

UTILIZATION OF RECYCLED CONCRETE WASTE AS AGGREGATE IN POROUS PAVEMENT BLOCK

Lestari Oktavia Sasqiaputri Meindeska, Muhammad Ikhwan Pebriansyah, Masaji Royhan Attoyla, Dinan Fariz, Surya Aditya Darma, Wahyu Satyaning Budhi*

Civil Engineering Department, Banyuwangi State Polytechnic

*Corresponding author: wahyu.satyaningbudhi@poliwangi.ac.id

Abstract

A consequence of building operations, concrete waste is seldom used and keeps expanding in bulk in tandem with fast growth, which raises CO₂ emissions as a result of rising concrete use. This study examines the feasibility of utilizing concrete waste from the Concrete Testing Laboratory as a substitute for coarse aggregate in the manufacture of porous pavement/paving blocks, with the objective of improving the sustainability of building materials. In the study, concrete waste was crushed to generate coarse aggregates (5-20 mm), which were combined with cement and water in non-sand concrete formulations with ratios of 1:5 and 1:6. The findings indicated that porous paving blocks with a cement-to-coarse aggregate ratio of 1:5 had the best compressive strength (5.861 MPa), above that of the 1:6 composition (4.850 MPa). The 1:6 mixture showed the maximum horizontal permeability at 7.985 cm/second, whereas the 1:5 composition had the lowest vertical permeability at 6.084 cm/second, related to a decrease in permeability resulting from the elevated aggregate content. The results indicate that porous paving blocks, possessing enhanced water absorption properties, provide benefits over conventional blocks, especially in reducing waterlogging. This study confirms that the use of concrete waste offers an innovative approach that enhances the sustainability and efficiency of construction materials.

Keywords: Compressive strength, Concrete waste, Permeability, Porous

INTRODUCTION

Concrete is a construction material that is continually advancing and holds significant importance in the realm of infrastructure development. In construction practices, the concrete waste produced, particularly from concrete testing and the demolition of structures, is frequently not utilized effectively and is predominantly discarded. Alongside the quick construction and remodeling of structures, the amount of uncontrolled concrete waste keeps growing (Dewi, 2023). The predominant types of concrete waste consist of test cylinders, cubes, pavement/paving blocks, and mortar, with test cylinders representing approximately 61% of the overall waste generated. Concrete usage has also been rising, with quantities hitting 40,000 m³ in 2011 and 50,000 m³ in 2017. With CO₂ emissions in 2017 reaching about almost 20 m³, this increasing usage of concrete has also led to an increase in CO₂ emissions, which can harm the environment (Han *et al.*, 2019)

The public's need for transportation infrastructure prioritizing safety is concurrently increasing alongside initiatives to enhance quality of life (Budhi *et al.*, 2023). In this context, porous pavement/paving technology has emerged as a significant advance. Porous paving is constructed with pores that facilitate the passage of water via its pores, aiding in the management of rainfall runoff. This is crucial to prevent accidents resulting from slick roadways, particularly during rainfall. Porous pavement/paving blocks, a component of contemporary paving technology, serve several functions including roadways, walkways, parks, and parking places. Porous paving blocks are more

efficient on low-traffic roads due to their high porosity and reduced compressive strength (Rifqi *et al.*, 2018).

This project intends to utilize concrete waste as a raw material for creating porous paving blocks with non-sand paving types. Previous studies indicate that aggregate comprises around 70% aggregates of the entire concrete volume and significantly influences the quality of concrete (Junaidi, 2015; Shandy & Hermanto, 2021). Destruction of this concrete material might facilitate the development of an eco-friendly technology for regenerating aggregates, hence diminishing CO₂ emissions associated with cement and concrete usage. This porous pavement block is anticipated to rapidly absorb water, hence addressing issues such as waterlogging or floods during the rainy season (Ginting, 2019). The use of concrete waste enhances environmental sustainability by diminishing waste disposal and repurposing resources that would otherwise be wasted. The utilization of concrete waste in the manufacture of porous paving blocks offers practical advantages for infrastructure development and represents a significant advancement in ecologically sustainable concrete waste management (Zalaya *et al.*, 2019).

