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# Utilization of Hospital Solid Waste as Paving Blocks

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***ABSTRACT***

The hospital X, infectious medical waste is chopped and sterilized at temperatures above 100ºC using a sterilwave to reduce the size of the wastet. This waste has potential to be used as construction materials, such as paving blocks. Therefore, this research was conducted to determine the best paving block mix design and composition using chopped medical waste as a fine aggregate substitution. In addition, this research carried out a TCLP test on paving blocks that had the best water absorption to find out whether paving blocks are good enough to strip potential soil contamination. This study's quality target for paving blocks was to meet class D quality with a minimum compressive strength of 8.5 MPa and a maximum water absorption of 10%. The results showed that the mix design used is 1:5 for the cement and fine aggregate ratio with an average compressive strength of normal paving blocks of 10 MPa. Paving blocks with a mixture of medical waste with the best absorption were those with as much as 8% substitution of fine aggregate. The results of the TCLP test showed that the levels of heavy metals in medical waste paving blocks were safe.

***Keywords:*** *Hospital, Medical waste, Paving blocks, TCLP*

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**ABSTRACT**

Rumah Sakit X menghasilkan limbah medis yang bersifat infeksius dicacah dan disterilkan pada suhu di atas 100ºC dengan menggunakan sterilwave dengan tujuan memperkecil ukuran limbah. Limbah ini berpotensi untuk dimanfaatkan menjadi material konstruksi seperti paving block. Oleh karena itu pada penelitian ini dilakukan dengan tujuan untuk mengetahui mix design dan komposisi paving block terbaik yang menggunakan limbah medis tercacah sebagai substitusi agregat halus. Selain itu pada penelitian ini juga dilakukan uji TCLP pada paving block yang memiliki penyerapan air terbaik untuk mengetahui paving block sudah cukup baik melakukan pelucutan terhadap potensi pencemaran tanah saat diimplementasikan di area taman. Target kualitas paving block pada penelitian ini adalah memenuhi kualitas kelas D dengan minimum kuat tekan sebesar 8,5 MPa dan penyerapan air maksimal 10%. Hasil penelitian menunjukkan bahwa mix design yang digunakan adalah 1:5 untuk perbandingan semen dan agregat halus dengan kuat tekan rata-rata paving block normal sebesar 10 MPa. Sedangkan paving block dengan campuran limbah medis dengan penyerapan terbaik adalah yang memiliki substitusi agregat halus sebanyak 8%. Hasil tes TCLP menunjukkan bahwa kadar logam berat pada paving block limbah medis aman untuk digunakan.

***Keywords:*** *Limbah medi,; Paving block, TCLP, Rumah sakit*

## INTRODUCTION

Hospitals, as health facilities, have an obligation to provide services to the community. In carrying out operational activities to serve health, there is waste produced by hospitals as a form of residual activity. Hospital waste can be categorized into solid, liquid, and gas. Each category of hospital waste has the potential to be pathogenic, infectious, and possibly radioactive [1]. Hospital solid waste includes all solid materials discarded during health examinations, treatment, patient immunization, observation, biological tests, or handling other accidents [2]. Liquid waste from hospitals can come from dirty water left over from patient activities or domestic dirty water, which can be determined through tests with BOD, COD, pH, microbiology, and other test parameters [1].

However, categories or types of hospital waste can also be differentiated based on their nature, namely medical and non-medical. According to Khatami M.F. et al. (2023), 70 – 90% of hospital solid waste consists of solid waste that resembles household waste, while the rest is medical waste, which is dangerous and impacts health [3]. For example, at the Haji Abdoel Madjid Batoe Regional Hospital in Batanghari Regency, the amount of infectious solid waste was 14,425 kg, and non-infectious solid waste was 101,356 kg [4]. Medical or infectious waste consists of waste originating from activities in inpatient services, outpatient services, emergency installations, operating rooms, laboratories, and pharmacies, where the waste is blood, microbiological waste, sharps waste, autopsy waste, and pathology waste, and other infectious disease waste [5].

