




Comparative Analysis of the Use of Coarse Aggregate from Merak and Coarse Aggregate from Batu Gadur on the Compressive Strength of Normal Quality Concrete

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Abstract

Concrete is a widely used construction material whose mechanical performance is strongly influenced by the properties of its constituent materials, particularly coarse aggregates. This study investigates the comparative effect of coarse aggregates sourced from Merak and Batu Gadur on the compressive strength of normal strength concrete. An experimental laboratory-based method was employed using concrete cube specimens measuring 150 mm × 150 mm × 150 mm. Three mixture variations were prepared: concrete with 100% Merak coarse aggregate, concrete with 50% Merak and 50% Batu Gadur coarse aggregate, and concrete with 100% Batu Gadur coarse aggregate. All specimens were cured and tested for compressive strength at 7 and 28 days. The results indicate that concrete containing 100% Merak aggregate exhibited stable and continuous strength development, while the 50% substitution mixture maintained relatively consistent compressive strength across curing ages. In contrast, concrete produced with 100% Batu Gadur aggregate achieved high early-age strength but showed a significant reduction at 28 days. These findings demonstrate that Batu Gadur aggregate can be utilized as a partial replacement for Merak aggregate at proportions not exceeding 50% without compromising concrete performance. This study supports the use of local aggregates to enhance sustainability in construction practices.

Keywords: Normal Strength Concrete, Coarse Aggregate, Compressive Strength

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INTRODUCTION

Concrete is the most widely used construction material in civil engineering due to its high compressive strength, durability, material availability, and adaptability to various structural applications. As a composite material composed of cement, water, fine aggregate, and coarse aggregate, the performance of concrete is strongly governed by the quality and interaction of its constituent materials. Although recent developments in concrete technology have introduced high-performance concrete and advanced cementitious additives (Han & Zhou, 2023; Patre et al., 2023; Prakash & Birali, 2024), normal strength concrete (NSC) remains the dominant material in practical construction owing to its cost efficiency and sufficient structural performance for most infrastructures.

Among concrete constituents, coarse aggregate plays a critical role, occupying approximately 60–80% of the total concrete volume and significantly influencing stress distribution, crack propagation, and long-term durability (Mohammed et al., 2021). Previous studies have demonstrated that aggregate properties such as shape, surface texture, water absorption, density, and abrasion resistance have a direct impact on compressive strength development (Hilal, 2021; Huang et al., 2020; Liu & Wei, 2021; Omoding et al., 2021; Subedi et al., 2025; Talib et al., 2021). Aggregates with low water absorption and high abrasion resistance

generally contribute to more stable strength gain and improved durability, particularly in NSC where the cement content is relatively limited.

Recent empirical studies have extensively examined the use of alternative, recycled, and industrial by-product aggregates in concrete. Makul et al (2021), Meddah et al (2020), Nduka et al (2020), Obaidat et al (2023), Shoaib et al (2023), Yoon et al (2026), and Younes et al (2025) reported that recycled concrete aggregates can be used in NSC with acceptable performance at moderate replacement levels. Similarly, Collivignarelli et al (2020) and Li et al (2022) found that partial substitution of natural aggregates with alternative materials can maintain mechanical properties when replacement ratios are controlled. Bai et al (2024) and Chen (2024) further emphasized that aggregates with higher porosity often exhibit high early-age strength but tend to experience strength degradation at later curing ages due to microstructural instability.

However, most previous studies focus on recycled aggregates, industrial waste materials, or laboratory-engineered aggregates, while comparative studies involving locally sourced natural aggregates with distinct physical characteristics remain limited, particularly in the context of normal strength concrete used in regional construction. Moreover, many studies emphasize either early-age or ultimate strength performance without thoroughly analyzing strength stability between 7 and 28 days, which is crucial for practical structural applications.

In Indonesia, especially in regions outside Java Island, construction practices still rely heavily on aggregates transported from distant sources, such as Merak stone, resulting in increased material costs and environmental burdens. In Kabupaten Seruyan, Central Kalimantan, Batu Gadur stone is abundantly available and commonly used in road base layers and masonry works. Despite its local availability, systematic experimental evaluation of Batu Gadur as a coarse aggregate in normal strength concrete is scarce, particularly regarding its comparative performance against Merak aggregate and its feasible substitution limits.