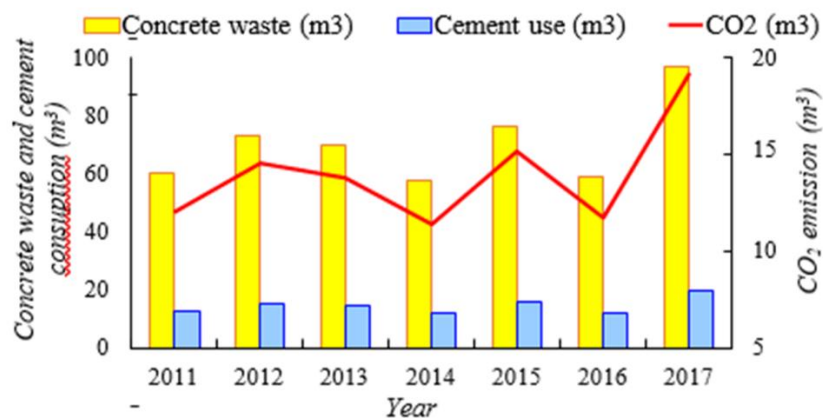


Figure 1. Projected concrete waste and associated CO₂ emissions (Han *et al.*, 2019)

LITERATURE REVIEW

Non-sand concrete is a lightweight concrete variant produced without fine aggregate (sand), resulting in voids among the coarse aggregates. The holes are uniformly distributed and linked, leading to a reduced concrete density. This concrete is sometimes referred to as zero-fines concrete, pervious concrete, and porous concrete (Mulyono, 2003). Non-sand concrete may be produced using various aggregates, including crushed stone, natural gravel, blast furnace slag (a byproduct of metallurgical processes), and clinker (calcined clay or burned rock). Crushed stone often offers superior compressive strength relative to natural gravel (Buerthey *et al.*, 2018).

Pervious concrete has several uses, particularly in locations necessitating high permeability, including parking lots, walkways, paths, tennis courts, gardens, and for slope stabilization and drainage systems. It is extensively utilized in pool decks, greenhouse flooring, animal enclosures, and road shoulders. Moreover, pervious concrete is appropriate as a top layer for highway pavements or as a permeable layer beneath concrete pavements, especially on low-traffic highways. Nonetheless, pervious concrete is unsuitable for pavements subjected to high traffic or substantial wheel loads owing to its diminished compressive strength and restricted endurance under pressure

(Najm *et al.*, 2017). Given these attributes, non-sand concrete offers an eco-friendly alternative for rainfall drainage and water management.

To support this research, the state of the art in this study is derived from a number of earlier studies as a guide for the author to conduct the upcoming research, which will subsequently be used as a reference and comparison in conducting this study. A number of journals will be presented in Table 1 in this state of the art.

