the use of bauxite tailings as a substitute for aggregate in road materials. The factors used for comparison are the Composition of bauxite tailings in the concrete mixture components and the Composition of the concrete mixture's water cement factor (FAS).

3 RESULTS AND DISCUSSION

This research is devoted to discussing the potential of bauxite tailings, or what is known as red mud, as an aggregate substitute. The potential application of bauxite waste or red mud

can be used [12] for cement, bricks, synthetic aggregates, geopolymers, and road construction. A road pavement is a type of multiple-layer structure, which is normally made up of asphalt mixture surface layers or a concrete surface layer, road base layers and road sub-base layers [10]. the bauxite sand or coarse aggregate is most effective in reducing the normalized penetration depth, followed by the crater volume, and least effective in reducing the equivalent crater diameter compared to the siliceous sand or granite coarse aggregate. The combined use of bauxite sand and coarse aggregate can further reduce the extent of localized impact damage, especially the normalized penetration depth [13].

Fig. 1 shows the bauxite ore mining process up to the washing process, where the bauxite washing process produces bauxite residue or waste known as redmud. Redmud and bauxite tailings are bauxite waste which still have economic potential if used properly.

Fig. 1. Bauxite mining process.

The bauxite residue originating from Ukraine which is also used in concrete mixes has radiation. Considering the radiation protection of RP122 for the evaluation of the total effective dose to workers no restrictions are necessary for the use of Ukrainian bauxite residue in road construction [14].

Research to examined the use of industrial waste materials as an alternative to natural sand which is increasingly rare. The use of industrial waste as an alternative to natural sand in concrete is an effort to utilize sustainable construction materials. 100% bauxite residue. Sands replacement obtained the highest strength properties in concrete. The study, therefore, concluded that bauxite mining waste is suitable for use as a replacement fine aggregate in concrete production. It is recommended that further research be carried out on the durability and chemical properties of concrete produced with mining waste bauxite because this research only focuses on strength properties [8].

Research to examines the use of bauxite residue for the construction industry, especially in terms of product processes and technology developed. The large waste material generated during alumina production is followed by the Bayer Process which processes approximately 1.25 – 1.5 tons of per ton of alumina production. Disposal of this waste raw material is a serious problem as the demand for aluminum increases over time [12].

Research to examined internal preservatives commonly used in concrete structures. The results showed that the dry CB aggregate absorbed water during mixing and released it after setting. The compressive and tensile strengths of the UHPC mixture were both significantly improved by using CB aggregate compared with the reference mixture, which was due to the lower actual effectiveness w/w, improved ITZ properties, and increased hydration through the internal curing process. However, the powdered product from CB did not provide

IC effect, but the higher CB powder content (600 kg/m3) helped to increase the strength of the UHPC Matrix while the matrix with 300 kg/m3 CB powder obtained the same strength compared to the reference mixed UHPC matrix [15].

Research to shows that there are many studies regarding the use of red mud, which is bauxite processing waste, as a mixture for making cement and making concrete. Research compared various studies on the use of red mud based on the characteristics of mechanical properties, durability, microstructure and environmental impact analysis. The results show that RMD increases the mechanical properties and durability of concrete while reducing its fluidity. Furthermore, by integrating 25% RDM, the environmental consequences of cumulative energy demand (CED), global warming potential (GWP), and major criteria air pollutants (CO, NOX, Pb, and SO2) are minimized. Additionally, this review assesses concrete guidelines for future researchers with RDM improving performance [16].

Research to used coarse bauxite residue in road construction has the potential for large volume reuse. This study investigated whether coarse bauxite residue is a viable road-based material in Western Australia. A pozzolanic-stabilized mixture was created to improve the properties of the residue, to satisfy the minimum requirements for road base. Laboratory tests for resilient modulus and permanent deformation were then performed. Comparisons were made between the stabilized residue and conventional road-based material in Western Australia. The performance of the stabilized residue was superior to that of the conventional material, and can provide improved performance when used as road base material in Western Australia [17].

Table 2. Chemical Composition of Red Mud from various journal references.