This research is therefore important because it addresses a practical and regional construction problem: the high dependency on imported aggregates and the underutilization of local natural resources. By scientifically evaluating Batu Gadur aggregate, this study seeks to support sustainable construction practices, reduce transportation-related environmental impacts, and provide engineers with evidence-based guidance for material selection in regions with similar geological conditions.

The objective of this study is to conduct a comparative experimental analysis of the compressive strength behavior of normal strength concrete using coarse aggregates from Merak and Batu Gadur. Specifically, this research evaluates concrete mixtures with 0%, 50%, and 100% Batu Gadur substitution at curing ages of 7 and 28 days to assess strength development, stability, and performance limitations.

The novelty and contribution of this study lie in its focused comparison of two natural coarse aggregates commonly used in regional Indonesian construction, rather than recycled or industrial aggregates. Unlike previous studies, this research highlights the contrasting early-age and later-age strength behavior of Batu Gadur aggregate and identifies a quantitative substitution threshold ($\leq 50\%$) that maintains compressive strength stability in NSC. The findings provide new empirical evidence for optimizing the use of local aggregates while ensuring structural reliability, thereby contributing to both sustainable material utilization and practical concrete engineering knowledge.

METHOD

This study employed an experimental laboratory-based research method to evaluate the effect of coarse aggregate type on the compressive strength of normal strength concrete. The experiments were conducted at the Concrete Construction Laboratory, Faculty of Engineering, University of Palangkaraya. The materials used consisted of Ordinary Portland Cement, river sand sourced from Sei Sembuluh as fine aggregate, and two types of coarse aggregates, namely Merak stone and Batu Gadur stone. Batu Gadur aggregate was obtained from Batu Gadur Village, Seruyan Raya District, Central Kalimantan, while Merak aggregate served as the reference material commonly used in regional construction. Prior to concrete mixing, all aggregates were subjected to standard laboratory tests, including sieve analysis, specific gravity, water absorption, moisture content, bulk density, and Los Angeles abrasion tests, in accordance with Indonesian National Standards (SNI), to determine their physical and mechanical characteristics.

Concrete specimens were prepared in the form of cubes measuring 150 mm × 150 mm × 150 mm. The mix design for normal strength concrete was determined using the SNI 03-2834-2000 method. Three mixture variations were produced: (1) 100% Merak coarse aggregate, (2) 50% Merak and 50% Batu Gadur coarse aggregate, and (3) 100% Batu Gadur coarse aggregate. Each mixture variation consisted of three specimens for each testing age. After casting, specimens were demolded after 24 hours and cured by water immersion until the testing ages of 7 and 28 days. Compressive strength testing was conducted using a compression testing machine to determine the maximum load at failure. The compressive strength values were calculated and averaged for each mixture variation and curing age. The results were then analyzed comparatively to evaluate the influence of Batu Gadur aggregate substitution on the compressive strength of normal strength concrete

RESULT AND DISCUSSION

Physical Characteristics of Fine Aggregate

Fine aggregate plays an important role in determining the workability and homogeneity of concrete mixtures. In this study, river sand obtained from Sei Sembuluh was used as the fine aggregate for all concrete mixtures to ensure consistency across specimens. Prior to mixing, laboratory testing was conducted to evaluate its physical properties and compliance with standard requirements for normal strength concrete. The assessment included sieve analysis, specific gravity, and water absorption tests. These parameters are critical in ensuring that variations in concrete performance can be attributed primarily to changes in coarse aggregate composition.

The grading analysis of the fine aggregate indicated that the sand fell within Zone 3 according to standard classifications. This grading is commonly used in normal strength concrete and provides adequate workability when combined with proper water content. The particle size distribution showed a balanced proportion of fine and medium particles, reducing the risk of segregation. These characteristics supported the suitability of Sei Sembuluh sand as a consistent fine aggregate throughout the experimental program.



Figure 1. Physical appearance of Sei Sembuluh river sand used as fine aggregate

The visual observation presented in Figure 1 shows that the sand particles are generally rounded with minimal impurities. Rounded particles are known to improve workability and reduce internal friction during mixing. The absence of visible organic material further indicates acceptable aggregate cleanliness. This visual assessment complements the laboratory test results and supports the selection of this sand as a suitable fine aggregate.