Table 1. State of the art

No	Authors	Research Title and Year	Method	Result
1	Muhammad Bagus Syahputra, Dian Rahayu Jati, Ochih Saziati	Identifikasi Potensi Abu Terbang (Fly Ash) Sebagai Bahan Pengganti Sebagian Semen Pada Pembuatan Paving Block Ramah Lingkungan (2023)	To evaluate the grade values generated by the combination of fly ash at ratios of (1:4), (1:5), and (1:6) over a total of 27 test specimens, and to assess the impact of fly ash as a partial substitute for cement on the physical qualities of paving blocks in accordance with SNI 03-0691-1996. The employed methodology is experimental, aimed at providing results that demonstrate the association among variables like compressive strength, water absorption, and abrasion resistance of paving stones.	This research reports a maximum compressive strength of 27.42 MPa for the 1:4 composition, specimen code A1. The maximum water absorption value is 4.2% for the 1:4 composition, specimen code A0, whereas the maximum abrasion resistance value is 0.131 mm/min for the 1:4 composition, specimen code A1. The paving block is classified as grade B, appropriate for application in parking lot locations. The substitution of cement with fly ash influences the compressive strength, water absorption, and abrasion resistance properties.
2	Evrianti Syntia Dewi	Pemanfaatan Limbah Hasil Pengujian Beton Pada Proyek Bypass (Bil) Mandalika Sebagai Pengganti Sebagian Agregat Kasar Beton Normal (2023)	This study employed concrete waste from compressive strength tests on the Bypass BIL Mandalika project to partially substitute coarse aggregates. The test specimens, cylindrical in shape with a diameter of 15 cm and a height of 30 cm, were utilized for compressive strength assessments, targeting a concrete strength of 30 MPa. The variations in the percentage of coarse aggregate	The test results indicated that the compressive strength improved with a 20% substitution of coarse aggregates with concrete waste, reaching 31.29 MPa. However, the compressive strength diminished as the proportion of coarse aggregate replaced by concrete waste increased, getting to 25.55 MPa with a 30% inclusion of concrete waste.

			replacement with concrete waste were 15%, 25%, 29%, and 30%. The standard procedure for the mix design of normal concrete adhered to SNI 03-2834-2000.	
3	N H Abd Halim, H Md Nor, R P Jaya, A Mohamed, M H Wan Ibrahim, N I Ramli and F M Nazri	Permeability and Strength of Porous Concrete Paving Blocks at Different Sizes Coarse Aggregate (2017)	This study used three primary elements for the creation of pervious concrete: cement, coarse aggregates (recycled concrete and crushed brick), and water, utilizing recycled aggregates obtained from local building sites in Vietnam. Testing was performed to evaluate the compressive strength, flexural strength, porosity, and water permeability coefficient of pervious concrete after 28 days, utilizing rectangular specimens, and further assessed for porosity and permeability.	The study indicates that pervious concrete built using recycled materials, such as crushed concrete and brick, provides viable alternatives for sustainable construction. Although enhanced porosity augments water permeability, it concurrently diminishes compressive and flexural strength. The utilization of recycled aggregates results in increased porosity and permeability, although may diminish mechanical qualities, rendering it appropriate for low-traffic applications such as parking lots and walkways. This study highlights the necessity of equilibrating porosity and strength to enhance the effectiveness of pervious concrete in practical applications.

RESEARCH METHOD

A clear and systematic research methodology is essential to further the study of porous pavement/paving. A flowchart may be employed to methodically and efficiently delineate each stage of this process. This flowchart will assist researchers in delineating every stage of the investigation, encompassing material preparation, sample production, testing, and result analysis. The flowchart facilitates a more systematic and regulated execution of each research activity, hence reducing mistakes and enhancing the precision of legitimate outcomes. The flowchart of this research can be seen in Figure 2.

- Stage I: Literature Review

This phase involves the collection of bibliographic information, including journals and regulations, to be utilized as references for the study.

- Stage II: Preparation of Testing Materials

This phase involves the preparation of materials for the research, including concrete waste and cement.

– Concrete Waste Crushing

At this stage, the concrete waste is crushed with a crusher until it transforms into coarse aggregate fragments. Subsequent to crushing, the aggregates are subjected to sieving, and only those within the 5-20 mm size range are used.

– Preparation of Other Components

This phase includes the procurement of supplementary materials, including cement and water.

• Stage III: Material Assessment

At this stage, examinations are performed on the materials designated for the production of test specimens, including cement and coarse aggregates. The testing conforms to ASTM and SNI norms. The material tests encompass normal consistency (ASTM C 187-79), setting time and hardening of cement (ASTM C 191-71), specific gravity of Portland cement (SNI 15-2531-1991), and bulk density of cement (SNI 15-2531-1991). Furthermore, the evaluation of coarse aggregates (concrete waste) encompasses sieve analysis (SNI 03-1968-1990), moisture content (ASTM C 556-72), specific gravity (ASTM C 128-73), absorption (ASTM C 127-77), bulk density (ASTM C 29-78), cleanliness with reference to clay (ASTM C 117-76), and abrasion testing utilizing a Los Angeles machine (SNI 2417:2008).