At the Hospital, managing hazardous and toxic waste through third parties requires quite large costs, starting from collection and transportation to processing. Hazardous waste might be utilized by the producers, provided they have a utilization permit as stated in the technical regulations. One of the utilization methods that can be used is the solidification/stabilization (S/S) method, where hazardous waste is isolated, and its structure is changed physically and chemically to minimize the impact of pollution on the environment [6]. One form of solidification/stabilization (S/S) is construction material products such as concrete, paving blocks, bricks, and roof tiles [7]. Therefore, research was carried out to process chopped medical waste into materials such as paving blocks.

The reason for choosing construction materials in the form of paving blocks as a form of utilization of medical waste is to complete the infrastructure at the hospital in the form of garden materials in green open spaces. The X Hospital continues to plan to develop green open spaces to reach 30% of the total area [8]. Therefore, the best mix design and composition that met the quality of paving blocks will be implemented in the parking area to reduce the cost of purchasing commercial paving blocks on the market.

In this research, medical waste was substituted for fine aggregate as a component in making paving blocks. In general, the fine aggregate used in commercial paving blocks is sand [9]. In improving the circular economy, several types of waste can also be used as a substitute for sand in paving blocks, such as fly ash [10], [11], [12], [13], bottom ash [14], [15][16], [17], [18], plastic, and coconut ash [19], [20]. Making paving blocks using medical waste chopped by sterilwave in small sizes has never been done, especially since sterilwave technology is still not widely used and in East Kalimantan Hospital X is the first to use it. Based on its size, this medical waste can be a substitute for fine aggregate because it has a size that passes sieve number 4 or 4.75 mm [21]. Hospital X's medical waste is almost the same size in this case.

Therefore, research was carried out to utilize non-hazardous medical waste from hospitals as a substitute for fine aggregate in class D paving blocks, which can be used for gardens with a minimum compressive strength of 8.5 MPa or an average of 10 MPa and a maximum water absorption of 10%.

## METHOD

### Paving Block

The paving block is a component of building materials made from a mixture of Portland cement, water, and aggregate with or without other additives that do not reduce its quality [22]. Portland Pozzolan Cement is a hydraulic cement consisting of a homogeneous mixture of Portland cement and fine pozzolan, which is made by rolling Portland cement clinker with pozzolan simultaneously or by mixing the two evenly, where the pozzolan content is 6% to 40% by mass of Portland pozzolan cement [23]. Fine aggregate such as sand is one of the mixed materials that can be used to increase the strength of paving blocks by filling the pores of the paving block so that it becomes dense and supports strength [24]. According to Nofrianto [25], the water in the paving block mixture assists the chemical reaction that produces the binding process.

**Hazardous Waste in Health Facility**

Medical waste can be found mostly in health activities and other supporting activities. When compared with waste produced by other agencies, the types of waste and waste produced by hospitals can be considered complex. This waste is included in the category of hazardous and toxic waste based on Indonesian Regulations, so it has the potential to endanger the environment and health. According to the Indonesian Minister of Health Regulation Number 18 of 2020, medical waste results from the medical activities of health services. The health service facility in question is a tool and/or place that is usually used to provide health service efforts, whether promotive, preventive, or recovery, carried out by the regional government, central government, and/or the community. This research consists of four stages: determining the mix design, making test materials, curing, and testing the quality of test materials.

**Determination of Mix Design**. Determination of mix design is based on SNI 03-6825-2002 concerning Testing Methods for Compressive Strength of Portland Cement Mortar for Civil Works [26] and SNI 03-0691-1996 concerning Concrete brick (Paving Block) [22] with a minimum compressive strength target of 8.5 MPa. Based on the compressive strength, paving blocks from medical waste are categorized as Quality D for use in gardens [18].

**Making Test Objects**. The test material was a medical waste paving block with three compositions: 0% medical waste and 100% sand, 25% medical waste and 75% sand, 50% medical waste, and 50% sand. Testing was carried out on the 7th and 28th days. The mass of a paving block was estimated at 3.5 kg.

Table 1. The Sample Composition

| Code | Cement (%) | Sand (%) | Medical waste (%) | Amount of Sample (units) |
|---|---|---|---|---|
| A | 100 | 100 | 0 | 3 |
| B | 100 | 75 | 25 | 3 |
| C | 100 | 50 | 50 | 3 |

**Curing**. The curing process is carried out at the Integrated Laboratory of the Kalimantan Institute of Technology. Curing is done by placing paving blocks in shady and dry places. The curing process is carried out with the aim of maintaining the test object during the freezing period because humidity and temperature conditions greatly influence the chemical properties of the paving block [25].

