

Analysis of the Potential and Impact of Utilizing Nickel Slag Powder and Recycled Plastic on the Technical Properties of Concrete Blocks: In Terms of Strength and Cost Efficiency

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Abstract

Plastic waste and nickel slag are significant environmental pollutants, while the construction sector demands sustainable building materials. This study investigates the use of nickel slag powder as a partial cement replacement and recycled High-Density Polyethylene (HDPE) plastic as a partial replacement for fine aggregate in concrete block production. Laboratory tests were conducted in accordance with SNI standards for compressive strength, splitting tensile strength, porosity, permeability, and cost. Results showed that low substitution levels (2.5–10%) improved both strength and durability. The highest compressive strength of 10.43 MPa was achieved at a 5% substitution level, compared to 7.13 MPa in the control mix, while the maximum tensile strength of 1.32 MPa was observed at a 2.5% substitution level. Porosity was reduced to 0.97% and permeability to 4.13×10^{-7} cm/s, indicating a denser microstructure. Cost analysis revealed a reduction from Rp9,128.80 per block (0% substitution) to Rp8,252.36 at 10%, yielding savings of about 9.6%. However, higher substitution levels (>10%) led to strength loss and increased porosity due to incomplete hydration and weak bonding. The results confirm that the optimal substitution range of 2.5–10% balances performance and cost, providing an eco-friendly and cost-effective solution for sustainable concrete block production within a circular economy framework.

Keywords: Concrete Block, Building Materials, Compressive Strength, HDPE, Nickel Slag Powder, Plastic Waste

1. Introduction

Environmental issues have become a global concern in recent decades. (Rosanti et al., 2022), particularly due to the effects of climate change. Its impacts, such as rising sea levels and land subsidence, underscore the need for integrated assessments that account for broader hydrological and geological consequences. (Syahrul et al., 2025). One of the most pressing problems is the increasing volume of waste, both organic and inorganic, which contributes to pollution of soil, water, and air. Among these, plastic waste and nickel slag powder are major contributors, particularly from industrial and household sources. In 2018, Indonesia produced about 64 million tons of plastic waste, of which 3.2 million tons entered the ocean (Meyrena et al., 2020). These types of waste are not readily decomposed and pose significant environmental risks. (Lamba et al., 2022; Wijaya et al., 2021). Additionally, nickel slag powder generated by industrial processes can contaminate soil and water bodies. (Hadipramana et al., 2023).

In the construction context, materials such as concrete blocks (*batako*) also have environmental impacts, including high energy consumption and carbon emissions during

production. As infrastructure demand continues to grow, the need for more sustainable alternatives in the construction sector becomes increasingly urgent, especially in alignment with Indonesia's Net Zero Carbon mission. (Nihayah et al., 2022). Furthermore, from a sustainable development perspective, construction projects may need to shift from short-term to long-term approaches, from local considerations to global impacts, and from merely considering costs to assessing overall value. (Kumara et al., 2025). In accordance with Indonesia's Net Zero Carbon mission, there is an urgent need to identify more environmentally friendly and sustainable alternatives to conventional construction materials (Nihayah et al., 2022).

One potential solution is the use of recycled materials in construction. This study investigates the potential use of nickel slag powder and recycled plastic as alternative materials in the production of concrete blocks. Plastics are generally classified into three main categories: High-Density Polyethylene (HDPE), Medium-Density Polyethylene (MDPE), and Low-Density Polyethylene (LDPE). (Rajawat et al., 2022). In particular, this research focuses on incorporating High-Density Polyethylene (HDPE) derived from recycled plastics, in combination with nickel slag

powder, to enhance the sustainability and performance characteristics of concrete block materials. The combination of these two materials is expected to reduce the volume of waste sent to landfills, minimize reliance on conventional raw materials, and decrease carbon emissions during production. This research aims to provide a sustainable, innovative solution to the dual problems of environmental pollution and the high demand for construction materials.