• Stage IV: Mixture Design

This phase involves figuring out the necessary material ratios for each test specimen utilizing the mix design methodology for non-sand concrete as specified by Subhannur (2002). The initial ratios employed in this study were 1 part cement to 5 parts coarse aggregate (1:5) and 1 part cement to 6 parts coarse aggregate (1:6). This is derived from prior experiments.

• Stage V: Specimen Production

This phase include the formulation of the mixture for the porous paving blocks, the preparation of the mix, and the production of test specimens of 20cm × 10cm × 6cm.

• Stage VI: Check Process

A preliminary assessment is conducted on the test specimens to ascertain their quality for subsequent testing. If the combination produced a specimen that was too dense, with voids that were too narrow for water to permeate, it should revert to stage IV.

• Stage VII: Sample Testing

At this stage, evaluations are performed on the test specimens during 28 days of curing. The assessments include compressive strength test and permeability test. The mathematical calculation of compressive strength follows to the formula (Prasanda *et al.*, 2015)

$$\sigma = \frac{P}{A \times 100} \times g$$

Where:

σ = compressive strength P = applied force on the paving surface (kg)

A = area of the paving surface (cm²) g = acceleration due to gravity (9.81 m/s²)

Additionally, the permeability coefficient is determined utilizing the formula (Indrayadi *et al.*, 2021):

$$K = \frac{\rho g L Q}{P A}$$

Where:

K = permeability coefficient (cm³/s) ρ = water density (kg/cm³)

g = gravitational acceleration (cm/s²) L = length or height of the sample (cm)

P = water pressure ($\text{kg/cm/s}^2/\text{cm}^2$) A = cross-sectional area of the sample (cm^2)

Q = water flow rate (cm^3/s)

- Stage VIII: Data Analysis and Conclusion

At this stage, the data acquired from stage III (material assesment), stage IV (mixture design), and Stage VII (sample testing) are processed and shown in tables and graphs. The analysis concludes that the ideal mixing ratios are 1 part cement to 5 parts coarse aggregate and 1 part cement to 6 parts coarse aggregate.