**Testing of Test Objects**. Paving blocks go through three stages of testing, namely the compressive strength test and absorption test for all samples and the TCLP test for test materials with the best quality compression and absorption tests. Compressive strength testing is carried out to determine whether the paving block strength quality meets quality. The quality standard for compressive strength of paving blocks is adjusted to the class based on its intended function [27]. The targeted compressive strength test value is a minimum of 10 MPa or meets class D quality. An absorption test also needs to be carried out to determine the amount of water that can be absorbed by the paving block. The higher the water absorption, the paving block can reduce stagnant water [15]. Class D's water absorption quality standard is a maximum of 10%. Meanwhile, the TCLP (Toxicity Characteristic Leaching Procedure) test removes hazardous waste so that it is solid and not released into the environment in the form of leachate or other polluting materials [28]. The TCLP test is carried out on paving block compositions with the best water absorption.

## RESULTS AND DISCUSSION

The material testing results reveal that the mix design used in this research is 1:5 for the cement and fine aggregate ratio, with an average compressive strength of 10 MPa. In the compressive strength test results of paving blocks made from medical waste at the age of 28 days with a composition of 25%, the average value was 10.5 MPa, and with a composition of 50%, the average value was 5.17 MPa. This shows that the 25% compressive strength paving block composition meets Quality D by SNI 03-0691-1996. As the composition of medical waste increases, the compressive strength value of the paving blocks also decreases. This is in line with research from Anisa (2022), which states that the more waste used, the bond between cement and water does not work optimally, so there are many voids and empty gaps, which causes the paving blocks not to be strong enough when tested [29].

Table 2. Result Test of Compressive Strength

| Percentage of medical waste | | 7 days | | | 28 days | | | Water content | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Weight (kg) | Density (kg/m$^3$) | Compressive Strength (MPa) | Weight (kg) | Density (kg/m$^3$) | Compressive Strength (MPa) | Wet weight (kg) | Dry weight (kg) | Water content (%) |
| 0% | A1 | 2,2 | 18333.3 | 7.74 | 2.2 | 18333.3 | 9.97 | 2.6 | 2.4 | 8.33 |
| | A2 | 2,2 | 18333.3 | 3.85 | 2.4 | 2000 | 10.12 | 2.7 | 2.4 | 12.5 |
| | A3 | 2,4 | 20000 | 4.62 | 2.2 | 18333.3 | 9.97 | 2.6 | 2.4 | 8.333 |
| | Average of A | 2,27 | 18888.87 | 5.4 | 2.27 | 12888.87 | 10.02 | 2.63 | 2.4 | 9.72 |
| 25% | B1 | 1,67 | 1192.9 | 6.07 | 1.8 | 12585.7 | 9.48 | 2.4 | 2 | 20 |
| | B2 | 1,94 | 1385.7 | 4.98 | 1.8 | 12585.7 | 10.34 | 2.2 | 2 | 10 |
| | B3 | 1,94 | 1385.7 | 5.06 | 1.8 | 12585.7 | 10.34 | 2.2 | 2 | 10 |
| | Average of B | 1,85 | 1385.7 | 5.02 | 1.8 | 12585.7 | 10 | 2.2 | 2 | 10 |
| 50% | C1 | 1,59 | 1135.7 | 4.78 | 1.4 | 1000 | 5.24 | 1.8 | 1.4 | 28.57 |
| | C2 | 1,58 | 1128.6 | 3.05 | 1.4 | 1000 | 5.24 | 1.8 | 1.6 | 12,5 |
| | C3 | 1,61 | 1150 | 3.66 | 1.4 | 1000 | 5.03 | 2 | 1.8 | 11.11 |
| | Average of C | 1,6 | 1139.3 | 3,36 | 1.4 | 1000 | 5.14 | 1.9 | 1.7 | 11.81 |

In this study, medical waste was dominated by hospital waste made from plastic, such as injections and used infusion containers, and waste made from fiber, such as gauze and masks. The presence of plastic material has a big impact on the compressive strength of the paving block because it causes the compressive strength to decrease due to the presence of large pores or cavities in the paving block due to the binding of the material not being optimal. Paving blocks with the addition of plastic waste affect the binding of the material, so the binding process is not strong, and this reduces the compressive strength of the paving blocks [30]. The decrease in the compressive strength of paving blocks is caused by the more fiber from waste used in paving blocks; there is a more significant opportunity for the formation of defective areas, which have the potential to reduce the compressive strength value [31].