Before presenting the numerical results, it is important to emphasize that the physical properties of fine aggregate directly influence water demand and cement paste bonding. Aggregates with high absorption or irregular grading can lead to inconsistencies in concrete strength. Therefore, the laboratory test results provide essential baseline data for interpreting the compressive strength results discussed later.

Table 1. Physical Properties of Fine Aggregate (Sei Sembuluh Sand)

Test Parameter	Result
Oven-dry specific gravity (bulk)	2.51
Saturated surface dry specific gravity (SSD)	2.55
Apparent specific gravity	2.62

Water absorption 1.63%

The data in Table 1 demonstrate that the fine aggregate met standard requirements for concrete production. The water absorption value of 1.63% indicates moderate absorption, which is acceptable for normal strength concrete. The specific gravity values suggest sufficient particle density to support compressive strength development. These results confirm that the fine aggregate did not introduce adverse effects into the concrete mixtures and allowed the study to focus on the influence of coarse aggregate variation.

Physical and Mechanical Properties of Merak Coarse Aggregate

Merak coarse aggregate was used as the control material in this study because it is widely applied in construction projects in Kalimantan. The physical and mechanical properties of this aggregate were evaluated to establish a benchmark for comparison with Batu Gadur aggregate. Laboratory testing included specific gravity, water absorption, and abrasion resistance using the Los Angeles abrasion test. These tests are essential in assessing aggregate durability and strength under mechanical loading.

The results showed that Merak aggregate exhibited high-quality characteristics. Its low abrasion value indicated strong resistance to wear and fragmentation, which is beneficial for maintaining concrete integrity under load. Additionally, the water absorption value was relatively low, suggesting limited porosity and reduced risk of excessive water demand. These properties are typically associated with aggregates that contribute positively to concrete compressive strength.



Figure 2. Merak coarse aggregate material

Figure 2 illustrates the physical appearance of Merak aggregate, which is characterized by angular particles with a rough surface texture. Angular aggregates generally improve interlocking within the concrete matrix, enhancing mechanical strength. The surface roughness also promotes better bonding between the aggregate and cement paste. These visual characteristics align with the favorable laboratory test results.

Before presenting the numerical test data, it should be noted that aggregate durability directly affects long-term concrete performance. Aggregates with high abrasion resistance are less likely to degrade under repeated loading. Therefore, the measured properties of Merak aggregate provide a strong reference point for evaluating the suitability of Batu Gadur aggregate.

Table 2. Physical Properties of Merak Coarse Aggregate

Test Parameter	Result
Oven-dry specific gravity (bulk)	2.54
Saturated surface dry specific gravity (SSD)	2.56
Apparent specific gravity	2.59
Water absorption	0.855%
Los Angeles abrasion	9.21%

Table 2 confirms that Merak coarse aggregate satisfies the requirements for high-quality concrete aggregate. The abrasion value of 9.21% is significantly lower than the maximum allowable limit, indicating excellent durability. Low water absorption further supports stable concrete mix proportions. These results justify the use of Merak aggregate as the control mixture in this comparative study.

Physical and Mechanical Properties of Batu Gadur Coarse Aggregate

Batu Gadur coarse aggregate was investigated as a potential local alternative to Merak aggregate. Due to its widespread availability in Batu Gadur Village, this material presents an opportunity to reduce dependency on imported aggregates. However, its physical and mechanical properties differ significantly from those of Merak aggregate. Laboratory tests were conducted to evaluate its suitability for use in normal strength concrete.

The results indicated that Batu Gadur aggregate had lower specific gravity and significantly higher water absorption. These characteristics suggest a more porous internal structure, which can affect water demand and strength development. Additionally, the abrasion resistance of Batu Gadur aggregate was lower than that of Merak aggregate, indicating reduced durability under mechanical stress. Despite these limitations, the aggregate still met minimum standards for Class II concrete applications.



Figure 3. Batu Gadur coarse aggregate material

Figure 3 shows that Batu Gadur aggregate has a more irregular shape and lighter color compared to Merak aggregate. The irregular particle geometry can increase internal friction during mixing, potentially reducing workability. Moreover, the visual texture suggests higher porosity, which aligns with the high water absorption values obtained from laboratory testing. These visual observations help explain the behavior of concrete mixtures containing Batu Gadur aggregate.

