



## Review of Mechanical Characteristics and Flexural Strength of Reinforced Concrete Beams Made from Bundubela Material, East Sumba

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### Abstract

The utilization of local aggregates is pivotal for promoting sustainable and cost-effective construction, yet their mechanical viability requires rigorous assessment. This study aims to evaluate the mechanical characteristics and flexural strength of concrete beams formulated with aggregates from Bundubela, East Sumba, to determine their suitability under Indonesian National Standards (SNI). The research employed a laboratory-based experimental method following SNI procedures. Two concrete mixtures were tested: a standard mix designed for a compressive strength ( $f_c'$ ) of 21.7 MPa and a second mix enhanced with additives, targeting an  $f_c'$  of 45 MPa. Results indicated that both mixtures failed to achieve their designed strengths. The standard mix only reached an average compressive strength of 18.15 MPa, while the additive-enhanced mix achieved 28.79 MPa. Furthermore, in flexural strength tests on concrete beams, both configurations exhibited excessive deflection, surpassing the maximum limits allowed by SNI. The beam without additives deflected 4.635 mm under a 1500 Kg maximum load, and the additive-enhanced beam deflected 6.145 mm under a 2100 Kg maximum load. These findings conclude that despite enhancement with additives, the Bundubela aggregate is unsuitable for structural concrete applications that must comply with current SNI requirements. This highlights a critical challenge in reconciling the use of local materials with stringent national construction codes, pointing to the need for material modification or specific-standard development.

**Keywords:** concrete, Bundubela material, mechanical characteristics

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## INTRODUCTION

The global construction industry is increasingly shifting towards sustainable practices, with a strength emphasis on the utilization of locally sourced materials to reduce transportation costs and associated carbon emissions [1], [2]. This approach is particularly vital for infrastructure development in geographically diverse nations like Indonesia, where reliance on standardized, imported materials can be economically prohibitive [3]. While the use of local aggregates is economically and environmentally beneficial, their inherent variability presents a significant technical challenge. The geological origin,

mineralogy, and physical properties of aggregates can dramatically impact the strength, durability, and overall performance of the resulting concrete [4], [5]. A critical factor governing concrete's mechanical performance is the Interfacial Transition Zone (ITZ)—the microscopic bond between the aggregate surface and the cement paste. A weak ITZ, often resulting from impurities or suboptimal aggregate characteristics, can compromise the concrete's strength, even if the aggregate itself passes basic quality tests [6], [7]. The literature confirms this, presenting mixed results on the efficacy of various local and recycled aggregates. While many studies report successful applications [8], others highlight significant performance shortfalls, underscoring that compliance with basic material standards does not guarantee structural viability [9].

This context reveals a critical knowledge gap concerning the material resources in East Sumba, Indonesia. Aggregates from the Bundubela region are conventionally used by the local community, but there is no published scientific data validating their suitability for structural concrete according to the Indonesian National Standard (SNI). This lack of empirical evidence forces a continued dependency on expensive, externally sourced materials for any significant construction.

This study aims to fill this research gap by conducting the first comprehensive investigation into the mechanical characteristics and flexural performance of concrete utilizing Bundubela aggregates. The primary objectives are to determine the concrete's compressive strength, modulus of elasticity, and flexural behavior, and to systematically compare these results against the required benchmarks outlined in the Indonesian structural code [10]. This research will provide crucial, evidence-based insights into the viability of this local resource for sustainable regional development.

## METHOD

This research was conducted using an experimental laboratory method. All aggregates, both fine (sand) and coarse (crushed stone), were sourced from a single location in the Bundubela region, East Sumba, Indonesia, to ensure material consistency (Figure 1). The binder used was a standard Portland Composite Cement (PCC). Two primary sets of concrete mixtures were designed and investigated as the main variables for this study. The first mixture (M1) was a standard concrete designed to achieve a target compressive strength ( $f_c'$ ) of 21.7 MPa without any chemical admixtures. The second mixture (M2) was a high-strength concrete designed for a target  $f_c'$  of 45 MPa, incorporating a polycarboxylate-based superplasticizer as an additive to enhance workability and strength [11]. The details of the experimental design are summarized in Table 1.



