

Optimization of Compressive Strength of Paving Blocks with Variations in Aggregate and Cement Mixtures

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ABSTRACT

To improve quality and cost efficiency, it is necessary to study the effect of varying aggregate and cement mixtures in paving block production. This research aims to determine the influence of different aggregate-cement mix ratios on the compressive strength and overall quality of paving blocks and to identify an optimal mix that meets the compressive strength requirements of the Indonesian National Standard (SNI) while still being economically feasible. This laboratory experimental study used five mixture variations with cement-to-aggregate ratios of 1:1, 1:2, 1:3, 1:4, and 1:5. Paving block specimens were cast and then cured for 28 days. After curing, each specimen was weighed and tested for compressive strength using a compression testing machine. The results show that the cement content has a significant effect on compressive strength. Cement acts as a binder that holds aggregate particles such as sand and stone dust together through the hydration process. The higher the cement content, the denser and stronger the bond between particles, resulting in higher compressive strength. However, the mixture with a 1:5 cement-to-aggregate ratio did not meet the SNI compressive strength requirements. On the other hand, excessive cement content is also not ideal, as it increases production costs and may lead to problems such as shrinkage and microcracking

INTRODUCTION

Paving blocks are one of the most widely used precast building materials for light pavement construction such as sidewalks, yards, parking areas, and residential roads. They are chosen because of several advantages: easy installation, simple maintenance, the possibility of removal and reinstallation, and environmental benefits due to their permeability, which allows rainwater to infiltrate into the soil (Yulianto et al., 2018). Paving blocks are also relatively cheap and easy to produce compared with other precast concrete elements.

The quality of paving blocks is strongly influenced by the characteristics of the constituent materials and the proportions of the mix. The main materials are cement as a binder, fine aggregate, and coarse aggregate as fillers. According to SNI 03-0691-1996 on paving blocks, compressive strength quality is classified into several classes such as K100, K200, and K300, which represent compressive strength values in kg/cm² or MPa. Class B paving blocks (minimum strength 20 MPa) are generally used for pedestrians and light vehicles, while Class A (≥ 30 MPa) is used in areas with heavy traffic.

The compressive strength of concrete, including paving blocks, is affected by several factors such as type and quality of aggregate, water-cement ratio (w/c), and the proportion of cement to aggregate (Neville & Brooks, 2010). Variations in aggregate type, size, gradation, and whether it is natural or recycled can result in different mechanical properties. Likewise, increasing the cement content generally increases compressive strength but also raises production costs.

To improve quality and cost efficiency, it is important to conduct a study on variations in aggregate and cement mixtures in paving block production. The goal is to determine an optimal mix composition that meets SNI compressive strength standards while considering sustainability and economic aspects. This study refers to SNI 03-0691-1996 on paving blocks and SNI 03-1974-1990 on testing methods for concrete compressive strength. The specific objective is to analyze the effect of different aggregate-cement mix ratios on the compressive strength and quality of paving blocks. The research findings are expected to contribute to the development of construction material technology, especially in medium- and small-scale infrastructure.

LITERATUR REVIEW

Paving blocks are widely used as modular concrete units for light to medium traffic pavements such as sidewalks, parking areas, and local roads. Their popularity is mainly due to ease of installation and maintenance, aesthetic flexibility, and the ability to be lifted and re-used when underground utilities require repair. In addition, paving blocks are considered more environmentally friendly than rigid concrete slabs because the joints between units allow surface water to infiltrate into the soil, thus supporting groundwater recharge and reducing surface runoff (Yulianto et al., 2018).

In Indonesia, the performance requirements for paving blocks are regulated by SNI 03-0691-1996, which classifies paving blocks into several strength classes based on compressive strength and recommends their use for

different types of loading. Class A paving blocks (≥ 30 MPa) are generally used for heavy traffic, while Class B (≥ 20 MPa) is suitable for light vehicle traffic and pedestrian areas. The compressive strength of paving blocks is thus a key quality indicator, and any mix design or production method must ensure compliance with this standard. Testing procedures usually follow SNI 03-1974-1990, which specifies the method for compressive strength testing of concrete specimens.

From the material science perspective, the compressive strength of concrete, including paving blocks, depends strongly on the water-cement ratio, cement content, aggregate properties, and degree of compaction. Neville and Brooks (2010) explain that cement acts as the binding phase which glues aggregate particles together through hydration products such as calcium silicate hydrate (C-S-H). Higher cement content, if accompanied by proper water-cement ratio and compaction, generally leads to denser microstructure, lower porosity, and increased compressive strength. However, excessive cement content may create problems such as higher shrinkage, thermal cracking, and uneconomical production costs.