Several studies have pointed out the importance of these waste-derived materials in enhancing the performance of construction products. For example, HDPE has been reported to increase compressive strength and reduce water absorption when used as a partial substitute for aggregates in cement bricks and blocks. However, excessive replacement may lower mechanical performance. Meanwhile, nickel slag powder, which contains silica and other pozzolanic compounds, has been proven to improve hydration, enhance density, reduce porosity, and significantly cut CO₂ emissions when partially replacing cement. (Yansiku and Duran, 2025; Ashad et al., 2010). These findings indicate that both HDPE and nickel slag powder can serve as eco-friendly construction resources with tangible technical and environmental benefits.

The novelty of this research lies in combining HDPE and nickel slag powder within a single concrete block formulation. While most prior studies investigated these materials independently, integrating them addresses two critical waste challenges simultaneously and offers synergistic improvements in mechanical strength and sustainability. In addition, investigations on nickel pig iron slag demonstrate its capacity to improve durability in aggressive environments, such as marine exposure, underscoring the broad potential of slag-based materials. (Dimitrioglou et al., 2016). Thus, this dual-waste utilization strategy not only aligns with circular-economy practices but also addresses Indonesia's pressing environmental issues and infrastructure needs. By redefining waste as a resource, this study aspires to contribute to the development of sustainable construction materials that reduce environmental pollution, lower production costs, and support national objectives toward eco-friendly development and carbon neutrality.

Plastic is widely used due to its durability, corrosion resistance, light weight, and low cost. (El-Metwally et al., 2023). The mechanical properties of plastics, including high durability and heat resistance, can enhance a building's thermal resistance (Fenollera et al., 2015). However, its non-biodegradable nature makes plastic waste a serious environmental issue. (Lamba et al., 2022). Several studies have demonstrated that recycled plastics can be utilized in construction materials to mitigate environmental impact. HDPE and PET are the most studied types, with findings suggesting that HDPE at 2.5–7.5% substitution can improve compressive strength when replacing fine aggregates (Ali et al., 2017; El-Metwally et al., 2023), whereas PET often decreases strength. Nevertheless, even with reduced strength, bricks with plastic content can still meet ASTM C62:2017 (15.2 MPa) and SNI-0349-1989 standards. (Padang et al., 2024; Sarwar et al., 2023). The performance is generally better with finer polymer particles. (Limami et al., 2020). However, excessive substitution leads to porosity and strength reduction due to the hydrophobic nature of plastics (Ali et al., 2017). Supporting this, experimental studies have demonstrated that adding up to 35% HDPE can improve

ductility and workability, though it reduces the density of plastic bricks.

The optimum compressive strength is often achieved at lower dosages, such as 3% HDPE, in Indonesia. Substituting fine aggregates with HDPE in batako has been shown to still comply with SNI 03-0349-1989, although the quality classification shifts from Grade III to Grade IV at higher substitution levels. (Padang et al., 2024). These findings confirm that HDPE waste has practical potential for eco-friendly construction, but careful dosage optimization is essential to balance strength and sustainability. (Nihayah et al., 2022; Sarwar et al., 2023). As a literature comparison, research on nano-admixtures such as carbon nanotubes (CNTs) has reported improvements in workability and compressive strength at very low dosages through their roles as nano-fillers, interfacial bridges, and C-S-H nucleation sites. (Sunarno et al., 2025). Their effects are often comparable to or even surpass those of conventional superplasticizers under certain conditions, but they remain susceptible to dispersion and agglomeration. Nevertheless, the present study focuses on a waste-based approach (recycled HDPE), with CNTs positioned only as a contextual comparison rather than as the primary experimental subject.

Research on utilizing waste materials for conventional construction methods demonstrates significant potential. (Mildawati et al., 2022) found that corn stalk ash (CSA) effectively serves as a partial cement replacement in rigid pavement concrete, improving compressive strength and cost efficiency while yielding only modest gains in flexural strength. In a related study, (Harmiyati et al., 2024) showed that incorporating 2–4% bagasse by cement weight yields pervious concrete with sufficient strength (>12 MPa) and high permeability (0.33 cm/s). Thus, both CSA and bagasse offer sustainable alternatives for construction—CSA for structural pavements and bagasse for permeable, water-managing surfaces.