Before presenting the numerical results, it is important to recognize that aggregates with high absorption require careful mix design adjustments. Failure to account for absorption can lead to reduced effective water-cement ratios and inconsistent strength development. Therefore, the test results presented below are critical for interpreting the compressive strength outcomes.

Table 3. Physical Properties of Batu Gadur Coarse Aggregate

Test Parameter	Result
Specific gravity	1.91
Water absorption	10.61%
Los Angeles abrasion	38.65%
Bulk density	1.56 kg/L

Table 3 indicates that Batu Gadur aggregate exhibits significantly higher water absorption compared to Merak aggregate. The abrasion value of 38.65% places it within the acceptable range for Class II concrete but indicates lower mechanical resistance. Nevertheless, the bulk density exceeded the minimum standard requirement of 1.2 kg/L, confirming that Batu Gadur aggregate can be used in concrete with appropriate mix design considerations.

Concrete Mix Design and Specimen Preparation

Concrete mix design is a critical factor in ensuring consistent and comparable results in experimental studies. In this research, the mix proportions were designed according to SNI 03-2834-2000 for normal strength concrete. Three mix variations were prepared to evaluate the influence of Batu Gadur aggregate substitution. Each mixture maintained consistent cement and fine aggregate content while varying the proportion of coarse aggregate.

The first mixture, designated BN0%, consisted entirely of Merak coarse aggregate and served as the control specimen. The second mixture, BNBG 50%, used an equal proportion of Merak and Batu Gadur aggregates. The third mixture, BNBG 100%, consisted solely of Batu Gadur aggregate. Water content was adjusted to compensate for differences in aggregate absorption and maintain workable mixes.

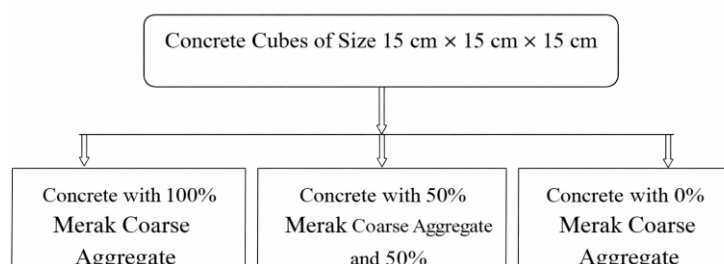


Figure 4. Concrete mix composition variations and specimen preparation

Figure 4 illustrates the mixing process and specimen preparation for each variation. The figure highlights the uniform cube dimensions of 150 mm × 150 mm × 150 mm. Consistent specimen size is essential for accurate compressive strength comparison. The visual documentation supports the reproducibility of the experimental procedure.

Before presenting the mix proportion data, it is important to emphasize that increasing Batu Gadur content required higher water usage. This adjustment was necessary to counteract the aggregate’s high absorption capacity. Such variations in water content were expected to influence the mechanical performance of the concrete.

Table 4. Concrete Mix Proportions per Specimen

Mix Type	Merak Aggregate (kg)	Batu Gadur Aggregate (kg)	Fine Aggregate (kg)	Cement (kg)	Water (L)
BN0% (100% Merak)	19.47	-	6.71	4.71	0.44
BNBG 50%	6.60	6.60	6.14	4.17	0.74
BNBG 100%	-	11.75	5.83	4.17	1.61

Table 4 shows a clear increase in water demand with higher Batu Gadur content. This trend reflects the high absorption characteristics of Batu Gadur aggregate. The changes in mix proportions provide important context for understanding the compressive strength results discussed in the following section.

Compressive Strength Test Results

Compressive strength testing was conducted to evaluate the mechanical performance of each concrete mixture. Tests were performed at curing ages of 7 and 28 days to observe strength development over time. The results revealed significant differences in behavior between mixtures with varying proportions of Batu Gadur aggregate. These differences highlight the influence of aggregate characteristics on concrete performance.

At 7 days, the BNBG 100% mixture exhibited the highest compressive strength. This result suggests that Batu Gadur aggregate may contribute to early-age strength due to its rough surface texture and high absorption, which can enhance initial bonding. However, this trend did not continue at later ages. In contrast, the BN0% mixture showed steady strength development between 7 and 28 days.