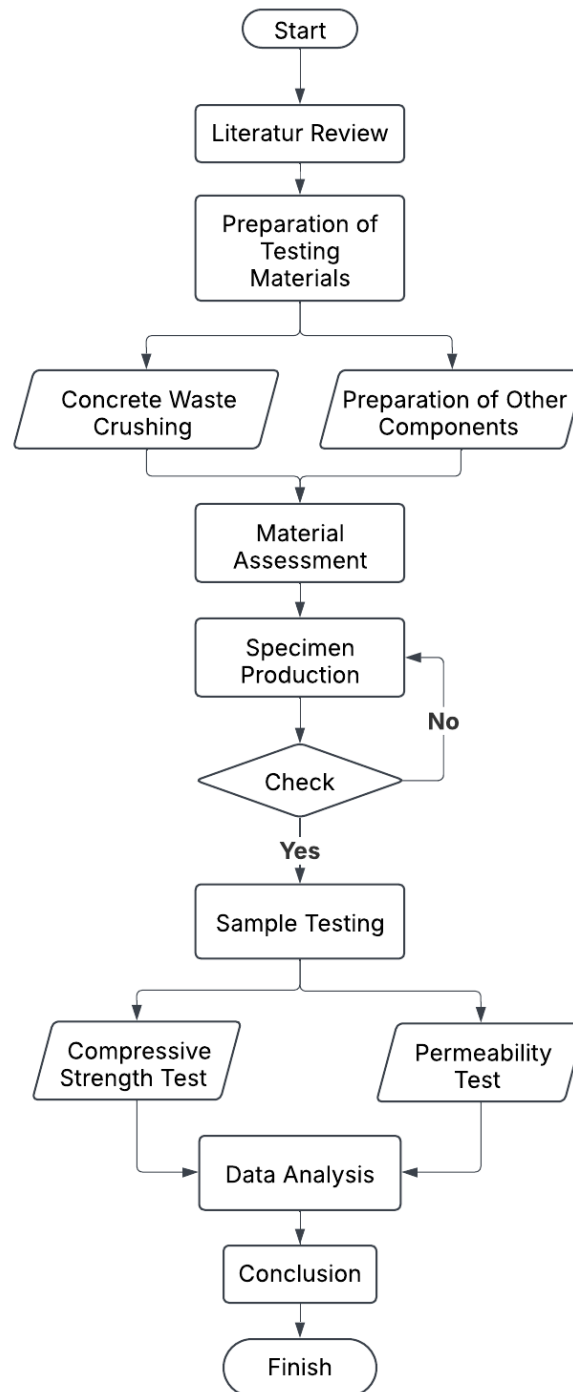


Figure 2. Research Flowchart

RESULTS AND DISCUSSION

The results obtained from the material testing conducted are as follows, according to ASTM, ACI, and SNI standards. The purpose of this test is to identify the properties of the material that will be utilized. The outcomes are presented in Table 2 below.

Table 2. Characteristic test result

No	Materials	Type of Test	Analysis
1	Cement	Normal consistency	Based on the normal consistency test, a value of 22% was obtained.
		Cement setting time	The initial cement setting time test, with a 25 mm penetration, showed a setting time of 109 minutes
		Specific gravity of cement	The specific gravity of the cement was found to be 3.00 t/m ³
		Cement volume weight	The cement bulk density, based on the data processing results, was 1.9 g/cm ³ .
2	Coarse aggregate	Moisture content of concrete waste	The moisture content of coarse aggregate is 4.17%.
		Specific gravity of concrete waste	The specific gravity of coarse aggregate is 2.37 g/cm ³
		Water infiltration of concrete waste	The water infiltration value of concrete waste is 6.53%
		Bulk density of concrete waste	The bulk density of coarse aggregate is 1.9 g/cm ³
		Abrasion test	Based on the data processing results, an average value of 31.66% was obtained.

The analysis suggests that the constituents of the porous paving mixture (cement and concrete waste) possess characteristics that require careful adjustment for optimal performance. The analysis suggests that the constituents of the porous paving mix (cement and concrete waste) possess characteristics that require careful adjustment for optimal performance. The cement's standard consistency facilitates optimal mixing with aggregates, while the regulated setting time guarantees structural integrity. The coarse aggregate exhibits low moisture content, which aids in preventing excess water from interfering with cement hydration; nonetheless, moisture levels must be meticulously regulated to avoid adversely affecting the ultimate strength and permeability of the paving blocks. The water absorption rate of the concrete waste is crucial for porous pavement, signaling the aggregates' suitability for water drainage. The abrasion resistance of 31.66% indicates that the paving blocks have moderate perseverance against wear and strain. The materials seem appropriate for porous paving blocks; however, more testing on long-term performance and durability under actual conditions is required to validate their suitability.

To create test specimens, the requisite material proportions for each specimen are necessary. In this case, specific proportions are prepared for each of the three test specimens. The material specifications for each cubic meter are presented in the Table 3 below.