Nickel slag powder, a by-product of nickel smelting, is categorized as hazardous waste (B3) (Wijaya et al., 2021), yet it contains silica (Si), which can improve concrete microstructure and durability. (Hadipramana et al., 2023; Yansiku et al., 2025). Previous studies have reported that partial substitution of cement with nickel slag or Nickel Pig Iron (NPI) can increase compressive strength, with NPI-zeolite cement paste reaching its highest strength at 40% substitution. (Selatan et al., 2024). Similarly, Ferronickel Slag (FNS) at 10% substitution in paving blocks improved compressive strength by about 15% compared to control samples. (Dimitrioglou et al., 2016). Other findings also confirm that replacing 5–10% of the nickel slag in cement can increase compressive strength by up to 5.76% at 28 days, while simultaneously reducing porosity and improving hydration, indicating its effectiveness as a supplementary cementitious material. (Nabiilah et al., 2019). Previous studies show that higher plastic replacement ratios reduce compressive strength. (Ahmed et al., 2022; Almeshal et al., 2020; Belmokaddem et al., 2020). Thus, the use of nickel slag not only reduces cement consumption and thereby lowers CO₂ emissions but also addresses industrial waste management challenges, thereby strengthening its role in sustainable construction. (Oksri-Nelfia et al., 2020).

Research combining nickel slag powder and recycled plastic in concrete blocks has not yet been conducted in Indonesia. Given that nickel slag enhances strength while HDPE offers lightweight and sustainability benefits, their

synergy offers potential as an innovative construction material. (Selatan et al., 2024). Further studies are required to determine the optimal composition that balances structural performance and environmental benefits.

2. Materials and Methods

2.1 Materials and Sample Preparation

The materials used in this study consisted of Ordinary Portland Cement (OPC) Type I, natural sand as fine aggregate, clean water, nickel slag powder obtained from PT Growth Java Industry, and recycled High-Density Polyethylene (HDPE) plastic waste sourced from PT Gajah Tunggal Tbk. Local craftsmen further processed the HDPE waste to achieve a particle size suitable for use as an acceptable aggregate substitute. Before use, all materials were tested in accordance with SNI standards, including sieve analysis, organic content testing, and specific gravity measurements, to ensure their quality and suitability for concrete block production.

The control mixture was composed of 70% sand, 25% cement, and 5% water, while experimental mixtures were prepared by partially substituting cement with nickel slag powder and fine aggregates with HDPE. Eight different variations were designed, with substitution levels of 0%, 2.5%, 5%, 7.5%, 10%, 20%, 30%, 40%, and 50%. Each mixture was homogenized using a mechanical mixer, and the water-cement ratio was kept constant to maintain consistency across samples. From these mixtures, a total of 72 specimens were produced, with nine samples prepared for each variation. The specimens included cube molds measuring 5 × 5 × 5 cm for compressive strength testing and cylindrical molds measuring 10 × 20 cm for splitting tensile strength. Following casting, the samples were cured by immersion in water for 7, 14, and 28 days, in accordance with SNI 1974:2011 standards. Subsequent testing was conducted to evaluate the mechanical and durability properties of the concrete blocks (Fatmawati et al., 2021; Zhong et al., 2021). Compressive strength tests were carried out on cube samples at ages 7, 14, and 28 days using a compression testing machine, while splitting tensile strength tests were performed on cylindrical samples after 28 days of curing. The results indicated that low-to-moderate levels of substitution improved compressive and tensile performance due to the pozzolanic reaction of nickel slag and the filler effect of HDPE. However, higher substitution levels led to reduced performance due to incomplete hydration caused by excessive nickel slag and the formation of weak zones resulting from HDPE's hydrophobic properties. In addition, porosity tests were conducted on larger specimens (15 × 30 cm) to measure internal density through oven-dry, saturated surface-dry, and submerged weight methods. These results showed that moderate substitution reduced porosity and enhanced durability, whereas excessive substitution increased pore formation and weakened the material's structural integrity.

Overall, the experimental design provided a comprehensive evaluation of the influence of nickel slag powder and recycled HDPE substitutions on the performance of concrete blocks. By employing multiple substitution levels and testing at different curing ages, this methodology enabled an in-depth analysis of both short- and long-term material behavior, providing a strong basis for assessing the potential of these waste materials as sustainable construction components.

