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Research paper

Sustainable Construction Materials Through the Utilization of High-Density Polyethylene (HDPE) Plastic Waste and Used Tires in The Production of Environmentally Friendly Concrete Roof Tiles

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ABSTRACT

Purpose: This study aimed to determine the use of High-Density Polyethylene (HDPE) plastic waste and tire rubber waste as partial replacements for fine aggregate in the production of concrete roof tiles. This study was conducted to determine the effect of adding one or a combination of these two waste materials on the mechanical and physical characteristics of concrete roof tiles. The study then sought to determine the optimal mixture for concrete roof tiles that meets the SNI 0096:2007 quality standard.
Methods/Design: This study used a quantitative experimental method through laboratory testing with eight mixture variations (HDPE and tire rubber waste): 0%-0%, 0%-5%, 5%-5%, 10%-5%, 15%-5%, 5%-0%, 5%-10%, and 5%-15%. Waste was obtained from the Kulon Progo Regency waste bank and tested at the UNY Building Materials Laboratory. The research stages included material preparation, specimen preparation, and testing for visual properties, dimensions, flatness, water absorption, water permeability, and flexural strength. Data were obtained from experimental results and literature review
Findings: The results show that adding HDPE plastic waste and tire rubber waste produces lightweight concrete roof tiles that meet SNI standards in terms of visual properties, dimensions, flatness, water absorption, and water permeability. However, increasing the content of both wastes tends to reduce flexural strength. Therefore, it is recommended to use less than 5% HDPE waste and to avoid using tire rubber waste due to the significant reduction in flexural strength.
Practical Implication: Utilizing HDPE and tire rubber waste in concrete roof tile production has the potential to produce a lighter, more environmentally friendly material and support waste management. However, because flexural strength decreases sharply with the mixture of both wastes, stricter waste usage restrictions are necessary to ensure that the concrete roof tiles maintain optimal physical and mechanical properties and are superior in terms of material lightness.

INTRODUCTION

Indonesia is facing a serious waste management challenge, with daily waste generation reaching approximately 144,839 tons in 2025. However, only 25% of the total waste is properly managed, while the remaining 75% contributes to environmental pollution (SIPSN, 2025). Plastic waste constitutes 20.49% of national waste composition, whereas rubber-based waste, including used tires, represents another major source of non-biodegradable solid waste (Ismawati et al., 2024). Low recycling rates, estimated at only 12%, further worsen environmental degradation, as most waste ends up in landfills, open burning systems, or aquatic ecosystems (Prihartanto et al., 2023). This condition highlights the urgent need for innovative waste utilization approaches aligned with sustainable construction principles.

Among various plastic types, High Density Polyethylene (HDPE) has considerable potential for construction applications due to its high tensile strength, resistance to chemicals and moisture, thermal stability, and low density (0.94–0.97 g/cm^3) (Ragaert et al., 2017; Singh et al., 2017). Similarly, waste tire rubber possesses elastic properties capable of improving crack resistance and flexibility in cement-based materials (Thomas & Gupta, 2016). Both materials are difficult to degrade naturally, making their reuse environmentally beneficial.

The waste management problem is also evident in Yogyakarta, where daily waste generation reaches 1,925 tons, contributing to overcapacity conditions at Piyungan Landfill since 2022 (Setiawan et al., 2025). This indicates that conventional waste management systems are insufficient and emphasizes the importance of implementing reduce, reuse, and recycle (3R) principles through material innovation.

Figure 1. Piyungan final disposal site (Nurdiyansyah, 2022)

Previous studies have investigated waste utilization in construction materials. HDPE waste has been used as a partial aggregate substitute to produce lighter concrete materials, although excessive additions tend to reduce mechanical strength (Permata, 2016; Belmokaddem et al., 2020; Trilaksono, 2025). Recycled materials incorporated into lightweight concrete bricks have demonstrated reduced density and improved thermal insulation (Aziz et al., 2017). In addition, crumb rubber from waste tires has shown potential to enhance elasticity and crack resistance in concrete and asphalt (Thomas & Gupta, 2016; Elhamy et al, 2018). Several studies have explored waste-based concrete roof tiles using sugarcane bagasse, rice husk ash (Nugroho et al, 2017), PET plastics, or single-type waste materials. However, limited research has examined the combined utilization of HDPE plastic waste and waste tire rubber in concrete roof tile production, particularly regarding compliance with SNI 0096:2007.