Table 3. Mix design result

Material requirements for every 1 m ³ of non-sand concrete		
No.	Description	Information
1	Type Of Cement	Type I Portland Cement
2	Aggregate Type	Concrete waste
3	Aggregate Size	5 - 20 mm
4	Cement-Aggregate Ratio	1 : 5 1 : 6
5	Requirement Of One Specimen	1 : 5 Agregate = 20,47 kg Cement = 5,2 kg Water = 2,1 kg 1 : 6 Agregate = 20,46 kg Cement = 4,3 kg Water = 1,7 kg

- Compressive Strength Result

In order to evaluate the quality of porous paving blocks, compressive strength testing is necessary. Once a certain compressive force is applied using a compression testing equipment as can be seen in Figure 2, the test specimen's compressive strength is the amount of load per unit area that causes it to fracture. Three test specimens were utilized for each variant, and the compressive strength tests were performed on all versions of the porous paving blocks following 28 days of curing, which is thought to be the optimal curing duration for this test. The results can be seen in Table 4.



Figure 2. Compressive strength test

Table 4. Compressive Strength (Mpa) test results

Speciment	Mixture Proportions	Compressive Strength (Mpa)	Average Compressive Strength (Mpa)
	1:5	5.129	5.861
		8.370	
		5.487	
	1:6	4.164	4.850
		5.183	
		4.430	

Based on the results of Table 4, the compressive strength test, the mixture proportions have a major impact on the porous paving blocks' compressive strength. With an average compressive strength of 5.861 MPa, the specimen with the cement-aggregate ratio of 1:5 demonstrated the maximum strength, indicating that this ratio offers the ideal balance between cement and aggregate materials. Additionally, each specimen's compressive strength varies somewhat, according to the test findings. Indicating that variables like mixing, curing conditions, and material homogeneity may affect the ultimate strength, the specimen with a 1:5 mixture, for instance, exhibited strengths ranging from 5.129 MPa to 8.370 MPa. For best results, it is crucial to maintain uniformity in the curing period and mixing procedure.

- **Permeability Test Result**

The permeability test was conducted on porous pavement using a readily available permeability instrument as can be seen in Figure 3, which measures the rate at which water can flow through the paving surface. The test was conducted in both horizontal and vertical water flow directions to make sure the pavement was capable of providing the best drainage under different circumstances. The ability of the material to channel water downward and drain water along the paving surface is measured by the vertical test and the horizontal test, respectively. These two tests give an entire overview of how well porous paving can support rainfall management and avoid puddles. For every variation that was employed, Table 5 displays the results of the porous paving block permeability test.

Table 5. Permeability test results

Mixture Proportions		Permeability in horizontal direction (cm/s)	Vertical direction permeability (cm/s)
1:5		6.930	6.014
		7.132	6.709
		6.463	5.532
1:6		9.854	7.799
		7.598	7.029
		6.502	6.502
Average	1:5	6.842	6.085
	1:6	7.985	7.11



Figure 3. Permeability Test

According to the above data, the 1:6 combination has greater vertical permeability, which allows water to flow further into the ground and avoids surface water buildup. This is especially advantageous for pavement that is utilized in open spaces, such parking lots or rain-prone walkways. Although the 1:5 mixture has a slight reduced vertical permeability, it still provides acceptable drainage. All things considered, either kind of combination can work well for porous pavement; nonetheless, the best mixture should be chosen based on the field's characteristics and the required drainage.

CONCLUSION

The research findings indicate that the combination of materials in different amounts produced different outcomes regarding the compressive strength and water absorption of porous paving blocks. The 1:5 cement-aggregate ratio provided the maximum compressive strength of 5.861 MPa, which may indicate an ideal equilibrium between cement and aggregate, hence producing a more robust paving block than the 1:6 combination. Meanwhile, the 1:6 mixture showed the highest permeability coefficient, which is essential for optimal drainage. The 1:5 ratio is preferred since it provides optimal equilibrium between strength and drainage efficacy. Nevertheless, if the primary emphasis is on water absorption, the 1:6 mixing ratio may also be deemed appropriate. This study emphasizes the significance of comprehensive procedures for testing and oversight during the mixing and curing phases. Further research may investigate other combination proportions, include additives, and assess resilience to traffic loads and long-term adjustments.