Figure 1 Material Collection Site (Sumba Island)

Table 1 Experimental Design and Specimen Details

Code	Target $f_c'$ (MPa)	Additive Used	Specimen Type & Size	Type of Test	Age of Test	Quantity
SKT	21.7	Without Additive	Cylinder, 150 mm diameter × 300 mm height	Compressive Strength & Modulus of Elasticity	7 days	3
SKTA	45.0	With Additive	Cylinder, 150 mm diameter × 300 mm height	Compressive Strength & Modulus of Elasticity	7 days	3
SLK	21.7	Without Additive	Cylinder, 150 mm diameter × 300 mm height	Splitting Tensile Strength	7 days	3
SLKA	45.0	With Additive	Cylinder, 150 mm diameter × 300 mm height	Splitting Tensile Strength	7 days	3
BL	21.7	Without Additive	Beam, 110 cm × 8 cm × 12 cm	Flexural Strength	28 days	2
BLA	45.0	With Additive	Beam, 110 cm × 8 cm × 12 cm	Flexural Strength	28 days	2
<b>Total Specimens</b>						<b>16</b>

A total of 16 specimens were prepared for the experimental program. For the assessment of compressive strength and modulus of elasticity, six cylindrical specimens (150 mm diameter x 300 mm height) were cast (three for M1 and three for M2). For splitting tensile strength tests, another six cylindrical specimens of the same size were prepared (three for each mixture). For flexural strength analysis, four reinforced concrete beams with dimensions of 1100 mm (length) x 80 mm (width) x 120 mm (height) were fabricated (two for each mixture). All specimens were demolded after 24 hours and subsequently cured in a water bath until the designated testing ages, a practice consistent with ASTM C192/C192M-19 [12], which specifies standard procedures for making and curing concrete specimens in the laboratory.

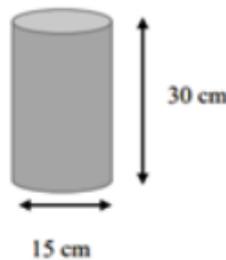


Figure 2 Concrete Cylinder Sample

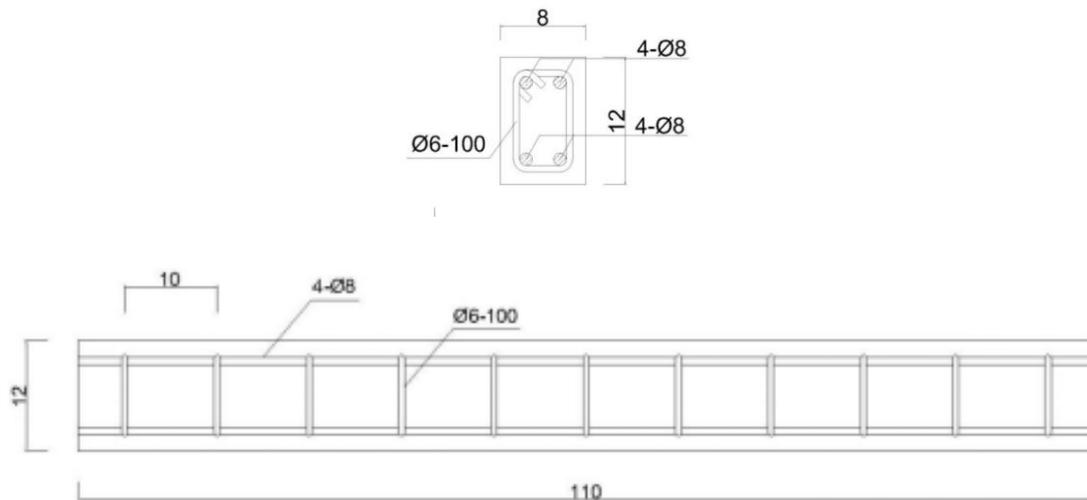


Figure 3 Concrete Beam Sample

Figure 3 shows a cross-section of a reinforced concrete beam detailing its reinforcement. It displays four main longitudinal reinforcing bars with a diameter of 8 mm (labeled "4-Ø8") placed along the length of the beam. Additionally, there are stirrups with a diameter of 6 mm spaced at 100 mm intervals (labeled "Ø6-100"), which serve to resist shear forces. The total dimensions of the beam are 110 length units (likely centimeters) and 12 length units in height, with a concrete cover indicated as 10 units from the edge.

All mechanical tests were performed following the relevant Indonesian National Standards (SNI), which align with internationally recognized testing protocols. The compressive strength of the cylindrical specimens was determined using a universal testing machine [13], a method comparable to ASTM C39/C39M [14]. The splitting tensile strength was evaluated [15] which corresponds to ASTM C496/C496M [16]. The flexural strength and deflection behaviour of the beam specimens were assessed under a three-point loading setup as stipulated [17], following the principles outlined in ASTM C78/C78M [18]. The resulting data from these tests were analyzed to determine the mechanical characteristics of both concrete mixtures and subsequently compared against the performance benchmarks required by the latest Indonesian structural concrete code [10].