Major Composition (wt%)						**References**
Al_2O_3	**Fe_2O_3**	**SiO_3**	**TiO_2**	**Na_2O**	**CaO**	
10.05	6.75	22.20	2.55	3.00	42.25	Liu et al, 2014
18.49	31.26	8.35	6.18	3.23	18.05	Rao, 2010
8.03	17.54	18.19	4.81	3.21	44.64	Zhang et al, 2018
25.11	36.43	16.93	6.02	12.27	1.54	Zhang et al, 2019
7.60	8.20	20.40	7.30	3.00	44.70	Jiang et al, 2017
9.18	6.66	18.10	6.72	4.00	38.09	Nan et al, 2009
19.80	39.23	8.77	10.09	5.02	4.54	Perez-Vallarejo, et al 2012
19.00	38.00	19.90	3.83	8.58	0.87	Hildebrando et al, 2013
22.36	34.27	8.31	17.13	6.12	1.73	Samal et al, 2015
20.00	46.00	5.00	6.00	8.00	1.00	Srikanth et al, 2005
19.95	40.80	6.80	5.80	2.70	12.60	Tsakiridis et al, 2004

Based on Table 2, it can be seen that in general the chemical composition of red mud is dominated by the chemical element Al2O3. The high Composition of aluminum content in red mud indicates that bauxite stone washing or processing waste can still be used as a

binding agent as a substitute for fine aggregate in concrete mixtures. The research results of Irzon (2018) show that bauxite waste on Selayar Island, Riau Islands has the Composition Al_2O_3, Fe2O_3, SiO3 and TiO_2. Sujarmiko's research (2020) shows that bauxite waste in Sanggau Regency, West Kalimantan is dominated by the chemical composition Al2O3, Fe2O3, SiO3, TiO2 as well as Na2O and CaO. The chemical composition of bauxite waste is similar to the Composition of sand. The difference is in the percentage content of each Composition. Bauxite waste is dominated by Al2 O3 content while sand is dominated by SiO_2 content (Fig. 2).

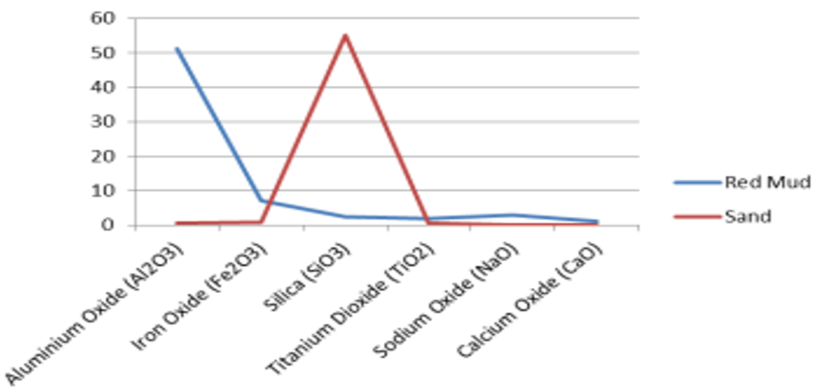

Fig. 2. Comparison of the chemical composition of red mud and sand.

Research to examined the characteristics of the bauxite mineral content found in the Tayan Mine area, West Kalimantan which was processed using the Bayer method. The characteristic of bauxite gabbro is that it has a concretion texture with the dominant minerals being aluminum hydroxide and iron oxide. The dominant geochemical elements are Al2O3 and FeO. The semi-quantitative XRD method shows the dominant mineral content of buhmite, goethite and halloysite. Granodiorite bauxite has a concretion texture with the dominant minerals being iron oxide and quartz. The dominant geochemical elements are Al_2O_3 and SiO_2 . The semi-quantitative XRD method shows the dominant mineral content in the form of gibbsite, diaspor, hematite and halloysite. These bauxite characteristics are thought to influence the efficiency of the Bayer process [18] .

Table 3 shows that red mud can replace the Composition of sand in the concrete mixture by up to 100%, while in other research, red mud can replace the position of sand and cement in the concrete mix in various percentages. The difference in the amount of red mud used as a substitute for sand or cement is because each research was conducted in a different place with different levels of red mud chemical content. Based on the results of this research, it can be concluded that red mud can be fully used as a substitute for sand but cannot be used entirely as a substitute for cement. Based on this study, the amount of red mud composition that can be used as a substitute for fine aggregate, especially as a substitute for sand, is in the range of 10% -20%. The best planting concrete performance was achieved at an A/P ratio of 0.2, with silica fume and diatomite contents 10% and 5%, respectively [22].

Table 3. Comparison of using red mud as a substitute for sand and cement in concrete mixes.

