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Research Article

Utilization of Radioactive Contaminated EAF Dust as Material for Making Paving Block

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ABSTRACT

Electric arc furnace dust, due to steel fabrication by-products, some of that material has been contaminated with radioactive materials from orphan sources. After calculating the concentration of radionuclide activity, it is known that the material meets the criteria for clearance of application and can be used for other purposes according to the appropriate characteristics. By determining the clearance, EAF dust will be processed through a stabilization/solidification method to be used as a material for making paving blocks. Through elemental analysis of EAF dust using the Micro-XRF method, it is known that sample 1 has a Ca content of 3.9%, CaO is 5.51%, Si is 0.64%, and SiO₂ is 1.36%, while sample 2 has Ca content. 4.8%, CaO 6.74% Si 0.63% and SiO₂ 1.34%. The compressive strength test results based on Indonesian National Standard (SNI) 03-0691-1996 give the results of paving blocks included in quality D with a value of 9.2 MPa which can be used for parks or other purposes. In the calculation of cost savings analysis, determining the clearance for EAF dust can provide cost savings of Rp. 205,562,000 compared to if it had to be managed as radioactive waste. The production cost for one paving block using a mixture of EAF dust is Rp. 2,213.77 or Rp. 97,405.88 for units per m².

Keywords: *Cost Saving, Clearance Level, EAF Dust, Radioactively Contaminated Material, Stabilization/Solidification*

Introduction

Electric arc furnace dust (EAF dust) is a residual in the form of fine grains originating from the smelting furnace of an iron-steel processing facility (Chiu et al., 2019). This material comes from the remaining raw materials in the form of metal scrap, which cannot be melted completely from an electric arc furnace (Huang

et al., 2021). This material collects in the dust filter section and the fine dust collector section (Sikarwar et al., 2020). EAF dust has the form of fine particles with sizes ranging from 20-500 μm to the smallest below 20 μm (Ranjetha et al., 2022). These materials have economic value and become export commodities through the use of these materials to be processed into

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supporting products such as Zirconium silicate and Zircon flour in countries that already have processing technology (De Buzin et al., 2017). EAF dust is currently classified as registered non-hazardous and toxic waste (Ministry of Environmental and Forestry, 2021). This grouping facilitates the process of the reuse of materials into products that match the characteristics of EAF dust (Esther et al., 2020).

In 2019 there was an incident of radioactive contamination originating from Cs-137 radionuclide on the export commodity of EAF dust, and it was detected at the port of arrival in the destination country (Nuclear Waste Management Installation-Directorate for Nuclear Facilities Management-BRIN, 2019). It is unknown where the radioactive substance came from or its ownership status and defined as orphan sources. This incident resulted in the return of these commodities to Indonesia and incurred considerable costs for exporters. One of the costs required to manage the contaminated material is the cost of storing radioactive waste. There is an alternative way to save costs for managing radioactively contaminated materials, namely by applying for a determination of clearance where materials/substrates that have a concentration value of radionuclide activity at the clearance level are exempt from supervision and the obligation to have a utilization permit.

Determination of clearances is an alternative solution because, in the implementation of radioactively contaminated material management, exporters experience problems in radioactive waste storage schemes due to the high costs required (Yang, 2022). Through the determination of clearances, radioactive contaminated EAF dust can be handed over to a solid hazardous and toxic waste management facility because, through this mechanism, the presence of radioactive substances can be freed from government control (Boulos et al., 2023). Apart from being stored in the facility, EAF dust that has obtained a clearance determination can be utilized through the stabilization/solidification method (Falciglia et al., 2017). This technology has been widely used for the treatment of solid hazardous and toxic waste, especially those from coal-type power plants (fly ash-bottom ash) and residual steel processing (Omran &

Fabritius, 2017). The stabilization/solidification process is relatively easy to implement and does not require the availability of equipment with sophisticated technology because, basically, this method utilizes a pozzolanic reaction in the form of cement bonds in the concrete mixture (Masrullita et al., 2018). The type of product produced using the stabilization/solidification method in managing EAF dust is a paving block (Goyal et al., 2022). The exporter hands over the remaining EAF dust that meets the requirements for the clearance level to a company that already has a hazardous and toxic waste management permit to be processed into paving block. Paving block are expected to comply with SNI 03-0691-1996 as a quality standard for paving block products in Indonesia (Amaral et al., 2019).