ACKNOWLEDGEMENT

We would like to extend our deepest gratitude to the Department of Civil Engineering and Politeknik Negeri Banyuwangi for their valuable assistance during the process of this research. We also would like to express our gratitude to the Directorate General of Learning and Student Affairs, Ministry of Research, Technology, and Higher Education of the Republic of Indonesia, for providing the funding for the Student Creativity Program in 2024.

REFERENCES

- Budhi, W. S., Utanaka, A., Wiryasuta, I. K. H., & Widyastuti, H. (2023). Identifying Traffic Accident Trends and Black Spot Locations on National Road (A Case Study: Rogojampi-Kabat, Banyuwangi). *International Conference on Architecture and Civil Engineering Conference*, 683–695.
- Buertey, J. I. T., Offei, S. W., Kumi, T. A., & Atsrim, F. (2018). Effect of aggregates minerology on the strength of concrete: Case study of three selected quarry products in Ghana. *Journal of Civil Engineering and Construction Technology*, 9(1), 1–10. <https://doi.org/10.5897/jcect2017.0472>
- Dewi, E. S. (2023). Pemanfaatan Limbah Hasil Pengujian Beton Pada Proyek Bypass (BIL) Mandalika Sebagai Pengganti Sebagian Agregat Kasar Beton Normal. *Jurnal Ilmiah Teknik Sipil Fakultas Teknik*, 3(1), 1–8. <https://handasah.unizar.ac.id/jh/article/view/4>
- Ginting, A. (2019). Kuat Tekan dan Porositas Beton Porous dengan Bahan Pengisi Styrofoam. *Jurnal Teknik Sipil*, 11(2), 76–98. <https://doi.org/10.28932/jts.v11i2.1404>
- Han, A. L., Setiawan, H., & Hajek, P. (2019). Laboratory Concrete Specimens Waste, a Case Study on Life Cycle Assessment. *IOP Conference Series: Earth and Environmental Science*, 290(1), 12015. <https://doi.org/10.1088/1755-1315/290/1/012015>
- Indrayadi, M., Sutandar, E., & Supriyadi, A. (2021). Beton Berpori Precast. *Jurnal TEKNIK-SIPIL*, 21(2), 146. <https://doi.org/10.26418/jtsft.v21i2.51318>
- Junaidi, A. (2015). Daur Ulang Limbah Pecahan Beton Sebagai Pengganti Agregat Kasar Pada Campuran Beton. *Daur Ulang Limbah Pecahan Beton Sebagai Pengganti Agregat Kasar Pada Campuran Beton*, 4(1), 5–15.
- Mulyono, T. (2003). *Teknologi Beton*. Andi Yogyakarta.
- Najm, H., Wang, H., Roda, A. M., Miskewitz, R., Hencken, J., Ali, A. A., He, H., & Chen, X. (2017). *The Use of Porous Concrete for Sidewalks* (Issue December 2017).
- Prasanda, A. F. E., Triwulan, & Ekaputri, J. J. (2015). Paving Geopolimer Berbahan Dasar Bottom Ash dan Sugar Cane Bagasse Ash (SCBA). In *Jurnal Teknik Its* (Vol. 4, Issue 2). Institut Teknologi Sepuluh Nopember.
- Rifqi, M. G., Amin, M. S., & Lesmana, Y. I. (2018). Karakteristik Paving Berongga Menggunakan Material Batu Kali Bulat Berbasis Ramah Lingkungan. *Potensi : Jurnal Sipil Politeknik*, 20(1). <https://doi.org/10.35313/potensi.v20i1.1000>
- Shandy, S., & Hermanto, J. (2021). Karakteristik kuat beton normal dengan penambahan limbah tempurung kenari pulau makian. *Jurnal Teknik*, 14(1), 5–14.
- Zalaya, Y., Handayani, P., & Lestari, I. W. (2019). Pengelolaan Limbah Hasil Konstruksi Pada Proyek Pembangunan Gedung. *Forum Ilmiah*, 16(1), 63–72.