Research	Red Mud	Sand	Cement
Santi and Aqla (2018)	60%	-	40%
Sujarmiko (2020)	3.33%	10%	-
Danso and Boadi (2019)	100%	0	-
Zhang et al (2020)	18%	20%	-
Qureshi et al (2022)	25%	20%	-
Revathi et al (2023)	20%	-	20%
Sharma and Jain (2022)	5-20%	-	20%
Vishawakarma et al (2022)	5-60%	-	25%
Girish and Bajamma (2022)	0-20%		25%
Sethi et al (2019)	0 – 20%	-	20%

Research shows that the Riau Islands region, specifically Lingga Regency, has quite high bauxite potential. Based on the results of field surveys and laboratory analysis, the bauxite potential in Lingga Regency is spread relatively evenly across Singkep Island, Selayar Island, Bendahara Island, Rusuk Buaya Island, and most of the islands in the northwest-southwest of Singkep Island. Potential levels of Al 2 0 3 are found on Bendahara Island and Rusuk Buaya Island [19] .

Bauxite processing residue using the Bayer process in the form of redmud can harm the environment if not handled properly because its pH is very alkaline. However, apart from the negative impacts it causes, redmud can be used in several applications such as geopolymer materials, catalysts and soil conditioners [20] . The results of the analysis are as follows (Table 4).

Table 4. Physical test results for coarse aggregate and fine aggregate on bauxite.

No	Test Type	Unit	Fine Aggregate	Coarse Aggregate
1	Water content	%	2.91	3.96
2	SSD Specific Gravity		2.55	2.53
3	Water Absorption	%	0.62	0.23
4	Effective Content Weight	g/cm^3	1.43	1.53
5	Sieve Analysis		zone 3	-
6	Maximum Grain Size	mmm	-	20.00

Source: various references, processed.

From the test results it can be seen that the water content in the coarse aggregate is 2.91 % and the fine aggregate is 3.96%. This aggregate meets SNI-03-1971-1990 standards and is suitable for use in concrete mixtures. For aggregate used as a mixture in concrete mix, it is 2% - 8%. So there is no need to add or subtract from the value of the amount of water needed. The amount of water contained in this aggregate needs to be known, because it will affect the amount of water needed in the concrete mixture. Wet aggregate (containing a lot of water) will make the mixture wetter and vice versa [1] .

When cement is hydrated, quartz and calcium oxide react, assisting in the development of CSH gel. The presence of larnite and hatrurite in the red mud concrete provides conclusive evidence that CSH gel was formed, giving the concrete strength qualities [16] .Based on the results of previous studies, it is known that bauxite found in Indonesia, specifically in the Riau Islands, has characteristics almost the same as bauxite results in other countries dominated by Al_20_3 content elements. At the same time, the composition of red mud as a substitute for aggregate follows the rules of use. Concrete to see the amount of compressive strength produced.

Utilization of bauxite waste as fine aggregate is very beneficial for the continuity of sustainable road construction work. This waste is not thrown away, but is used as a substitute for cement or sand. In terms of replacing cement, it can be used at a rate of 40%, while in replacing sand, this bauxite waste can replace the role of sand in the concrete mix at a rate of around 5% to 20% of the total concrete mix. The research results of Liu and Wei (2021) and Qureshi et al (2022) show that 10% bauxite waste content has the highest compressive strength value at 7 days. Based on the results of these studies, researchers conducted experiments using bauxite waste levels of between 10% and 15% to see which composition produces the highest compressive strength and lowest shrinkage.

Concrete mix of 0%, 10%, 20% and 30% replacement of fly ash and constant replacement of 20% of Red mud in cement were made. Partial replacement of Red mud and fly ash as replacement of cement in the preparation of concrete bricks [25]. The experiment investigations revealed that both mechanical properties and the tensile strenght of concrete diminish when red mud content was increased (higher than 10%). The ideal replacement rate for cement in terms of weight discover to be 10%. Result from this substitution are almost on par with those of ordinary concrete. For non structural operations, red mud and cement are mixed together [26].

The amount of compaction factor increases with an increase in the percentage of red mud from 0% to 60% in both wet or non-liquid lime. The highest quality compression was obtained in 10% red mud for 7 days and 28 days for healing. With more than 10% change the concrete compression strength decreases [27]. Red mud can be effectively used as replacement material for cement and replacement enables the large utilization of waste product. Red mud did not affect the cement properties rather improved the cement quality by way reducing the setting time, improving compressive strength and tensile strength[2].