This research will focus on the analysis of the concentration of radionuclide activity in EAF dust samples to find out whether they can be classified according to the clearance level or treated as radioactive waste. After being stated in the determination of clearances, the use of the stabilization/solidification method is applied to the processing of EAF dust through the use of this material as a raw material for making paving block (Alsheltat & Elfigih, 2023). Furthermore, the compressive strength test is carried out according to the standards applicable to the paving block product (Singh et al., 2022). In addition, this study also discusses the cost-saving aspects of managing radioactively contaminated EAF dust through the determination of clearances (Collivignarelli et al., 2020).

Methods

EAF dust

The EAF dust used in the study came from exporters who experienced radioactive contamination in the form of Cs-137 radionuclide originating from orphan sources. The value of the clearance level for Cs-137 radionuclide is 1 Bq/g. Based on that parameter, if the concentration value of the material activity is within the clearance level and is released from obligation to have a license. The number of EAF dust samples was two samples taken from the jumbo bag of EAF dust, which had the highest concentration of radionuclide activity (Araujo et al., 2022). EAF dust will also undergo a test

for elemental content using the Mico-XRF method using the Bruker X-Ray Fluorescence (XRF) equipment model M4 Tornado to determine the composition of its constituent elements, especially those derived from metal elements. Testing the concentration of radionuclide activity and elemental analysis of EAF dust was carried out in an accredited laboratory (Rasaki et al., 2019).

Clearance Establishment Regulation

Clearance are released from regulatory body (Bapeten) supervision of unshielded radioactive substances, radioactive waste, or contaminated or activated materials. The clearance level is the value set by regulatory body and expressed in activity concentration; at or below that value, open radioactive substances, radioactive waste, or contaminated or activated materials can be released from supervision. The International Atomic Energy Agency (IAEA) also provides guidelines for its member countries regarding the application of clearance, as stated in Safety Guide No. RS-G-1.7: Application of the Concept of Exclusion, Exemption and Clearance, which contains provisions on the application of the principles of exclusion, exemption and clearance in each member country (Nunes & Borges, 2021). Determination of clearance provides the consequence of exemption from the obligation to have a permit to use from a regulatory agency for a material/object that has radioactive content in it. This designation also makes it possible to freely release this material into the environment, but there is no safety justification for doing so. Instead, radioactively contaminated material should not be released into the environment at all (Bamigboye et al., 2021).

Stabilization/Solidification Methods

The stabilization/solidification method is a process that involves mixing waste with a binder to reduce the leaching of contaminants both physically and chemically (Anrozi et al., 2017). This method is generally used to treat solid B3 waste as a mixture for making street asphalt, a mixture of fillers in mortar mix, making paving block (Mohasin et al., 2022). One of the products of this method is paving block. Paving block is a building material composition

which has a mixture of cement or hydraulic adhesive materials similar to water and aggregate with or without other additives (Han et al., 2020).

Utilization of EAF dust in the manufacture of the paving block is used as an additional or substitute material because the material contains metal elements such as Iron (Fe), Magnesium (Mg), Manganese (Mn), and other elements such as Carbon (C), Oxygen (O), Sodium (Na), Calcium (Ca) which has the potential to be used as a substitute for sand and cement (Rajagukguk & Surbakti, 2021). The stabilization/solidification process in EAFD as a material for making concrete can react chemically to form a pozzolanic reaction due to the presence of iron (Fe), calcium (Ca) and silica (Si) in EAFD which are also present in cement (He et al., 2021).

Paving Block Compressive Strength Test

Paving block that using EAF dust as a manufacturing material will undergo a compressive strength test in accordance with the Indonesian National Standard (SNI) 03-0691-1996 for paving block for floors with the classification of paving block of quality A to D. Paving block of quality A have a compressive strength value. An average of 40 MPa and a minimum compressive strength value of 35 MPa for use on roads. Quality B paving block has an average compressive strength value of 20 MPa and a minimum compressive strength value of 17 MPa with the allotment of use in parking lots (Falciglia et al., 2017). C-quality paving block has a compressive strength value of 15 MPa and a minimum compressive strength value of 12.5 MPa with the designation of use for pedestrians (Omran & Fabritius, 2017). Quality D paving block has an average compressive strength value of 10 MPa and a minimum compressive strength value of 8.5 MPa with the allotment of use as parks and other uses (De Buzin et al., 2017). The concrete strength test is carried out in a laboratory that has accreditation according to the SNI test that applies to paving blocks (Rakhimova, 2022).