From the results of water absorption testing, medical waste paving blocks with a composition of 25% have an average value of 10.00%, and with a composition of 50% have an average value of 11.81%. In this study, paving blocks with a composition of 25% were the best water absorption test results because an average value of 10% was obtained, which is the maximum for water absorption in Quality D. An increase in the average value of the percentage of water absorption in paving blocks with medical waste can be achieved. This happens if the use of medical waste as a substitute for fine aggregate increases; the binder between cement, sand, and waste will decrease. Cavities appear in the paving blocks, which can trigger water to enter and be absorbed by the paving blocks. This is confirmed by previous research conducted research with plastic waste, which stated that the increase in water absorption capacity was in line with the rise in the composition of plastic waste found in making paving blocks, resulting in a lack of binders between the materials [32]. As stated by another previous research, the water absorption value of paving blocks depends on the density and gaps in the paving blocks [33].

Table 2. Result Test of Toxicity Test (TCLP)

| Parameters | TCLP-A | TCLP-B | Sample Results |
|---|---|---|---|
| | (mg/L) | (mg/L) | (mg/L) |
| Arsenic (As) | 3 | 0.5 | < 0.6 |
| Boron (B) | 150 | 25 | 0.26 |
| Barium (Ba) | 210 | 35 | 0.124 |
| Cadmium (Cd) | 0.9 | 0.15 | 0.009 |
| Mercury (Hg) | 0.3 | 0.05 | 0.248 |
| Nikel (Ni) | 21 | 3.5 | 0.141 |
| Perak (Ag) | 40 | 5 | 0.009 |
| Selenium (Se) | 3 | 0.5 | 0.933 |
| Seng (Zn) | 300 | 50 | 0.041 |
| Copper (Cu) | 60 | 10 | 0.117 |
| Timbal (Pb) | 3 | 0.5 | <0.07 |
| Fluoride ($F^-$) | 450 | 75 | 0.54 |
| Chloride ($Cl^-$) | 75000 | 12500 | 7.57 |
| Nitrate ($NO_3^-$) | 15000 | 2500 | 27.64 |
| Nitrite ($NO_2^-$) | 900 | 150 | 1.081 |
| Cyanide ($CN^-$) | 21 | 3.5 | <0.0020 |

The TCLP test was carried out on objects that had been solidified to determine the pollutants in waste and the leaching potential of the waste. The results of this test were then compared with quality standards. In this study, the TCLP test results for pollutants As, B, Ba, Cd, Hg, Ni, Ag, Zn, Cu, Pb, $F^-$, $Cl^-$, $NO_3^-$, $NO_2^-$, and $CN^-$ had lower values than the quality standards based on Indonesian Government Regulation Number 22 of 2021 concerning Implementation of Environmental Protection and Management [28]. This happens because medical waste resulting from solidification processing, namely paving blocks, can potentially reduce the content of pollutants in hazardous waste. The concentration of heavy metals decreases as the bonding process between paving block materials occurs. In the solidification process, the paving block material, namely cement, is known to have high effectiveness in resisting leaching so that the parameters of pollutant substances can be contained and reduced until they do not exceed quality standards [34].

In this research, heavy metals exceeded the quality standard values based on Government Regulation Number 22 of 2021 concerning the Implementation of Environmental Protection and Management, namely Selenium (Se) and Mercury (Hg) [28]. Medical waste from hospitals contains Selenium (Sn) because this substance is used to help cure cancer and other chronic diseases. Selenium is also used as a micronutrient and supplement for patients with various diseases, including patients with AIDS and COVID-19 [35]. Likewise, medical waste containing mercury (Hg) is found in hospitals, especially dental clinics. Medical waste containing mercury is found in medical waste from dentist tools, where amalgam for filling teeth contains mercury and tools that touch the amalgam are contaminated with mercury [36].