Concrete roof tiles are widely used due to their durability, fire resistance, and long service life, but they generally possess relatively high weight, approximately 4.4 kg per unit, increasing structural load and construction costs (SNI 0096:2007). Therefore, reducing roof tile weight while maintaining mechanical performance remains an important challenge. The incorporation of HDPE and crumb rubber potentially offers lighter, more flexible, and environmentally sustainable roofing materials.

The novelty of this study lies in the simultaneous utilization of HDPE plastic waste and waste tire rubber as partial substitutes for fine aggregate in concrete roof tiles. Unlike previous studies focusing on single waste materials or structural concrete applications, this research evaluates the combined effect of both waste types on physical and mechanical properties, including visual characteristics, water absorption, permeability, and flexural strength according to SNI 0096:2007 standards. Therefore, this study aims to analyze the effects of HDPE plastic waste and waste tire rubber additions on the mechanical characteristics of concrete roof tiles and determine the optimum mixture composition for producing lightweight, environmentally friendly, and sustainable roofing materials.

METHODS/DESIGN

This study employed a quantitative experimental method to analyze the effects of High-Density Polyethylene (HDPE) plastic waste and waste tire powder (crumb rubber) on the physical and mechanical characteristics of concrete roof tiles. The research was conducted over a period of six months, including material collection, specimen preparation, curing, laboratory testing, and data analysis. Material collection was carried out at Dhuawar Sejahtera Waste Bank, Kulon Progo, while specimen production and laboratory testing were conducted at the Building Materials Laboratory of the Faculty of Vocational Studies and the Building Materials Technology Laboratory, Faculty of Engineering, Yogyakarta State University.

The primary materials used in this study consisted of Portland cement, Merapi sand as fine aggregate, HDPE plastic waste, and waste tire powder. HDPE plastic was obtained from household waste and landfill sources, while waste tires were processed into crumb rubber to facilitate mixing and distribution within the concrete roof tile mixture. The study applied eight mixture variations with different proportions of HDPE and crumb rubber as independent variables, namely: 0%-0%, 0%-5%, 5%-0%, 5%-5%, 5%-10%, 5%-15%, 10%-5%, and 15%-5%. These variations were used as partial substitutes for fine aggregate to evaluate their effects on concrete roof tile performance. Controlled variables included cement type, water content, mixing procedure, molding method, and curing conditions, while the dependent variables were the physical and mechanical properties of the concrete roof tiles.

Specimen preparation involved material mixing, molding, and curing for 28 days using immersion and drying methods to optimize strength development. After curing, testing was conducted according to SNI 0096:2007, including visual appearance, dimensional accuracy, flatness, water absorption, water permeability resistance, and flexural strength tests. Three specimens were tested for each mixture variation, and the results were analyzed using average values for each testing category.

The collected data were analyzed quantitatively through comparative evaluation among mixture variations to determine the optimum composition capable of producing concrete roof tiles with reduced weight, improved water resistance, and mechanical properties that satisfy quality standards. The findings were presented using tables, graphs, and comparative analyses to facilitate interpretation of the relationship between waste composition and concrete roof tile performance.

FINDINGS

Testing was conducted on eight mixture variations containing HDPE plastic waste and waste tire powder (crumb rubber) as partial substitutions in concrete roof tiles. The evaluated parameters included visual appearance, dimensional accuracy, flatness, water absorption (porosity), impermeability, and flexural strength, following SNI 0096:2007 standards. The findings indicate that the incorporation of waste materials produced varying effects on the physical and mechanical properties of concrete roof tiles.

Mechanical Characteristics of Concrete Roof Tiles without Additives.