Cost Savings Aspect

Calculation of the cost-saving aspect is carried out by analyzing the cost components for

compacting solid B3 waste storage at the waste storage facility belonging to the Nuclear Waste Management Installation-Directorate for Nuclear Facilities Management (IPLN-DPFK) – National Research and Innovation Agency with the cost component referring to the Regulation of the Minister of Finance (PMK) Number 210 of 2021 concerning Types and Tariffs for Types of Urgent Necessity Non-Tax State Revenues that Apply to the National Research and Innovation Agency (Guo & Sasaki, 2022). The analysis of these cost components will be compared with the cost components needed to process EAF dust into paving block (Donald et al., 2022).

Result and Discussion

EAF Dust Elemental Analysis

Analysis of EAF dust elements was carried out using the Micro-XRF reading method. Through this equipment, the distribution of the constituent elements of EAF dust can be identified. Elemental analysis of EAF dust was carried out to determine the percentage content of Silica (Si), Iron (Fe) and Calcium (Ca) as elements present in cement so that it becomes a guideline for whether or not EAF dust is used in making paving block. Table 1 shows the results of the elemental analysis of EAF dust from the readings of two samples.

Table 1. Elemental analysis Result of EAF Dust

Element name	Sample 1	Sample 2
Iron (Fe)	23.37	24.03
Calcium (Ca)	3.9	4.8
Calcium Oxide (CaO)	5.51	6.74
Silica (Si)	0.64	0.63
Silica Oxide (SiO ₂)	1.36	1.34

Based on the results of the analysis, it is known that radioactively contaminated EAF dust contains low percentages of Silica (Si), Silica Oxide (SiO₂), Calcium (Ca) and Calcium Oxide (CaO) so that theoretically, it can make paving block stronger. This is consistent with preliminary research on the effect of Silica Oxide, polyethylene and shelf life on compressive strength and water absorption in paving block (Hambali et al., 2013). The use of silica sand as a substitute for sand can increase the strength of the paving block with a curing time of 28 days (Luthfizar et al., 2019).

Clearance Establishment

The determination of clearance is carried out by submitting an application to regulatory body with the guidance of Bapeten Regulation Number 16 of 2012 concerning Level of Clearance. The regulation contains provisions for determining clearance by submitting the results of radiation exposure measurements and analysis documents regarding activity concentrations. Based on the results of measuring the radionuclide activity concentration (RAC) of each jumbo bag of EAF dust, these values were obtained, as shown in Table 2.

Table 2. Radionuclide activity concentration value

No	Sample Code	Weight (kg)	RAC (Bq/kg)
1	Bag-28	757	6.82 ± 0.73
2	Bag-33	718	44.18 ± 1.70
3	Bag-23	976.5	93.16 ± 2.29
4	Bag-37	709	23.4 ± 1.86
5	Bag-38	604.5	54.36 ± 1.79
6	Bag-39	872	71.25 ± 3.08
7	Bag-40	1048	63.52 ± 1.73
8	Bag-41	977.5	55.91 ± 2.03
9	Bag-42	798	91.33 ± 2.63
10	Bag-43	762	55.8 ± 1.87

Bapeten issues an approval letter to manage radioactively contaminated EAF dust with a radionuclide activity concentration value of 1 Bq/g with a statement that the EAF dust has been verified to meet the criteria for the clearance level or the criteria for exemption from permits so that it can be used for purposes according to its characteristics. Through the determination of clearances, EAF dust has a legal basis to be able to cover its processing activities into paving block.

Processing of EAF Dust into Paving Block

Paving block production begins with providing raw materials in the form of coarse sieve sand (180 kg), lime (8 kg), bottom ash waste (80 kg), mixed metal waste (44 kg), cement (100 kg) and sugar industry wastewater (3 liters). The entire material is put into the mixer until it is evenly mixed and then printed using a printer. Once fully formed, remove it from the machine, then dry it for up to 24 hours. The next step is to soak it in a pool of water for 48 hours and then dry it for 24 days for curing process. After being left for 24 days, the product sorting process is carried out. Products that do not pass sorting will be put back into the dough to be made into paving block again.