The Selenium (Se) and Mercury (Hg) content can be removed by encapsulation. Based on the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number 56 of 2015 concerning the technical management of hazardous and toxic waste from health service facilities, medical waste containing B3 can be encapsulated, where the encapsulation process in principle, carries out solidification of the waste to avoid leaching of the waste [37]. Encapsulation is carried out by adding 2/3 of the container's volume to the waste and then adding immobilization material until it is complete before the container is closed and confined. The immobilization material can be sand or cement, and the metal drum container can be used.

## CONCLUSION

The use of medical waste from Hospital X 10% met the paving block standard quality of class D, so it is suitable for use in gardens. However, the results of the TCLP test showed several contaminants have levels below the quality standard, except Selenium (Se) and Mercury (Hg), which exceed the quality standards in TCLP-B based on Government Regulation Number 22 of 2021 concerning the Implementation of Environmental Protection and Management. This showed that paving blocks with medical waste as a substitute for fine aggregate cannot be used because two contaminants in the TCLP test results are not below the quality standard. Also, the economic feasibility of paving blocks should be analyzed against the production cost.

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## BIBLIOGRAPHY

[1] R. U. , P. R. K. H. , dan A. S. Wulandari, “Evaluasi Kapasitas Pengolahan Air Limbah Rumah Sakit (Studi Pada Rumah Sakit X Surabaya),” *Nusantara Hasana Journal*, vol. 2, no. 8, pp. 205–211, 2023, Accessed: Apr. 05, 2023. [Online]. Available: http://nusantarahasanajournal.com/index.php/nhj/article/view/673/572

[2] A. M. Osman, Z. Ukundimana, F. B. Wamyil, A. A. Yusuf, and K. Telesphore, “Quantification and characterization of solid waste generated within Mulago national referral hospital, Uganda, East Africa,” *Case Studies in Chemical and Environmental Engineering*, vol. 7, p. 100334, Jun. 2023, doi: 10.1016/J.CSCEE.2023.100334.

[3] Khatami M.F., Mirwan M., and Aulidia S., “Evaluasi Sistem Pengelolaan Limbah Padat Bahan Berbahaya dan Beracun (B3) di Rumah Sakit X Surabaya,” *Nusantara Hasana Journal*, vol. 2, no. 8, pp. 182–191, 2023, Accessed: Apr. 05, 2023. [Online]. Available: http://nusantarahasanajournal.com/index.php/nhj/article/view/707/569

[4] N. Nasrul, “Analisis Pengelolaan Limbah Medis Padat Di Rumah Sakit Umum Daerah Haji Abdoel Madjid Batoe (RSUD Hamba) Kabupaten Batanghari,” Mar. 2023.

[5] Agus Susanto, Yusni Ikhwan Siregar, and Bayhakki, “Strategi Pengelolaan Limbah Bahan Berbahaya dan Beracun Fasilitas Pelayanan Kesehatan Rumah Sakit X Mandau,” *SEHATI: Jurnal Kesehatan*, vol. 3, no. 1, pp. 17–29, Feb. 2023, doi: 10.52364/sehati.v3i1.32.

[6] I. D. W. S. Rini, M. Maria, E. M. Anifah, A. A. I. Saputra, A. Gunawan, and A. I. Arobi, “Analisis Dampak Lingkungan Pengolahan Limbah Fly Ash dan Bottom Ash dengan Metode Siklus Daur Hidup (Life Cycle Assessment/LCA) di Industri Pembangkit Listrik Tenaga Uap,” *SPECTA Journal of Technology*, vol. 6, no. 3, pp. 263–272, Jan. 2023, doi: 10.35718/specta.v6i3.761.

[7] J. J. Ekaputri and M. S. Al Bari, “Perbandingan Regulasi Fly Ash sebagai Limbah B3 di Indonesia dan Beberapa Negara,” *Media Komunikasi Teknik Sipil*, vol. 26, no. 2, pp. 150–162, Dec. 2020, doi: 10.14710/MKTS.V26I2.30762.

[8] Pemerintah Republik Indonesia, “Undang-undang Nomor 26 Tahun 2007,” 2007.

[9] H. Nofrianto and H. Hutrio, “Analisis Mutu Paving Block Dengan Variasi Agregat Halus,” *Jurnal Teknologi dan Vokasi*, vol. 1, no. 1, pp. 54–62, Jan. 2023, doi: 10.21063/JTV.2023.1.1.8.