## RESULT AND DISCUSSION

The experimental investigation revealed a significant contradiction: while the aggregates from Bundubela, East Sumba, met all fundamental quality requirements stipulated by the Indonesian National Standards (SNI), the resulting concrete consistently demonstrated poor mechanical performance, failing to achieve its targeted structural design strengths. Initial characterization of the fine (sand) and coarse (crushed stone) aggregates confirmed compliance with all standard criteria, including gradation (Fineness Modulus of 3.05 for sand and 7.05 for gravel), moisture content, specific gravity (both approx. 2.58), and abrasion resistance (20.76%). These results would typically indicate the aggregate's

suitability for use in concrete. However, the performance-based testing of the concrete mixtures told a starkly different story.

The primary finding of this study is the pronounced failure of the concrete to reach its target compressive strength, as summarized in Table 1 and visualized in Figure 1. The standard concrete mixture (M1), designed for a target  $f_c'$  of 21.7 MPa, only achieved an average 28-day compressive strength of 18.15 MPa. This represents a significant shortfall, reaching only 83.6% of its target and thus definitively failing the design requirements. The performance of the high-strength mixture (M2) was even more concerning. Despite the inclusion of a superplasticizer additive to target an  $f_c'$  of 45 MPa, it only attained an average strength of 28.79 MPa—a mere 64% of its design capacity. This consistent underperformance strength suggests that conforming to basic physical properties is insufficient to guarantee the suitability of an aggregate. A potential explanation lies in the material's finer characteristics. Although the mud content of the aggregate (0.67%) was within the acceptable SNI limit (<1%), it is considerably higher than that of high-quality volcanic aggregates from other Indonesian regions, which can exhibit mud contents as low as 0.0021% [19]. It is hypothesized that this higher content of fine, potentially clay-like particles, created a weak Interfacial Transition Zone (ITZ) between the aggregate surface and the cement paste, thereby hindering effective stress transfer and limiting the composite strength [5]

Table 2 Summary of Mechanical Properties of Concrete Mixtures

Mechanical Property	Mixture	Target Value	Achieved Value (Avg.)	Status
Compressive Strength ( $f_c'$ )	M1 (Standard)	21.7 MPa	18.15 MPa	Fails
	M2 (High-Strength)	45.0 MPa	28.79 MPa	Fails
Modulus of Elasticity ( $E_c$ )	M1 (Standard)	21,894 MPa*	16,907 MPa	Fails
	M2 (High-Strength)	29,171 MPa**	23,774 MPa	Fails
Splitting Tensile Strength	M1 (Standard)	1.74 - 2.72 MPa***	1.91 MPa	Passes
	M2 (High-Strength)	3.6 - 6.75 MPa***	2.94 MPa	Fails

\*Calculated based on SNI 2847:2019 formula ( $E_c = 4700\sqrt{f_c'}$ ). \*\*Calculated based on ACI 363R formula. \*\*\*Based on the general range of 8-15% of  $f_c'$ .

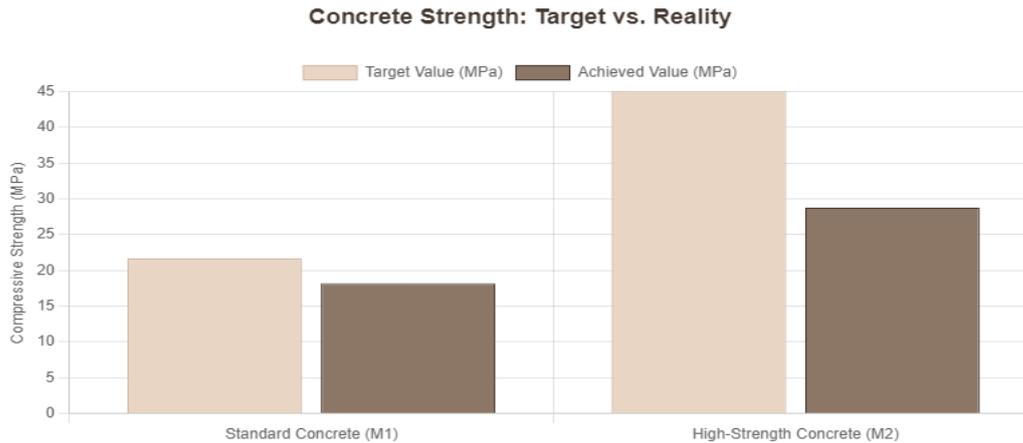


Figure 4 Comparison of Target vs. Achieved Compressive Strength (28-Day)

This chart clearly illustrates that the achieved compressive strength for both concrete mixtures (M1 & M2) was significantly lower than their design targets. Figure 4 presents a comparison between the planned compressive strength of concrete (target value) and the actual compressive strength achieved on-site (actual value) for two distinct concrete categories: Standard Concrete (M1) and High-Strength Concrete (M2). For Standard Concrete (M1), it is observed that the target compressive strength was approximately 21.5 MPa, but the achieved value was only around 18 MPa, indicating a negative deviation from the target. Meanwhile, with High-Strength Concrete (M2), the disparity between the target and reality is far more pronounced; the target value was approximately 44.5 MPa, whereas the achieved value was only about 29 MPa.