The optimum value of the compressive strength of red mud concrete for 7 days curing was observed at 10% red mud replacement. And also for 28 days compressive strength observed at 10% red mud replacement. The compressive strength of concrete using 5% hydrated lime is more as compared with the concrete without hydrated lime. The optimum value of split tensile strength by using hydrated lime and without using hydrated lime are observed at 10% red mud replacement. And also split tensile strength is high for 5% hydrated lime concrete [28].

Replacement up to 15% the compressive strength values of the red mud concrete coincides with that of conventional concrete. But beyond 10% there is a reduction in the strength value of the concrete. Optimum percentage of the replacement of cement by weight is found to be 10%. By this replacement results got are greater than to the results of conventional concrete [29]. The strength properties of concrete increased by replacing

cement with Red mud by 20% of weight of cement. In case of its durability property, water absorption percentage of the concrete replaced with 30% Red mud by weight of cement is lower than that of conventional OPC concrete. Surface resistivity value is slightly higher when compared with the conventional concrete. Higher the surface resistivity value, lower the conduction property of concrete [30]. In many ways, it is discouraging that despite so much work over the last century only some 2–3 % of the 150 million tonnes of bauxite residue produced annually is used in a productive way. Some of the applications have been economically attractive for a number of years and then factors have changed which renders them no longer economically viable [31].

Quantitative descriptive analysis describes a situation or problem that it is easier to understand using numbers, tables and graphs [32]. If analyzed quantitatively in rupiah, the use of bauxite waste as a fine aggregate material can provide savings of approximately IDR 200,000 per colt assuming the bauxite waste is obtained free of charge and the only costs charged are shipping costs and if it is for cement replacement, the savings can be IDR 40,000 – IDR 55,000 per m^3. The price for casting K300 quality concrete 15 cm thick plus labor services is IDR 327,000/m^2, while K350 quality concrete is IDR 329,000/m^2. So, in building a 1 km road, the Rupiah value that can be saved is approximately IDR 300,000 to IDR 400,000. This breakthrough is very useful in terms of value engineering in the field of road construction.

4 CONCLUSION

The article relates to a thorough examination of dozens of papers related to the use of bauxite waste, both waste as a substitute for fine aggregate and coarse aggregate. The object studied concerns the use of bauxite waste as a partial replacement for sand and cement materials in highway construction. Analysis and studies regarding the use of bauxite waste, also known as red mud, as a concrete mixture for highways, have not been fully explored. Therefore, the use of bauxite waste material as a partial substitute for fine and coarse aggregate in concrete can be carried out by carrying out an analysis of its chemical properties, physical properties, durability and mechanical properties. This can be analyzed further, using visual methods, inspection and experiments in road and bridge laboratories. The experimental analysis used can be related to the chemical elements contained in bauxite material, density and porosity tests using Scanning Electron Microscopy / Energy Dispersive Spectroscopy (SEM/EDS), compressive strength tests, fatigue tests, split tests, flexibility tests and others. The use of bauxite waste as a substitute for fine aggregate in sand in the top layer of concrete mix can increase strength, but density also increases to a certain level, namely with sand substitution of up to 20%. Several investigations into the cement content of red mud show that every time cement is replaced with red mud, with a certain composition, the properties change. Tests on mortar bonding showed that the use of red mud to a certain extent as a cement substitute in mortar showed better compression qualities than ordinary cement mortar. Some analyses show that red mud can effectively replace about 10–20% of cement, where the replacement rate also depends on the source of the red mud. Thus, the use of red mud as a substitute for fine aggregate in concrete mixtures, for example in the top layer of road construction, can increase cost efficiency to a certain level and is beneficial for reusable road materials.

References

1. S. Hariyani, Asmadi, and M. Rafani. Pemanfaatan Limbah Pengolahan Bauksit untuk Pembuatan Agregat Buatan. Retensi - J. Rekayasa Tek. Sipil, vol. 1, no. 1, pp. 31–35. (2020).