[10] V. Ansari and E. Prianto, “Ciptakan Rumah Ramah Lingkungan Dengan Material Dinding Limbah Fly Ash Dan Bottom Ash (FABA),” *Prosiding Seminar Sains Nasional dan Teknologi*, vol. 1, no. 1, Nov. 2021, Accessed: Apr. 07, 2023. [Online]. Available: https://publikasiilmiah.unwahas.ac.id/index.php/PROSIDING_SNST_FT/article/view/4972

[11] M. Jiang *et al.*, “Different Material Footprint Trends between China and the World in 2007-2012 Explained by Construction- and Manufacturing-associated Investment,” *One Earth*, vol. 5, no. 1, pp. 109–119, Jan. 2022, doi: 10.1016/j.oneear.2021.12.011.

[12] V. T. Dewi, M. L. Ashari, and D. Darmawan, “Analisis Pengaruh Limbah Slag dan Debu EAF (Electric Arc Furnace) Terhadap Uji SEM, Uji Kuat Tekan Beton, dan Uji TCLP,” *Proceeding 1st Conference on Safety Engineering and Its Application*, pp. 292–296, 2017.

[13] I. Dwi *et al.*, “Penggunaan Fly Ash Industri Pembangkit Listrik Tenaga Uap (PLTU) Sebagai Pengganti Semen Pada Beton,” *Seminar Nasional Fakultas Teknik*, 2019.

[14] R. Fadhilatul and T. Sulistyaningsih, “Paving Block Berbahan Dasar Limbah Plastik Polyethylene dan Bottom Ash,” *Seminar Nasional Teknologi Industri Hijau 2*, vol. 2, no. 1, pp. 138–150, 2020.

[15] A. Soehardjono, T. Hidayat, and G. S. Prawito, “Pengaruh Penggunaan Bottom Ash Sebagai Pengganti Semen Terhadap Nilai Kuat Tekan dan Kemampuan Resapan Air Struktur Paving,” *Jurnal Rekayasa Sipil*, vol. 7, no. 1, pp. 74–80, 2013.

[16] W. W. Ningrum, A. Rakhmawati, and R. M. Jannah, “Pemanfaatan Limbah Plastik Low Density Polyethylene (LDPE) pada Paving Block Non Pasir,” *ULIL ALBAB : Jurnal Ilmiah Multidisiplin*, vol. 2, no. 2, pp. 617–624, Jan. 2023, doi: 10.56799/JIM.V2I2.1320.

[17] M. R. Nurfaizi, A. Arifin, and G. C. Asbanu, “Pemanfaatan Limbah Plastik PET (Polyethylene Terephtalate), Limbah Pecahan Keramik dan Limbah Oli Bekas Menjadi Paving Block,” *Jurnal Teknologi Lingkungan Lahan Basah*, vol. 11, no. 1, pp. 034–040, Feb. 2023, doi: 10.26418/JTLLB.V11I1.57576.

[18] E. Silfiani, D. W. Kurniawidi, T. Ardianto, and S. Rahayu, “Plastik LDPE (Low Density Polyethylene) Sebagai Campuran Komposit Polimer Paving Block,” *ORBITA. Jurnal Hasil Kajian, Inovasi, dan Aplikasi Pendidikan Fisika*, vol. 1, no. 1, pp. 1–7, 2023.

[19] A. I. N. Diana and N. Zainah, “Pemanfaatan Limbah Abu Batok Kelapa dan Kapur Hidrolis Sebagai Bahan Substitusi Semen pada Paving Block,” *Media Komunikasi Teknik Sipil*, vol. 28, no. 2, pp. 276–283, 2022, Accessed: Apr. 08, 2023. [Online]. Available: https://ejournal.undip.ac.id/index.php/mkts/article/view/36136/23318

[20] A. Intan, N. Diana, and N. Zainah, “Pemanfaatan Limbah Abu Batok Kelapa dan Kapur Hidrolis sebagai Bahan Substitusi Semen pada Paving Block,” *MEDIA KOMUNIKASI TEKNIK SIPIL*, vol. 28, no. 2, pp. 276–283, Jan. 2023, doi: 10.14710/MKTS.V28I2.36136.