In one production batch, it can produce 150 rectangular paving block with a size of 21 cm (length) x 10 cm (width) and 7 cm (thickness) weighing 2.5 kg each.

The use of EAF dust replaced 30 kg of cement and 40 kg of sand so that the composition of the materials for making paving block in this study was 140 kg of coarse sieve sand, 8 kg of lime, 44 kg of mixed metal waste, 80 kg of bottom ash waste, 70 kg of cement, 70 kg of EAF dust and 3 litres of sugar industry wastewater. The composition is based on the provisions made by the solid B3 waste processing facility. In this study, no comparison was made between the percentage of EAF dust used in the manufacture of paving block and its effect on the compressive strength test.

Compressive Strength Testing of Paving Block

The compressive strength test of paving block was carried out by taking 15 samples. Tests were carried out based on SNI 03-0691-1996 with A grade quality (use of paving block for roads) to determine the strength of the paving block when receiving maximum pressure. The results of the compressive strength test can be seen in Table 3.

Table 3. Paving block compressive strength test results

Size	Measurement
Long	204.62 mm
Wide	104.68 mm
Thick	74.42 mm
Compressive strength	Measurement
Speciment length	85.25 mm
Specimen width	85.42 mm
Wide	6985.28 mm ²
Crush load	54298.5 N
Strong press	9.2 Mpa

Based on the results of the compressive strength test, paving block made using EAF dust have a compressive strength value of 9.2 MPa, where this value is included in the quality D paving block with the allotment of use for garden purposes and other purposes. In this test, the percentage of EAF dust used was 30%

as a substitute for sand and cement. The quality of the paving block in this study was low because theoretically, the percentages of Silica (Si), Silica Oxide (SiO₂), Calcium (Ca), and Calcium Oxide (CaO) content obtained from the results of Micro-XRF analysis were low enough to affect the strength paving block structure.



Figure 1. Paving block processing

To get maximum compressive strength test results, namely A quality, the manufacture of paving blocks can use several additional materials such as silica sand and silica fume. This is by preliminary research, which shows that the addition of silica fume can strengthen paving blocks compared to no additions (Endika et al.,

2016). The addition of the percentage of cement can also be done to strengthen the paving block structure utilizing the pozzolanic principle of the elements present in Portland cement. In Table 4, there is a chemical composition of Portland cement produced by PT. Semen Padang.

Table 4. Elemental composition of Portland cement

Elemental component	Percentage (%)
CaO	65.07
MgO	0.78
SiO ₂	21.94
Al ₂ O ₃	5.46
Fe ₂ O ₃	3.43
SO ₃	1.74
Another element	1.62

Based on Table 4, it is known that Portland cement contains significant CaO and SiO₂, so theoretically, it can significantly increase the strength of the paving block (Hambali *et al.*, 2013). In the manufacture of paving blocks, it is known that the addition of bottom ash waste and mixed metal waste with an unknown composition of the elements inside it can affect the level of strength.

Cost Saving Analysis

The analysis was carried out with the assumption that EAF dust is radioactive waste so that it is subject to the obligation to store it at the nuclear waste storage facility at IPLN-DPFK-BRIN as solid waste (Bapeten, 2013). The solid waste treatment process includes preparation, pressing/compacting, and

cementation processes. The pressing process is a waste volume reduction process using a compactor (pressing machine). This process is carried out with a compactor pressure of 600-kilo newtons (kN). Through Regulation of the Minister of Finance No. 210, it is known that the service fee for radioactive waste treatment for compacted gamma emitter (γ) low-activity solid waste is Rp. 2,500,000 per 100 litres. Based on Table 2, it is known that the total weight of radioactively contaminated EAF dust is 8,222.5 kg, so the cost required to store EAF dust is Rp. 205,562,000.

Meanwhile, if the EAF dust has gone through the clearance determination mechanism, then the material does not have to be stored at the IPLN-DPFK-BRIN and can be used as a material for making paving blocks. The cost calculation

is based on the condition of the B3 waste processing facility, which actually gets fees from other companies for the storage of the B3 waste

they produce so that the costs for bottom ash waste.