Several studies have investigated the use of different aggregates and waste materials in paving block production. Fitria (2019) reported that stone dust waste can be utilized as an additional building material, contributing to both environmental benefits and mechanical performance when used in appropriate proportions. Harun (2006) studied the influence of crushed stone as a coarse aggregate on the compressive strength of paving blocks and found that properly graded crushed aggregates can significantly enhance strength compared with natural river sand alone. These studies highlight that aggregate type, gradation, and surface texture are important parameters in designing paving block mixtures.

The manufacturing process also plays a crucial role in determining paving block quality. Jember (2021) emphasized the importance of impact or tamping tools in the compaction stage and their consistency in producing uniform density and strength. Klinge (2019) further studied pressing pressure and vibration frequency in paving block production and showed that adequate pressing force and vibration time are necessary to minimize voids and improve compressive strength. Modern paving block factories generally use vibration-press machines that combine static pressure and high-frequency vibration to produce dense and uniform units.

In addition to mechanical performance, several authors have highlighted the importance of cost efficiency and quality control in paving block production. Rachmi and Gufran (2017) discussed the use of conversion factors in compressive strength testing and their implications for quality assurance of paving products in Indonesia. Economic analysis of mix variations is particularly important for small and medium enterprises that operate in highly competitive markets with tight margins. Mix designs with very high cement content may produce strong paving blocks but can become financially unattractive when compared with prevailing market prices. Conversely, mixes with low cement content may reduce costs but risk failing to meet SNI strength requirements and compromising durability.

Overall, previous studies show that optimizing paving block mixes requires a balance between mechanical performance, production cost, and compliance with national standards. Research that systematically evaluates variations in cement-aggregate ratios under controlled manufacturing and curing conditions can provide important guidance for industry practitioners. Such studies contribute to the development of more efficient, economical, and sustainable paving block production, particularly in regions where infrastructure development continues to grow and the demand for affordable paving materials is increasing.

METHODOLOGY

This research is a laboratory experimental study conducted at PT. Putri Paving Blok, Maros. Both specimen fabrication and compressive strength testing were carried out there.

Materials and Equipment

- Portland cement (PC)
- Fine aggregate (sand)
- Coarse aggregate (gravel or stone dust)
- Water
- Paving block molds (21 cm × 10.5 cm × 8 cm)
- Digital balance (accuracy 0.1 g)
- Mixing containers for the paving block mixture
- Compression testing machine

Mix Variations

Five mix variations of cement and aggregate were used, with three specimens for each variation:

Sample Code	Cement: Aggregate	Number of Specimens
C1	1 : 1	3
C2	1 : 2	3
C3	1 : 3	3
C4	1 : 4	3
C5	1 : 5	3

Research Procedure

1. Prepare all materials and equipment.
2. Weigh materials according to the specified mix proportions.
3. Mix the materials until a homogeneous mixture is obtained.
4. Place and compact the mixture into the paving block molds.
5. Demold the specimens and perform curing for 28 days.
6. Conduct compressive strength testing using a hydraulic compression machine at the age of 28 days, following SNI 03-0691-1996.
7. Analyze the data and draw conclusions.

Specimen Production Procedure

Specimen production was carried out at PT. Putri Paving Blok, Maros Regency. The factory is equipped with a pressing machine for paving production, ensuring uniform products and even distribution of compaction pressure. The manufacturing process follows structured stages to ensure that the resulting paving blocks meet the required compressive strength standards.

The main stages are as follows:

1. Preparation of Raw Materials

The primary materials are fine aggregate (sand), coarse aggregate (gravel or stone dust), cement as binder, and water. For research purposes, the aggregate and binder mixture was varied according to the predefined mix design. All materials were checked beforehand to ensure cleanliness and compliance with technical specifications, especially moisture content and aggregate size.

2. Weighing and Mixing

All materials were weighed according to the mix design using a digital balance to ensure precise proportions. The materials were then placed into a mixing container or wheelbarrow. Mixing was performed for approximately 3–5 minutes until a homogeneous and workable mix was achieved. The water content was strictly controlled to obtain optimal workability and the desired compressive strength. (Figure 1 shows the mixing process for the paving block mixture.)

3. Paving Block Molding

After a homogeneous mix was obtained, the mixture was placed into a hydraulic or vibration-press machine. This machine automatically compacts the mixture into paving block molds with sufficient pressure and vibration to achieve maximum density. The process is relatively quick and produces paving blocks with uniform shape, dimensions, and thickness. In this study, the paving block size produced was 21 cm × 10.5 cm × 8 cm. (Figure 2 shows the molding process.)

4. Initial Drying and Curing

Freshly molded paving blocks were removed from the machine and neatly arranged in a curing area. During the first 24 hours, the paving blocks were kept in a moist condition to prevent rapid evaporation of water. Subsequently, curing was performed either by immersion in water or by regular sprinkling for 14–28 days, depending on the curing method used. This curing process is crucial to ensure that the cement hydration reaction proceeds properly, allowing the concrete to achieve its optimal compressive strength. (Figure 3 shows the paving block specimens ready for curing.)