2.2 Sample Casting and Curing

The concrete block samples were prepared using a mechanical concrete mixer to ensure homogeneous mixing. The fresh mix was then cast into standard molds measuring 5 × 5 × 5 cm, which were used for compressive strength testing. Each mold was filled in three successive layers, and every layer was compacted using 25 tamping strokes to minimize voids and ensure uniform density throughout the specimen. After casting, the samples were left to dry at ambient laboratory conditions for 24 hours before demolding. Following demolding, the specimens underwent water curing in curing tanks for 7, 14, and 28 days, in accordance with SNI 1974:2011 standards, to allow proper hydration and strength development.

2.3 Compressive Strength Testing

The compressive strength tests were performed in accordance with SNI 03-2493-1990 and SNI 03-1974-1991. The specimens were placed in a compression testing machine and loaded at a rate of 2–4 kg/cm²/s until failure. The maximum load was recorded to determine the compressive strength.

$$\text{compressive strength } (f'c) = \frac{P}{A} \quad (1)$$

2.4 Cost Analysis

Cost analysis in this study involved calculating the material and production costs of both conventional and modified concrete blocks. The calculation used unit prices for cement, sand, nickel slag powder, HDPE, and water, obtained directly from suppliers and local markets to ensure the accuracy and representativeness of the data. In addition to raw material costs, the analysis included expenses for mixing, molding, curing, and testing, as well as labor costs incurred during production. The total cost for each mix variation was then compared to that of conventional concrete blocks to evaluate the economic feasibility of incorporating nickel slag powder and recycled HDPE into block production. This approach enabled a comprehensive assessment of not only the mechanical performance but also the cost-effectiveness of the proposed material substitutions, providing valuable insights for practical applications in the construction industry.

3. Results And Discussion

3.1 Material Testing Result

All raw materials, including binding agents (cement and nickel slag powder) and fine aggregates (sand and recycled HDPE plastic waste), were tested in accordance with the relevant SNI standards to verify their compliance with the required specifications. For binder materials, the specific gravity of Ordinary Portland Cement (OPC) Type I and nickel slag powder was measured using the Le Chatelier method to determine their density and ensure consistency with standard values. For the aggregates, a series of tests was performed to assess their physical and mechanical properties. These tests included the determination of bulk density in both loose and compacted states, water content measurement through oven-drying at 110 ± 5 °C, mud content determination by washing and re-weighing in accordance with SNI 03-4142-1996, sieve analysis to establish particle size distribution and fineness modulus, and organic content testing using a 3% NaOH solution as specified in SNI 03-4141-1996. These procedures provided

comprehensive data regarding the physical properties of sand and HDPE plastic waste, ensuring that all materials met the technical requirements for use in concrete block production. The summarized results of these tests are presented in Table 1.

Table 1. Material Testing Result

Properties	Cement	Nickel Slag Powder	Sand	HDPE
Specific Gravity	3.112	3.06	2.37	1.1934
Loose Bulk Density	-	-	1.28	0.4179
Compacted Bulk Density	-	-	1.43	0.4609
Water Content	-	-	8.61%	0.20%
Mud Content	-	-	2.41%	0.36%
Organic Content	-	-	No organic content	No organic content

3.2 Compressive Strength Test Results of Concrete Blocks

The compressive strength of the concrete blocks was evaluated at curing ages of 7, 14, and 28 days using cube specimens measuring 5 × 5 × 5 cm in accordance with SNI standards. At 7 days of curing, the specimens exhibited the initial development of compressive strength. However, the hydration process remained incomplete, and the matrix microstructure had not yet fully formed. By 14 days, a significant increase in strength was observed, indicating the continuation of hydration reactions and improved bonding between the cementitious paste and aggregates. At 28 days, the specimens reached their optimal compressive strength, which served as the reference value for evaluating the overall mechanical performance of the modified concrete blocks.