2. V. Shirodkar, R. Patel, and M. Verma. Utilization of Red Mud in Cementitious Concrete - A Review. Int. J. Adv. Res. Eng. Technol., vol. 11, no. 2, pp. 426–430. (2020). doi: http:dx.doi.org/ 10.17605/OSF.IO/HGN3W
3. S. Wang, H. Jin, Y. Deng, and Y. Xiao. Comprehensive Utilization Status of Red Mud in China: A Critical Review. J. Pre Proof, p. 125136. (2020). Doi: https://doi.org/10.1016/j.jclepro.2020.125136
4. A. Lisantono, J. J. Sudjati, and A. E. Lianasari. Flexural Behavior of Fly Ash-Based Geopolymer R/C Beam with Bauxite Material As Coarse Aggregates. Int. J. Geomate, vol. 18, no. 65, pp. 80–85. (2020). doi: https://doi.org/10.21660/2020.65.43211
5. E. Rabihati, M. S. Adjie, and V. D. Rachmawan. Pemanfaatan Limbah Bauksit (Tailing Bauxite) sebagai bahan pengganti Agregat Halus terhadap Kuat Tekan, Kuat Tarik Belah dan Modulus Elastisitas pada Beton. Retensi - J. Rekayasa Tek. Sipil, vol. 1, no. 1, pp. 16– 22. (2020).
6. S. Hariyani, R. M. Arif, M. A. Farizky, and M. Nuryani. Pengaruh Limbah Bauksit sebagai Pengganti Pasir terhadap Kuat Tekan dan Daya Serap Batako. Retensi - J. Rekayasa Tek. Sipil, vol. 2, no. 2, pp. 1–5. (2022).
7. M. Santi and S. Aqla. Pemanfaatan Tailing Bauksit Sebagai Bahan Campuran Pengganti Pasir Pada Pembuatan Paving Block. Politeknosains, vol. XVII, no. 1, pp. 42–46. (2018).
8. P. Sujarmiko. Potensi Tailing Hasil Pencucian Bauksit Sebagai Pengganti Agregat Halus di Kabupaten Sanggau Kalimantan Barat. Strategi. Pengelolaan Lingkung. Sumberd. Miner. dan Energi Untuk Pembang. Berkelanjutan, no. November, pp. 46–51. (2020). doi: https://doi.org/10.31315/psb.v2i1.4444
9. A. E. Lianasari. Potensi Batu Bauksit Pulau Bintan Sebagai Pengganti Agregat Kasar Pada Beton. J. Tek. Sipil, vol. 12, no. 3. (2016). doi: https://doi.org/10.24002/jts.v12i3.623
10. A. E. Lianasari, A. Lisantono, and J. J. Sudjati. Shear behavior of fly ash-based geopolymer R/C beam with bauxites as coarse aggregates: Experimental program. Int. J. GEOMATE, vol. 20, no. 79, pp. 155–160. (2021). doi: https://doi.org/10.21660/2021.79.j2039
11. H. Danso and J. K. Boadi. Replacement of Sand with Bauxite Mining Waste in Concrete Production. J. Mater. Eng. Struct., vol. 6, no. 2019, pp. 525–534. (2019).
12. J. Choudhary, B. Kumar, and A. Gupta. Performance evaluation of bauxite residue modified asphalt concrete mixes. Eur. J. Environ. Civ. Eng., vol. 0, no. 0, pp. 1–17. (2019). doi: https://doi.org/10.1080/19648189.2019.1691662
13. J. Zhang et al. Sustainable utilization of bauxite residue (Red Mud) as a road material in pavements: A critical review. Constr. Build. Mater., no. xxxx, p. 121419. (2020). doi: https://doi.org/10.1016/j.conbuildmat.2020.121419
14. M. P. Pohan. Tinjauan Pemanfaatan Tailing Tambang Bijih untuk Bahan Bangunan sebagai Solusi di Bidang Konstruksi. Bul. Sumber Daya Geol., vol. 3, no. 1. (2008). doi: https://doi.org/10.47599/bsdg.v3i1.152
15. A. S. Raghubanshi, M. Mudgal, R. Chouhan, A. Kumar, and A. K. Srivastava. Recycling and potential utilization of red mud (Bauxite Residue) for construction industry applications. Indian J. Eng. Mater. Sci., vol. 29, no. August, pp. 401–410. (2022). doi: https://doi.org/10.56042/ijems.v29i4.52349
16. F. Zhang, L. H. Poh, and M. H. Zhang. Effect of bauxite aggregate in cement composites on mechanical properties and resistance against high-velocity projectile impact. Cem. Concr. Compos., vol. 118, no. April. (2021). doi: https://doi.org/10.1016/j.cemconcomp.2020.103915