Conventional concrete roof tiles (0% HDPE : 0% crumb rubber) demonstrated the best overall performance and satisfied all requirements of SNI 0096:2007. The highest flexural strength value was 1483.63 N, which served as the reference for evaluating the effects of waste material additions. These results suggest that conventional concrete possesses a denser internal matrix and stronger bonding compared to waste-modified mixtures.

Table 1. Mechanical performance of control concrete roof tiles

Mixture Variation	Flexural Strength (N)	SNI Requirement (N)	Compliance
0%HDPE ; 0% Rubber	1483,63	1400	√

Effect of HDPE Addition on the Mechanical Characteristics of Concrete Roof Tiles

The addition of HDPE plastic waste did not significantly affect visual appearance, dimensional accuracy, flatness, porosity, or water permeability resistance, indicating that all mixtures still met the physical requirements of SNI standards. However, increasing HDPE content tended to reduce flexural strength, although it contributed to lower water absorption. The mixture containing 5% HDPE achieved a flexural strength of 1389.14 N, which was lower than the control mixture and did not fully satisfy the required flexural strength standard, so a mixture of less than 5% will be preferred.

The reduction in flexural strength is likely associated with weak interfacial bonding between plastic particles and cement paste. Nevertheless, the hydrophobic properties of HDPE contributed to reduced water penetration and improved moisture resistance. This finding is consistent with previous studies by Belmokaddem et al. (2020), which reported that increasing plastic content produces lighter materials but decreases mechanical performance.

Effect of Waste Tire Addition on the Mechanical Characteristics of Concrete Roof Tiles

The incorporation of crumb rubber showed minimal influence on visual appearance, dimensional accuracy, and permeability resistance, but resulted in increased porosity and a greater reduction in flexural strength compared to HDPE. The mixture containing 5% crumb rubber exhibited a flexural strength of 1088.75 N, lower than the control specimen. These findings indicate that the elastic properties of crumb rubber enhance material flexibility but reduce load-transfer capacity due to the formation of internal voids within the concrete matrix. This observation aligns with the findings of Wijaya and Cruz (2021), who reported that higher waste tire content significantly reduces concrete strength.

Effect of Combined HDPE and Waste Tire Additions on Concrete Roof Tile Characteristics

The combined use of HDPE and crumb rubber maintained acceptable performance in terms of visual characteristics, dimensional stability, flatness, porosity, and water impermeability, with all mixtures satisfying permeability requirements according to SNI 0096:2007. However, the incorporation of waste materials generally resulted in reductions in flexural strength, with the lowest recorded value reaching 437.43 N, which did not satisfy the required standard. These findings indicate that the interaction between HDPE and crumb rubber decreases the internal density of the concrete matrix, thereby reducing load-bearing capacity. Although the combination of both waste materials has the potential to produce lighter and more water-resistant roofing materials, higher waste contents compromise mechanical performance.

Table 2. Comparison of flexural strength of concrete roof tile mixtures based on SNI 0096:2007

Variation		Flexural Strength (N)	SNI Requirement (N)	Compliance
HDPE	Rubber			
0%	0%	1483,63213	1400	√
0%	5%	1088,75190	1400	X
5%	5%	957,71216	1400	X
10%	5%	864,92817	1400	X
15%	5%	766,74234	1400	X
5%	0%	1389,14184	1400	X
5%	10%	775,93574	1400	X
5%	15%	437,43171	1400	X

To further evaluate the effect of waste incorporation on flexural performance, Table 2 presents the comparison of flexural strength values for all mixture variations and their compliance with SNI 0096:2007 requirements. Table 2 demonstrates that only the control mixture (0% HDPE : 0% rubber) fulfilled the flexural strength requirement specified by SNI 0096:2007, while increasing proportions of HDPE and crumb rubber progressively reduced mechanical performance. The most significant reduction occurred in the 5% HDPE : 15% crumb rubber mixture, indicating that excessive waste incorporation adversely affects the structural integrity of concrete roof tiles.