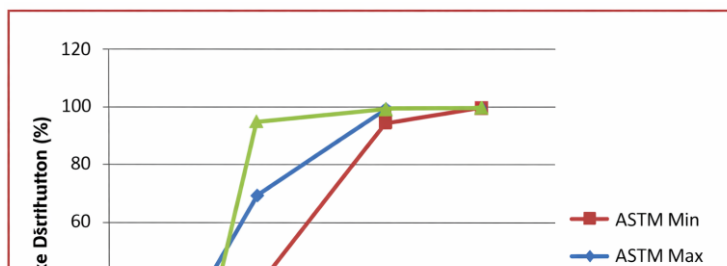


Figure 5. Compressive strength testing process using compression testing machine

Figure 5 shows the compressive strength testing setup used in the laboratory. The standardized testing procedure ensured uniform load application across all specimens. Visual documentation of the testing process enhances transparency and reproducibility. The observed failure patterns were consistent with typical concrete crushing behavior.

Before presenting the numerical results, it is important to note that early-age strength does not always correlate with long-term performance. Factors such as aggregate durability and microstructural stability play a larger role at later ages. Therefore, both testing ages must be considered together to evaluate overall concrete performance.

Table 5. Average Compressive Strength Results

Mixture Type	Compressive Strength at 7 Days (kg/cm ²)	Compressive Strength at 28 Days (kg/cm ²)
BN0% (100% Merak)	397.5	550.0
BNBG 50%	470.0	470.0
BNBG 100%	680.0	330.0

Table 5 indicates that the BNBG 50% mixture achieved stable compressive strength across both curing ages. The BNBG 100% mixture showed a significant reduction in strength at 28 days, suggesting long-term performance limitations. The BN0% mixture demonstrated the most reliable strength growth, reinforcing the superior durability of Merak aggregate.

DISCUSSION

The results of this study demonstrate that the type and proportion of coarse aggregate exert a significant influence on the compressive strength behavior of normal strength concrete, both at early and later curing ages. Concrete produced with 100% Merak coarse aggregate exhibited stable and continuous strength development from 7 to 28 days, indicating favorable aggregate–paste bonding and durable internal structure. In contrast, concrete incorporating 100% Batu Gadur aggregate achieved very high early-age compressive strength but experienced a pronounced reduction at 28 days. Meanwhile, the mixture containing 50% Merak and 50% Batu Gadur aggregate showed relatively constant compressive strength across both curing ages, suggesting a balanced performance between strength development and aggregate substitution. These findings confirm that strength stability, rather than early-age strength alone, is a critical indicator of concrete performance in practical applications.

The observed behavior highlights the dominant role of aggregate physical characteristics, particularly water absorption and abrasion resistance, in governing compressive strength development in normal strength concrete. Aggregates with low water absorption and high abrasion resistance, such as Merak stone, facilitate stable hydration and efficient stress transfer within the concrete matrix, resulting in consistent strength gain. Conversely, the high porosity and elevated water absorption of Batu Gadur aggregate likely altered the effective water–cement ratio and weakened the interfacial transition zone over time, contributing to the observed reduction in later-age strength. Similar relationships between aggregate quality and compressive strength have been reported by Akhtar et al. (2025), Chaturvedy et al (2025), Deep & Sarkar (2025), Liu et al (2025), Nasare et al (2025), Peiris et al (2025), Silva et al. (2025), Su et al. (2023), and Zhong et al (2025)

who emphasized that aggregates with irregular shape and high absorption tend to reduce long-term concrete performance.