17. T. Croymans et al. Radiological characterization and evaluation of high-volume bauxite residue alkali-activated concretes. J. Environ. Radioact., vol. 168, pp. 21–29. (2017). doi: https://doi.org/10.1016/j.jenvrad.2016.08.013
18. Y. Liu and Y. Wei. Effect of calcined bauxite powder or aggregate on the shrinkage properties of UHPC. Cem. Concr. Compos., vol. 118, no. January, p. 103967. (2021). doi: https://doi.org/10.1016/j.cemconcomp.2021.103967
19. H. J. Qureshi, J. Ahmad, A. Majdi, M. U. Saleem, A. F. Al Fuhaid, and M. Arifuzzaman. A Study on Sustainable Concrete with Partial Substitution of Cement with Red Mud: A Review. Materials (Basel)., vol. 15, no. 7761, pp. 1–26. (2022). doi: https://doi.org/10.3390/ma15217761
20. P. Jitsangiam and H. Nikraz. Sustainable use of coarse bauxite residue for alternative roadway construction materials. Aust. J. Civ. Eng., vol. 11, no. 1, pp. 1–12. (2013). doi: https://doi.org/10.7158/C11-711.2013.11.1
21. D. Wulandari, L. D. Setijadji, and I. W. Warmada. Karakteristik Kandungan Mineral dalam bauksit dengan Metode XRD semi kuantitatif di kawasan tambang Tayan Kalimantan Barat. in Proceeding Seminar Nasional Kebumian Ke-9. (2016).
22. W. Chen and J. Li. Effects of Different Silicon Sources on the Properties of Geopolymer Planting Concrete Mixed with Red Mud. Sustainability, vol. 15, no. 4427, pp. 1–21. (2023). doi: https://doi.org/10.3390/su15054427
23. D. V. Mamengko. Potensi Bauksit di Kabupaten Lingga Provinsi Kepulauan Riau. ISTECH J. Inf. Media Sci. Technol., vol. 5, no. 2, pp. 65–69. (2013).
24. A. F. Jaya, M. P. Rumapea, and N. K. Akbar. Implementasi integrasi proses pengolahan bauksit dan pemanfaatan Red Mud di Tayan, Kalimantan Barat untuk Indonesia Maju 2045. in Prosiding TPT XX!X, pp. 653–664. (2020).
25. M. Revathi, M. Aishwarya, K. Akhil, M. B. Naik, T. S. Vaibhav, and K. Akhil. Partial Replacement of Cement with Red Mud and Fly Ash in Preparation of Concrete Bricks. IJARST Int. J. Adv. Res. Sci. Technol., vol. 12, no. 12, pp. 324–333. (2022). doi: https://doi.org/10.1007/978-3-030-51354-2_6
26. P. Sharma and A. K. Jain. Experimental Investigation on a Concrete Sample using Red Mud as a Partial Replacement of Portland Cement Lit. Res. J. Eng. Technol. Med. Sci., vol. 05, no. 03, pp. 10–19. (2022).
27. R. Vishwakarma, G. Bhoi, and M. R. Patel. Suitability and Utilization of Neutralized Red Mud and Hydrated Lime as a Partial Replacement of Cement in Concrete. Int. J. Reseacrh Appl. Sci. Eng. Technol., vol. 10, no. 5, pp. 2570–2574. (2022).
28. P. Girish and S. K. Bajamma. Experimental study on concrete & mortar by partial replacement of cement with red mud. J. Eng. Sci., vol. 13, no. 12, pp. 267–278. (2022).
29. P. Sethi and S. R. Sarangi. Internet of Things: Architectures, Protocols, and Applications. J. Electr. Comput. Eng., vol. 2017. (2017). doi: https://doi.org/10.1155/2017/9324035
30. K. Viyasun, R. Anuradha, K. Thangapandi, D. S. Kumar, A. Sivakrishna, and R. Gobinath. Materials Today: Proceedings Investigation on performance of red mud based concrete. Mater. Today, Proc., no. xxxx. (2020). doi: https://doi.org/10.1016/j.matpr.2020.09.637

31. K. Evans. The History, Challenges, and New Developments in the Management and Use of Bauxite Residue. J. Sustain. Metall., vol. 2, no. 4, pp. 316–331. (2016). doi: https://doi.org/10.1007/s40831-016-0060-x
32. Biantoro, Agung Wahyudi and Muh. Kholil. 2020. Statistika Penelitian : Analisis Manual dan IBM SPSS. Publisher El Markazi – Waru Sejahtera Press. ISBN : 978-623-6865-73-6. https://warusafety.com/analisis-statistik-deskriptif-dan-distribusi-frekuensi/