Interpretation of Findings and Research Novelty

Unlike previous studies that generally investigated single waste materials, this study examined the combined utilization of two non-biodegradable wastes (HDPE and crumb rubber) in concrete roof tiles according to SNI 0096:2007 standards. The findings indicate that all mixture variations maintained acceptable physical characteristics, including visual appearance and impermeability. However, increasing waste content reduced flexural strength, suggesting a trade-off between environmental sustainability and mechanical performance. To further evaluate the effect of waste incorporation on mechanical behavior, Table 3 summarizes the flexural strength values and their reductions compared with the control mixture. The results demonstrate that crumb rubber caused a greater decrease in flexural strength than HDPE at the same addition level.

Table 3. Comparison of flexural strength reduction relative to control mixture

Variation		Flexural Strengh (N)	Difference From Control (N)	Reduction per 1% Addition (N)
HDPE	Rubber			
0 %	0 %	1483,63213	-	
0 %	5 %	1088,75190	394,88	78,98
5 %	0 %	1389,14184	94,49	18,90

Based on Table 3, the incorporation of 5% waste tire powder (crumb rubber) resulted in a substantially greater reduction in flexural strength compared to the addition of 5% HDPE. This finding indicates that rubber particles have a stronger influence on weakening the internal matrix of concrete roof tiles. The phenomenon is likely associated with increased formation of internal voids and reduced load transfer capacity within the concrete structure.

The results suggest that lower waste proportions than those tested in this study may provide better mechanical performance while maintaining environmental benefits. Based on the observed trend of flexural strength reduction, future studies are recommended to investigate HDPE additions below 4% and crumb rubber additions below 1% to determine the optimum composition capable of balancing mechanical strength, material weight reduction, and environmental sustainability. In addition, further research should optimize the mixing and compaction processes to improve the overall performance of concrete roof tiles.

Overall, this study demonstrates that the utilization of HDPE plastic waste and waste tire powder has potential to support the development of sustainable construction materials, although further optimization is required to achieve an appropriate balance between mechanical performance, lightweight properties, and environmental sustainability.

PRACTICAL IMPLICATION

The findings of this study demonstrate the potential utilization of HDPE plastic waste and waste tire powder (crumb rubber) as alternative materials in the production of environmentally friendly concrete roof tiles. Although increased waste content reduced flexural strength, the incorporation of these materials contributed to lower material density and maintained acceptable physical properties, particularly in water resistance and impermeability.

From an industrial perspective, the use of recycled HDPE and crumb rubber may support the development of sustainable construction materials, reduce dependence on conventional raw materials, and promote circular economy practices within the construction sector. The implementation of waste-based concrete roof tiles also offers opportunities to reduce construction waste and improve solid waste management, particularly in regions experiencing landfill overcapacity problems, such as Yogyakarta.

For society and government, the utilization of non-biodegradable waste in construction materials may contribute to reducing environmental pollution and support the achievement of Sustainable Development Goals (SDGs) 11 and 12, namely Sustainable Cities and Communities and Responsible Consumption and Production. These findings may also provide reference material for policymakers in encouraging waste recycling programs and sustainable construction regulations.

However, the reduction in flexural strength indicates that optimization of mixture composition remains necessary before large-scale implementation. Future studies are recommended to investigate lower waste proportions, alternative processing methods, and additional additives to improve mechanical performance while maintaining environmental benefits. Overall, this study provides practical insight into the integration of waste management strategies and sustainable material innovation in the construction industry.

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DISCLOSURE STATEMENT

The author declares no potential conflicts of interest concerning the research, authorship, and publication of this article. The funding source had no role in study design, data collection, analysis, interpretation, or publication decisions.

NOTES ON CONTRIBUTOR

Intan Melyana is a student in the Department of Applied Civil Engineering Faculty of Vocational, Universitas Negeri Yogyakarta. Her research interests include construction materials technology, sustainable construction materials, environmentally friendly building material innovation, and waste utilization in construction applications. Muhammad Nuruzzaman is a lecturer in the Department of Applied Civil Engineering Faculty of Vocational, Universitas Negeri Yogyakarta.

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