Table 2. Compressive Strength Result

Percentage of Material Substitution	Compressive Strength (MPa)		
	7 days	14 days	28 days
0%	3.73	6.15	7.13
2.50%	5.48	8.48	11.04
5%	5.09	7.85	10.43
7.50%	4.65	7.40	10.01
10%	4.45	6.65	9.36
20%	3.23	4.65	6.12
30%	2.37	3.84	5.39
40%	1.73	2.63	3.71
50%	0.92	1.81	2.36

The experimental program incorporated substitution levels of nickel slag powder and HDPE plastic ranging from 0% (control) to 50%, with incremental increases of 2.5%. The results in Table 2 showed that moderate substitution levels, particularly 2.5–10%, improved compressive strength compared to the control specimens. Beyond this range, however, compressive strength values tended to decline, attributed to matrix disruption from excessive replacement materials and the hydrophobic properties of HDPE, which inhibit proper cement hydration. The highest compressive strength was recorded in the 5% substitution mixture, achieving 10.43 MPa at 28 days of curing. This result highlights that controlled incorporation of nickel slag powder and HDPE can enhance the performance of concrete blocks, while higher substitution levels may compromise their structural integrity.

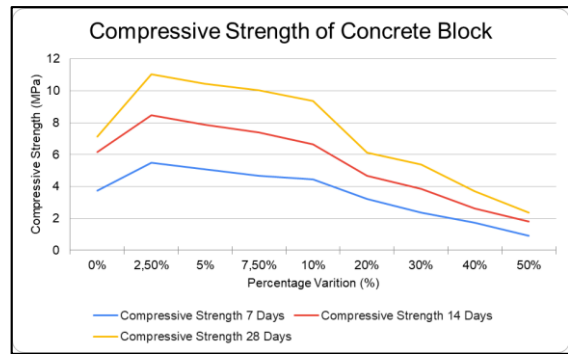


Fig 1. Compressive Strength Result



Fig 2. Image of the compressive strength test using a 5x5x5 cm concrete block sample, showing the setup including the compression testing machine, loading plates, block specimen, load sensor, and data recording system used to monitor the maximum load applied during the test.



Fig 3. Image of the splitting tensile strength test on a cylindrical concrete specimen, showing the compression machine, line-contact loading plates, specimen, load sensor, and data recording system.

3.3 Split Tensile Strength Test Results of Concrete Block

The splitting tensile-strength test was conducted in accordance with SNI 03-2491-2002 to determine the indirect tensile capacity of the concrete block specimens. Each cylindrical specimen was first labeled, and its average diameter was obtained by taking three measurements at different points to ensure accuracy and representativeness. The specimens were then carefully placed on the testing machine, with their central axes aligned with the center of the upper loading plate to achieve uniform stress distribution during loading. The applied load was increased

gradually until failure, and the maximum load was recorded to calculate the splitting tensile strength.

Table 3. Split Tensile Strength Result and Ratio Split Tensile Strength to Compressive Strength

Percentage	Split Tensile Strength of Concrete Block (MPa)	Ratio Split Tensile Strength to Compressive Strength
0,0%	0,53	7,5%
2,5%	1,32	12,0%
5,0%	1,20	11,5%
7,5%	1,02	10,2%
10,0%	0,93	10,0%
20,0%	0,67	10,9%
30,0%	0,49	9,0%
40,0%	0,36	9,7%
50,0%	0,36	15,2%

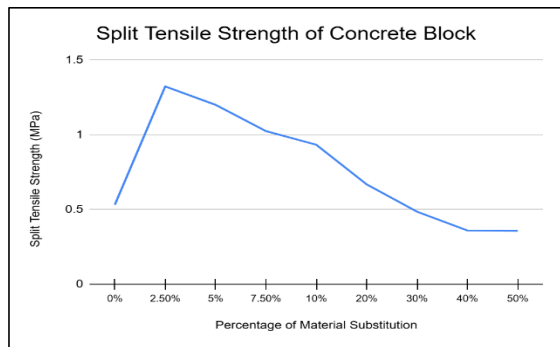


Fig 4. Split Tensile Strength Result

The results, as presented in Figure 4, indicate that moderate substitution levels of nickel slag powder and HDPE plastic improved the splitting tensile strength compared to the control mix. However, tensile strength values began to decline as substitution levels exceeded the optimum range, attributed to matrix discontinuities and weakening of internal bonding due to excessive replacement materials. The highest splitting tensile strength was achieved at a 2.5% substitution level, reaching 1.32 MPa, thereby confirming that the low-level incorporation of nickel slag and HDPE provides a beneficial balance between waste utilization and mechanical performance. Increased microstructural discontinuities and poor stress transfer between the cement matrix and HDPE particles can explain the reduction in tensile strength at higher substitution levels. Supporting evidence was provided by porosity and permeability tests, which showed that low substitution ratios reduced pore connectivity and improved water resistance, with the lowest porosity of 0.97% recorded at 2.5% substitution. Conversely, higher substitution levels produced greater pore volumes and permeability coefficients (up to 9.008×10^{-7} cm/s), indicating compromised microstructural integrity and increased susceptibility to water ingress.