After curing was completed, compressive strength testing was carried out using a concrete compression testing machine in accordance with SNI 03-0691-1996. The test results served as the main data for analyzing the effect of mix variations on paving block quality. Specimens that met the strength requirements were stored for possible further research or for demonstration and distribution.

RESEARCH RESULTS AND DISCUSSION

After 28 days of curing by immersion or regular sprinkling, the specimens were ready for testing. Each specimen was weighed and then tested for compressive strength. The results show a clear relationship between cement content and compressive strength.

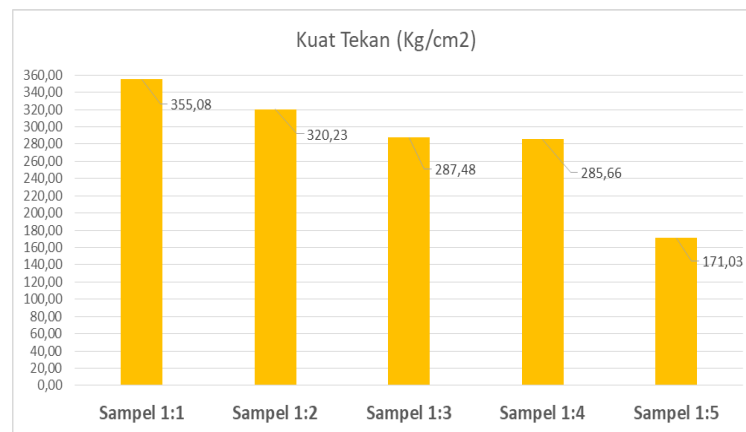


Figure 1. Compressive Strength Test Graph

In general, the data indicate that the higher the cement content in the mixture, the stronger and denser the bond between particles. This leads to more compact paving blocks, reduced porosity, and higher ability to withstand compressive loads. In other words, increasing cement content directly improves the structural quality of paving blocks.

Increasing the cement content also reduces the amount of air voids within the paving block. Fewer voids make the block more homogeneous and robust, so it is less prone to cracking under traffic loading. Laboratory tests confirmed that mixtures with higher cement ratios showed higher compressive strength than those with lower cement content. For example, a 1:3 cement-to-aggregate mix produced stronger paving blocks than a 1:5 mix.

However, based on SNI 03-0691-1996, conventional paving blocks commonly used in Indonesia for sidewalks, parking areas, and residential roads must have a minimum compressive strength of 17 MPa (equivalent to about 173.352 kg/cm²). Under this requirement, the 1:5 mix variation did not meet the standard quality threshold.

On the other hand, excessively high cement content is not always beneficial. If too much cement is used, production costs become uneconomical, and the paving blocks may experience problems such as excessive shrinkage or microcracking due to heat of hydration. Therefore, an appropriate balance between cement and aggregate is needed so that paving blocks meet SNI standards while remaining cost-efficient. With an optimal cement content, paving blocks are not only strong in compression but also durable and suitable for various field conditions.

Production Cost Analysis

Table 1 presents the production cost per 1 m² for each mix variation:

Table 1. Paving Block Production Cost per 1 m²

Mix Ratio	Cement Volume (m ³)	Sand Volume (m ³)	Cement (bags, 50 kg)	Material Cost (Rp)	Labor Cost (Rp)	Total Cost (Rp/m ²)
1 : 1	0.0375	0.0375	1.08	79,640.00	20,000.00	99,640.00
1 : 2	0.0250	0.0500	0.78	63,200.00	20,000.00	83,200.00
1 : 3	0.01875	0.05625	0.54	49,162.00	20,000.00	69,162.00
1 : 4	0.0150	0.0600	0.43	43,080.00	20,000.00	63,080.00

The market selling price of conventional paving blocks ranges from approximately Rp 80,000 to Rp 85,000 per m². Therefore, the 1:1 and 1:2 mix variations are considered not feasible because their production costs are higher than the typical market selling price.

In contrast, the 1:3 and 1:4 mixtures are more economical, with production costs well below market price, while still meeting SNI compressive strength requirements. Thus, these two mix ratios are considered the most optimal for paving block production.

CONCLUSIONS AND RECOMMENDATIONS

Laboratory test results show that mixtures with higher cement content tend to have higher compressive strength than mixtures with lower cement content. However, the 1:5 cement-to-aggregate mix variation fails to meet the SNI compressive strength standard for conventional paving blocks.

Excessive cement use is also not recommended, as it increases production costs and may lead to technical problems such as shrinkage and microcracking. Based on both mechanical performance and cost analysis, the 1:3 and 1:4 mix variations are the most optimal. They meet the SNI compressive strength requirements and have production costs lower than typical market prices, making them suitable for practical paving block production.

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