Table 5. EAF dust treatment cost components (in Rupiah)

Material	Need	Retail price (Rp)	Cost (Rp)
Sand	140 kg	Rp. 242,000/m ³	Rp. 44,000
Cement	70 kg	Rp. 75,000 per 50 kg	Rp. 75,000
Limestone	8 kg	Rp. 10,000/kg	Rp. 80,000
Bottom ash waste	80 kg	Rp. 0	Rp. 0
Metal waste	44 kg	Rp. 0	Rp. 0
EAF dust	70 kg	Rp. 0	Rp. 0
Sugarcane wastewater	3 liter	Rp. 0	Rp. 0
Total cost of raw materials		Rp. 273,560	

Each production batch can produce 150 paving blocks with a standard rectangular size of 21 cm (length) x 10 cm (width) and 7 cm (thickness). In one day, the facility can make eight batches of rectangular shape production so that in one month (25 working days), as many as 30,000 paving blocks are produced. In addition to rectangular paving blocks, the processing facility also produces hexagonal and

worm-shaped paving blocks at 5,000 and 15,000 pieces, respectively, per month so that it is known that the loading percentage on each paving block product is 60% for rectangular paving blocks, 10% for hexagonal paving blocks and 30% for worm-shaped paving blocks. Based on this information, the cost of production of rectangular paving blocks for one month is obtained, as shown in Table 6.

Table 6. Monthly production cost (in Rupiah)

Raw material cost		
Rp. 273.560 x 8 x 25		Rp. 54.712.000
Direct labor cost		
Bagian Produksi	30.000 x Rp. 150/buah	Rp. 4.500.000
Miscellaneous expense		
Electricity	Rp. 5.500.000 x 60%	Rp. 3.300.000
Water	Rp. 500.000 x 60%	Rp. 300.000
Purchasing goods	Rp. 4.000.000 x 60%	Rp. 2.400.000
Machine maintenance cost	Rp. 1.000.000 x 60%	Rp. 600.000
Indirect labor cost	Rp. 1.000.000 x 60%	Rp. 600.000
	Total other cost	Rp. 7.200.000
Total production cost		Rp. 66.412.000
One month production of paving block		30.000 pieces
Cost of manufacture		Rp. 2.213,77 / pieces

Based on Table 5, it is known that the cost of production of the single paving block is Rp. 2213.77. In general, these goods are sold in units per square meter (m²) (Masrullita et al., 2018). Based on the size of the paving block in the shape of a rectangular, to cover an area of 1 m² it takes 44 pieces, so the selling price is Rp. 97405.88.

Conclusion

This research provides an overview of how to carry out the management of radioactively contaminated materials safely and securely. Determination of clearance for EAF dust contaminated with Cs-137 radionuclide allows the material to be used for purposes according to

its characteristics. The stabilization / solidification method as a method used to treat EAF dust can be well applied in Indonesia because the process is simple and does not require a large amount of money. The results of the compressive strength test indicate that the concrete brick has quality D, which is strong enough to be used in landscaping or other activities that do not receive excessive loads.

The percentage of the use of EAF dust can affect the costs required in processing it as a material for making concrete bricks. This research does not take into account the selling price of the product along with the investment analysis but only takes into account the production price. Determination of the selling price and business analysis depends on the target of the facility owner to increase the quality and quantity of the concrete brick products produced. The hazardous and toxic waste treatment facility in this study has also invested in equipment to support concrete brick production activities because it is mandatory to obtain a waste management permit from the relevant government ministry/agencies.

This should state clearly the main conclusions of the research and give a clear explanation of their importance and relevance. Summary illustrations may be included.