3.4 Porosity Test Results of Concrete Block

The porosity test was carried out on concrete specimens measuring 15×30 cm to determine the proportion of void volume within the material relative to its total solid volume. The porosity value was calculated by comparing the differences between the oven-dry weight, saturated surface-dry (SSD) weight, and submerged weight of each specimen, following standard gravimetric procedures. This method

revealed the internal pore structure, which directly affects the material's durability and density.

The results, as shown in Figure 5, demonstrate that the substitution levels of nickel slag powder and HDPE plastic influenced porosity. The lowest porosity was observed at 2.5% substitution, with a value of 0.97%, suggesting a denser internal structure and improved resistance to water absorption. In contrast, the highest porosity value of 2.53% was recorded at 50% substitution, indicating the formation of additional voids and a weaker microstructure. These findings confirm that limited substitution of waste materials can enhance the compactness of concrete blocks, whereas excessive replacement can increase pore formation and compromise durability.

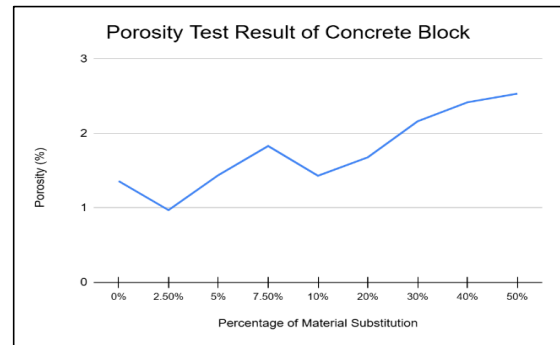


Fig 5. Porosity Test Result

3.5 Permeability Test Result of Concrete Block

The permeability test was conducted to quantitatively evaluate the resistance of concrete blocks to water penetration under constant hydraulic pressure. Cylindrical specimens measuring 15×30 cm were subjected to a controlled water head, and the depth of water ingress was measured to determine the material's watertightness. Concurrently, compressive strength measurements were recorded for the same mix variations to correlate mechanical performance with permeability behavior.

The compressive strength of the tested specimens ranged from 3.24 MPa to 9.71 MPa. The maximum strength of 9.71 MPa was achieved at 2.5% substitution of nickel slag powder and HDPE, while the lowest value of 3.24 MPa occurred at 50% substitution. This variation reflects the direct influence of substitution level on the microstructural integrity of the concrete matrix, where limited substitution enhances particle packing and hydration efficiency. In contrast, excessive substitution disrupts the cementitious matrix and reduces bonding efficiency.

The calculated permeability coefficients ranged between 4.130×10^{-7} cm/s and 9.008×10^{-7} cm/s. The data revealed a clear inverse correlation between compressive strength and permeability: specimens exhibiting higher compressive strength consistently demonstrated lower permeability coefficients, attributable to reduced pore connectivity and improved matrix densification. Conversely, specimens with lower compressive strength exhibited higher permeability, indicating increased porosity and microstructural discontinuities that facilitated water transport through the material.

These findings confirm that the interplay between matrix density, pore structure, and substitution level strongly governs the permeability characteristics of concrete blocks. The results underscore the importance of optimizing the

proportion of nickel slag powder and HDPE to achieve a balance between mechanical durability and hydraulic resistance, thereby ensuring that the concrete blocks meet both structural performance and long-term durability requirements.

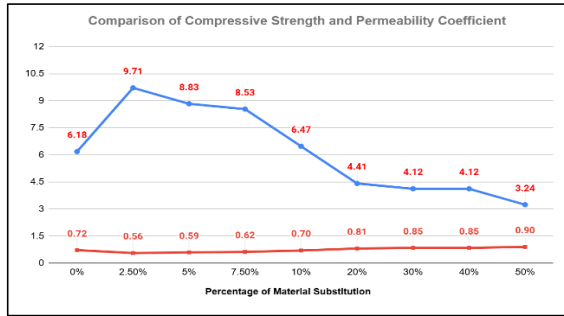


Fig 6 Permeability test results in comparison with compressive strength results.