[21] A. Dumyati and D. F. Manalu, “Analisis Penggunaan Pasir Pantai Sampur Sebagai Agregat Halus Terhadap Kuat Tekan Beton,” *Jurnal Fropil*, vol. 3, no. 1, pp. 1–14, Jan. 2015.

[22] Badan Standarisasi Nasional, *SNI 03-0691-1996 Bata beton (Paving Block)*. Badan Standarisasi Nasional, 1996.

[23] Badan Standardisasi Nasional, *SNI 15-2049-2004*. 1990, pp. 1–32.

[24] A. P. Putri, C. C. S. Khala, and G. R. Prayogi, “Comparative Study Of Changes in SNI 1727 (2013-2020) and SNI 1726 (2012-2019),” *Journal of Advanced Civil and Environmental Engineering*, vol. 5, no. 2, p. 74, Nov. 2022, doi: 10.30659/jacee.5.2.74-83.

[25] H. Nofrianto and Hutrio, “Analisis Mutu Paving Block Dengan Variasi Agregat Halus,” *Jurnal Teknologi dan Vokasi*, vol. 1, no. 1, pp. 54–62, Jan. 2023.

[26] Badan Standardisasi Nasional, *SNI 03-6825-2002 Metode Pengujian Kekuatan Tekan Mortar Semen Portland Untuk Pekerjaan Sipil*. Badan Standarisasi Nasional , 2002.

[27] C. Aditya, “Pengaruh Penggunaan Limbah Pasir Onyx Sebagai Substitusi Pasir Terhadap Kuat Tekan, Penyerapan Air, dan Ketahanan Aus Paving Block,” *Widya Teknika*, vol. 20, no. 1, Mar. 2012, Accessed: Apr. 12, 2023. [Online]. Available: http://publishing-widyagama.ac.id/ejournal-v2/index.php/widyateknika/article/view/3

[28] Pemerintah Republik Indonesia, “Peraturan Pemerintah Nomor 22 Tahun 2021,” Jakarta, 2021.

[29] R. Anisa, “Studi Pemanfaatan Limbah Abu Incinerator RSUD Dr Kanujoso Djatiwibowo Balikpapan menjadi Paving Block,” Balikpapan, 2022.

[30] Zianuri, “Penanganan Sampah Plastik pada Produksi Paving Block,” *Jurnal Teknologi Lingkungan*, vol. 22, no. 2, pp. 170–177, 2021.

[31] T. B. Aulia and Rinaldi, “Bending capacity analysis of high-strength reinforced concrete beams using environmentally friendly synthetic fiber composites,” in *Procedia Engineering*, Elsevier Ltd, 2015, pp. 1121–1128. doi: 10.1016/j.proeng.2015.11.136.

[32] F. Syefringga, “Pengaruh Penambahan Limbah Plastik Sebagai Campuran Beton Terhadap Kuat Tekan dan Daya Serap Air Pada Paving Block,” Pekanbaru, 2021.

[33] D. Larasati and I. Setyanto, “Uji Kuat Tekan Paving Block Menggunakan Campuran Tanah dan kapur dengan Alat Pemadat Modifikasi,” *JRSDD*, vol. 4, no. 1, pp. 11–22, 2016.

[34] Rezasyah Alifiadi and Agus Slamet, “Utilization of Sandblasting Waste as an Alternative Material for Paving Blocks,” *Jurnal Multidisiplin Madani*, vol. 2, no. 12, pp. 4399–4407, Dec. 2022, doi: 10.55927/mudima.v2i12.1911.

[35] A. A. Werkneh, G. G. Gebretsadik, and S. B. Gebru, “Review on Environmental Selenium: Occurrence, Public Health Implications and Biological Treatment

Strategies," *Environmental Challenges*, vol. 11, Apr. 2023, doi: 10.1016/j.envc.2023.100698.

[36] R. D. Singh, S. K. Jurel, S. Tripathi, K. K. Agrawal, and R. Kumari, "Mercury and other biomedical waste management practices among dental practitioners in India," *Biomed Res Int*, vol. 2014, 2014, doi: 10.1155/2014/272750.

[37] Pemerintah Republik Indonesia, *Peraturan Menteri Lingkungan Hidup dan Kehutanan Nomor 56 Tahun 2015*. 2015, pp. 1–114. [Online]. Available: www.peraturan.go.id

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