When compared with previous studies, the results of this research both corroborate and extend existing findings. Several studies have shown that partial replacement of natural aggregates with alternative materials can maintain acceptable mechanical performance when substitution levels are moderate (Abdelhady et al., 2025; Ahmed et al., 2025; Bahmani et al., 2025; Bahmani & Mostafaei, 2025; Lu, 2024; Sau et al., 2024; Silva et al., 2021). The stable strength behavior observed in the 50% Batu Gadur mixture is consistent with these studies, suggesting that the presence of higher-quality aggregates can compensate for weaker aggregate characteristics. However, unlike many recycled aggregate studies that report gradual strength reductions with increasing replacement ratios (Amario et al., 2023; Bidari et al., 2024; Gebremariam et al., 2023; S. Liu et al., 2023; Sahani et al., 2025; Sedghi et al., 2023; Soomro et al., 2023; Yu et al., 2026), this study identified a distinct pattern in which Batu Gadur aggregate produced exceptionally high early-age strength followed by a sharp decline at 28 days. This discrepancy may be attributed to differences in material origin and properties, particularly the extremely high water absorption (10.61%) and lower abrasion resistance of Batu Gadur aggregate, as well as contextual factors related to local geological conditions.

The findings of this study offer a novel contribution to the literature by providing empirical evidence on the performance of a locally sourced natural aggregate rather than recycled or industrial by-product materials, which dominate prior research. Unlike previous studies that focus primarily on engineered or recycled aggregates, this research establishes a quantitative substitution threshold for Batu Gadur aggregate, demonstrating that replacement levels not exceeding 50% can maintain compressive strength stability in normal strength concrete. This contribution is particularly relevant because normal strength concrete is more sensitive to aggregate quality than high-strength concrete due to its lower cement content and simpler mix design, as noted by Arifuzzaman et al (2024), Haider et al (2025), Khan et al (2025), Prasittisopin et al (2025), Shaaban et al (2025), Sohail et al (2020), and Tang et al (2022). The identification of contrasting early-age and later-age strength behavior further enriches understanding of aggregate-specific performance mechanisms.

From a practical perspective, the results provide direct guidance for engineers and practitioners regarding the feasible use of Batu Gadur aggregate in concrete production. The ability to partially substitute Merak aggregate with Batu Gadur offers opportunities to reduce material transportation costs and promote the utilization of local natural resources. Academically, this study contributes to aggregate substitution research by emphasizing the importance of evaluating strength development over time rather than relying solely on early-age performance. From a policy standpoint, the findings support regional construction strategies aimed at enhancing sustainability through local material utilization while maintaining structural reliability.

Despite these contributions, the study has several limitations that should be acknowledged. The experimental investigation focused exclusively on compressive strength and did not consider other mechanical properties such as tensile or flexural strength, nor durability-related aspects such as permeability, shrinkage, or sulfate resistance. In addition, the evaluation was limited to curing ages of 7 and 28 days, which may not fully represent long-term performance. The absence of microstructural analysis, particularly of the interfacial transition zone, also limits the ability to explain the observed strength degradation mechanisms in greater detail.

Future research is therefore recommended to extend the evaluation of Batu Gadur aggregate by incorporating microstructural investigations, such as scanning electron microscopy, to better understand aggregate–paste interactions. Long-term performance studies beyond 28 days, as well as assessments of durability and service life, would further enhance the applicability of the findings. Additionally, field-scale studies and comparative investigations involving other local aggregates from different regions are encouraged to establish a broader framework for sustainable aggregate utilization in normal strength concrete.

CONCLUSION

This study demonstrates that the type and proportion of coarse aggregate significantly influence the compressive strength behavior of normal strength concrete. Concrete produced with 100% Merak coarse aggregate exhibited stable and continuous strength development from early to later curing ages, indicating superior durability and long-term performance. The mixture

containing 50% Merak and 50% Batu Gadur coarse aggregate showed relatively constant compressive strength at both 7 and 28 days, suggesting that partial substitution of Merak aggregate with Batu Gadur is feasible without compromising structural performance. In contrast, concrete made with 100% Batu Gadur coarse aggregate achieved high early-age compressive strength but experienced a substantial reduction at 28 days, reflecting limitations in long-term strength development. The observed strength behavior is closely related to the physical characteristics of the aggregates, particularly water absorption and abrasion resistance. The high porosity and water absorption of Batu Gadur aggregate increased water demand and reduced durability, which adversely affected later-age compressive strength. Based on these findings, Batu Gadur coarse aggregate can be recommended as a partial replacement for Merak aggregate at proportions not exceeding 50% for normal strength concrete applications. This study supports the utilization of local aggregates to reduce dependency on imported materials while emphasizing the importance of proportion control to ensure structural reliability and sustainable construction practices.

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