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References

- Alsheltat, M. Fathi, & Elfigih, M. A. (2023). Effects Of Electric Arc Furnace Slag Powder And Fly Ash Within Ternary Waste Blend On Performance Of Concrete. *Open Ceramics*, 14, 100359. <https://doi.org/10.1016/j.oceram.2023.100359>
- Amaral, L. F., Carvalho, J. P. R. G. De, Silva, B. M. Da, Delaqua, G. C. G., Monteiro, S. N., & Vieira, C. M. F. (2019). Development Of Ceramic Paver With Ornamental Rock Waste. *Journal Of Materials Research And Technology*, 8(1), 599–608.
- Araujo, F. S. M., Llano, I. T., Fantucci, H., Nunes, E. B., & Santos, R. M. (2022). *Recycling Strategies Of Mine Tailing, With Environmental, Safety, Technical And Materials Considerations*.
- Bamigboye, G. O., Bassey, D. E., Olukanni, D. O., Ngene, B. U., Adegoke, D., Odetoyan, A. O., Kareem, M. A., Enabulele, D. O., & Nworgu, A. T. (2021). Waste Materials In Highway Applications: An Overview On Generation And Utilization Implications On Sustainability. *Journal Of Cleaner Production*, 283, 124581. <https://doi.org/10.1016/j.jclepro.2020.124581>
- Boulos, M. I., Jurewicz, J. W., Fauchais, P. L., & Pfender, E. (2023). Plasma In The Waste Treatment Industry. In *Handbook Of Thermal Plasmas* (Pp. 1739–1804). Springer International Publishing. https://doi.org/10.1007/978-3-030-84936-8_40
- Chiu, A. C. F., Akeseh, R., Moumouni, I. M., & Xiao, Y. (2019). Laboratory Assessment Of Rice Husk Ash (RHA) In The Solidification/Stabilization Of Heavy Metal Contaminated Slurry. *Journal Of Hazardous Materials*, 371, 62–71. <https://doi.org/10.1016/j.jhazmat.2019.02.051>
- Collivignarelli, M. C., Cillari, G., Ricciardi, P., Miino, M. C., Torretta, V., Rada, E. C., & Abbà, A. (2020). The Production Of Sustainable Concrete With The Use Of Alternative Aggregates: A Review. *Sustainability*, 12(19), 7903. <https://doi.org/10.3390/su12197903>
- De Buzin, P. J. W. K., Heck, N. C., & Vilela, A. C. F. (2017). EAF Dust: An Overview On The Influences Of Physical, Chemical And Mineral Features In Its Recycling And Waste Incorporation Routes. *Journal Of Materials Research And Technology*, 6(2), 194–202. <https://doi.org/10.1016/j.jmrt.2016.10.002>
- Donald, A. N., Raphael, P. B., Olumide, O. J., & Amarachukwu, O. F. (2022). Environmental Heavy Metal Pollution: Physicochemical Remediation Strategies To The Rescue. *Journal Of Environment Pollution And Human Health*, 10(2), 31–45.
- Endika, Eko; Kurniawandy, A. (2016). *Pengaruh Penambahan Silika Fume Pada Campuran Paving Block Terhadap Karakteristik Paving Block*. 1–23.