3.6 Cost Estimation of Concrete Block

The cost estimation analysis was carried out to evaluate the economic feasibility of producing concrete blocks with partial substitution of cement and fine aggregates using nickel slag powder and recycled HDPE plastic waste. The production cost calculation included the prices of cement, sand, nickel slag powder, HDPE plastic waste, and water, as well as processing and curing expenses. All unit prices were obtained from local suppliers to ensure realistic market conditions. The estimation revealed that the unit cost of concrete blocks varied significantly depending on the level of substitution, with the control mix (0% substitution) showing the highest production cost at Rp9,128.80 per block. Introducing a 2.5% substitution reduced the cost slightly to Rp8,913.80 per block, and further substitution to 5% decreased the cost to Rp8,693.32 per block. At 7.5% and 10% substitution, the unit costs dropped further to Rp8,472.84 and Rp8,252.36 per block, respectively, confirming that even low substitution levels produce notable savings compared to the control.

Table 4. Cost Estimation Result

Percentage of Material Substitution	Price per Block (Rp)
0%	Rp9,128.80
2.50%	Rp8,913.80
5%	Rp8,693.32
7.50%	Rp8,472.84
10%	Rp8,252.36
20%	Rp7,370.45
30%	Rp6,488.53
40%	Rp5,606.61
50%	Rp4,724.69

The cost estimation and experimental analysis demonstrated that partial substitution of cement and fine aggregates with nickel slag powder and recycled HDPE plastic waste provides both economic and technical benefits when applied at low substitution levels. The production cost of concrete blocks decreased progressively with increasing substitution, from Rp 9,128.80 per block at 0% substitution to Rp 4,724.69 per block at 50%, representing a cost

reduction of nearly 48%. However, while higher substitution levels significantly reduced costs, they also led to declines in compressive and tensile strength and in durability due to incomplete hydration and increased pore connectivity.

The results of this study clearly show that the production costs of standard concrete blocks are lower than those of modified blocks made with HDPE plastic and nickel slag powder. The findings indicate a consistent reduction in cost as the substitution level increases; however, the prices obtained are still higher than those of conventional blocks available on the market. Other studies have reported that the average market price of a standard block is approximately Rp 4,500 per unit. (Harahap, n.d.). This discrepancy is mainly because the present research was conducted without the use of industrial-scale machinery and equipment commonly employed by commercial producers. Nevertheless, it can be concluded that the addition of nickel slag powder and HDPE plastic waste has the potential to reduce the production cost of concrete blocks. With further optimization and the use of advanced manufacturing technology, the price could approach or even undercut that of conventional blocks.

The optimal balance was observed within the substitution range of 2.5%–10%, where concrete blocks not only achieved reduced production costs (Rp8,913.80–Rp8,252.36 per block) but also exhibited improved mechanical properties. The highest compressive strength of 10.43 MPa at 28 days was achieved at 5% substitution, while the peak tensile strength of 1.32 MPa occurred at 2.5% substitution. At these levels, porosity and permeability were minimized, resulting in denser, more durable blocks than the control mix.

4. Conclusions

This study demonstrates that partial substitution of cement and fine aggregates with nickel slag powder and recycled HDPE plastic can enhance the performance of concrete blocks when applied at low levels. The optimal range was found to be 2.5–10%, with a maximum compressive strength of 10.43 MPa at 5% substitution and a peak tensile strength of 1.32 MPa at 2.5%. At these levels, porosity and permeability were minimized, resulting in denser and more durable blocks. At the same time, production costs decreased compared to conventional mixes; substitution beyond 10% reduced strength and durability due to incomplete hydration and weak interfacial bonding. Beyond the technical findings, this study underscores the potential of using industrial and household waste as sustainable construction materials in line with circular-economy practices. Further research is recommended to scale up production using industrial equipment, evaluate the long-term durability of this material under field conditions, and explore its integration with other supplementary cementitious materials. Such efforts will enhance the feasibility of adopting waste-based concrete blocks as an eco-friendly, cost-effective alternative in the construction industry.

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