- Esther, L. A., Pedro, L. G., Irune, I. V., & Gerardo, F. (2020). Comprehensive Analysis Of The Environmental Impact Of Electric Arc Furnace Steel Slag On Asphalt Mixtures. *Journal Of Cleaner Production*, 275. <https://doi.org/10.1016/j.jclepro.2020.123121>
- Falciglia, P. P., Romano, S., & Vagliasindi, F. G. A. (2017). Stabilisation/Solidification Of 137Cs-Contaminated Soils Using Novel High-Density Grouts: Γ -Ray Shielding Properties, Contaminant Immobilisation And A Frs Index-Based Approach For In Situ Applicability. *Chemosphere*, 168, 1257–1266. <https://doi.org/10.1016/j.chemosphere.2016.10.068>
- Goyal, S., Siddique, R., Sharma, D., & Jain, G. (2022). Reutilization Of Textile Sludge Stabilized With Low Grade-Mgo As A Replacement Of Cement In Mortars. *Construction And Building Materials*, 338, 127643. <https://doi.org/10.1016/j.conbuildmat.2022.127643>
- Guo, B., & Sasaki, K. (2022). Stabilization/Solidification Of Radioactive Waste In Geochemical Aspects. In *Low Carbon Stabilization And Solidification Of Hazardous Wastes* (Pp. 469–482). Elsevier. <https://doi.org/10.1016/b978-0-12-824004-5.00012-8>
- Han, L., Li, J., Xue, Q., Chen, Z., Zhou, Y., & Poon, C. S. (2020). Bacterial-Induced Mineralization (BIM) For Soil Solidification And Heavy Metal Stabilization: A Critical Review. *Science Of The Total Environment*, 746, 140967. <https://doi.org/10.1016/j.scitotenv.2020.140967>
- He, L., Wang, Z., & Gu, W. (2021). Evolution Of Freeze–Thaw Properties Of Cement–Lime Solidified Contaminated Soil. *Environmental Technology & Innovation*, 21, 101189. <https://doi.org/10.1016/j.eti.2020.101189>
- Huang, Z., Liu, K., Duan, J., & Wang, Q. (2021). A Review Of Waste-Containing Building Materials: Characterization Of The Heavy Metal. *Construction And Building Materials*, 309, 125107. <https://doi.org/10.1016/j.conbuildmat.2021.125107>
- Kehutanan, K. L. H. Dan. (2021). Peraturan Pemerintah Nomor 22 Tahun 2021. *Sekretariat Negara Republik Indonesia*, 1(078487A), 483.
- Masrullita, Perry Burhan, R. Y., & Trihadiningrum, Dan Y. (2018). Stabilization/Solidification Of Waste Containing Heavy Metals And Hydrocarbons Using OPC And Land Trass Cement. *Journal Of Ecological Engineering*, 19(6), 88–96. <https://doi.org/10.12911/22998993/92926>
- Mohasin, M., Habib, K., & Rao, P. S. (2022). Heavy Metals Pollution In Soil And Their Remediation Techniques: A Review. *International Journal Of Environment And Climate Change*, 12(1), 1231–1250. <http://institutearchives.uk/id/eprint/1872>
- Nunes, V. A., & Borges, P. H. R. (2021). Recent Advances In The Reuse Of Steel Slags And Future Perspectives As Binder And Aggregate For Alkali-Activated Materials. *Construction And Building Materials*, 281, 122605. <https://doi.org/10.1016/j.conbuildmat.2021.122605>
- Omran, M., & Fabritius, T. (2017). Effect Of Steelmaking Dust Characteristics On Suitable Recycling Process Determining: Ferrochrome Converter (CRC) And Electric Arc Furnace (EAF) Dusts. *Powder Technology*, 308, 47–60. <https://doi.org/10.1016/j.powtec.2016.11.049>
- Pusat Teknologi Limbah Radioaktif-BATAN. (2019). *Kajian Radiologik Untuk Klierens Bersyarat Terhadap Limbah Ash Furnace Terkontaminasi*.
- Rajagukguk, A., & Surbakti, B. (2021). Pengaruh Penambahan Limbah Debu Pengolahan Baja (Dry Dust Collector) Dan Penambahan Serat Polypropylene Terhadap Sifat Mekanis Beton. *Jurnal, Teknik Sipil Universitas Sumatera Utara*, 5(1), 1–13.
- Rakhimova, N. (2022). Recent Advances In Alternative Cementitious Materials For Nuclear Waste Immobilization: A Review. *Sustainability*, 15(1), 689. <https://doi.org/10.3390/su15010689>
- Ranjetha, K., Alengaram, U. J., Alnahhal, A. M., Karthick, S., Zurina, W. J. W., & Rao, K. J. (2022). Towards Sustainable Construction Through The Application Of Low Carbon Footprint Products. *Materials Today: Proceedings*, 52, 873–881. <https://doi.org/10.1016/j.matpr.2021.10.27>

- 5
Rasaki, S. A., Bingxue, Z., Guarecuco, R., Thomas, T., & Minghui, Y. (2019). Geopolymer For Use In Heavy Metals Adsorption, And Advanced Oxidative Processes: A Critical Review. *Journal Of Cleaner Production*, 213, 42–58. <https://doi.org/10.1016/j.jclepro.2018.12.145>
- 5
Royyan Anrozi, & Yulinah Trihadiningrum. (2017). Kajian Teknologi Dan Mekanisme Stabilisasi/Solidifikasi Untuk Pengolahan Limbah B3. *Jurnal Teknik Its*, 6 No. 2(2), 456–461.
- Sikarwar, V. S., Hrabovský, M., Van Oost, G., Pohořelý, M., & Jeremiáš, M. (2020). Progress In Waste Utilization Via Thermal Plasma. *Progress In Energy And Combustion Science*, 81, 100873. <https://doi.org/10.1016/j.pecs.2020.100873>
- Singh, P., Roy, A. B. D., & Singh, H. (2022). Mechanical And Durability Properties Of Concrete Incorporating Weathered Coarse Linz-Donawitz (LD) Steel Slag. *Journal Of Building Engineering*, 61, 105301. <https://doi.org/10.1016/j.jobe.2022.105301>
- Yang, J. (2022). Waste Treatment And Disposal Technology. In *From Zero Waste To Material Closed Loop* (Pp. 49–101). Springer Nature Singapore. https://doi.org/10.1007/978-981-16-7683-3_7