This hypothesis is further supported by the modulus of elasticity ( $E_c$ ) values, which were substantially lower than the theoretical predictions for both mixtures (Table 1). The M1 mixture yielded an  $E_c$  of only 16,907 MPa, far below the 21,894 MPa expected based on its target strength according to SNI 2847:2019. This indicates that the concrete is less stiff and more susceptible to deformation, suggesting a more brittle nature potentially linked to the intrinsic properties of the aggregate. The splitting tensile strength tests provided a nuanced insight: the M1 mixture, with an average strength of 1.91 MPa, successfully fell within the expected 8-15% range of its achieved compressive strength, thus passing this criterion. However, the M2 mixture, with a tensile strength of 2.94 MPa, failed to reach the minimum 8% threshold of its *target* compressive strength, suggesting that the tensile properties of the material do not scale up effectively for high-strength applications.

The flexural tests on the reinforced beam specimens definitively confirmed the material's poor structural performance. The load-deflection analysis (Figure 2) revealed that both beam types deviated significantly from their theoretical behavior, exhibiting excessive deflection at much lower loads than predicted. The maximum moments sustained by the M1 and M2 beams were only 416.03 kg.m and 581.33 kg.m, respectively, indicating low flexural capacity and poor ductility. This underperformance is a direct consequence of the low compressive strength and stiffness of the concrete matrix. The findings of this study are limited to the specific aggregate source from Bundubela and the particular mix designs employed. However, the results carry critical implications for local construction

practices, highlighting the danger of relying solely on basic aggregate quality tests. Future research should focus on methods to improve the performance of these local aggregates, such as advanced washing techniques to reduce fine particle content or the exploration of different pozzolanic admixtures to enhance the ITZ.



Figure 5 Load-Deflection Curve of Concrete Beams

Figure 5 presents data on the deflection behavior of concrete beams under load, comparing experimental results with theoretical predictions for two types of beams, M1 and M2. The horizontal axis of the graph indicates the applied load in Kilograms (Kg), while the vertical axis shows the resulting deflection in millimeters (mm). For Beam M1, the solid brown line represents the experimental data, illustrating that deflection increases progressively with increasing load, reaching approximately 4.6 mm at a 1500 Kg load. Conversely, the dashed brown line depicts the theoretical deflection values, which are consistently lower than the experimental results, for instance, only about 2.4 mm at a 1500 Kg load. A similar pattern is observed for Beam M2 (indicated by the green lines); the experimental data (solid green line) shows a significant increase in deflection up to over 6 mm at a 2000 Kg load, whereas its theoretical value (dashed green line) is considerably lower, around 2 mm at the same load. Overall, this graph clearly indicates that the deflections observed in experimental tests for both beam types consistently exceed the values predicted by theoretical calculations. Furthermore, at equivalent loads, Beam M2 tends to exhibit greater experimental deflection compared to Beam M1, especially at higher load levels, highlighting differences in the structural characteristics or stiffness between the two beam designs.

Figure 5 illustrates that the experimental deflection (solid lines) consistently exceeds the theoretical deflection (dashed lines) across the entire tested load range for both M1 and M2 beams. For instance, in Beam M1, the experimental deflection at a 1500 Kg load is approximately 4.6 mm, nearly double the theoretical value of 2.4 mm. This disparity is even more pronounced in Beam M2; at a 2000 Kg load, the experimental deflection surpasses 6 mm, whereas its theoretical prediction is only about 2 mm, indicating that the actual behavior of this beam is three times more flexible than theoretically anticipated. This consistent discrepancy suggests several potential issues, such as inaccurate material properties (e.g., a lower elastic modulus of concrete than

assumed), overly simplified theoretical models that do not account for factors like concrete cracking or creep, or differences between ideal and actual boundary conditions during experiments.

Furthermore, the comparison between the deflection behavior of Beam M1 and M2 is also highly significant. The description states that "at equivalent loads, Beam M2 tends to exhibit greater experimental deflection compared to Beam M1, especially at higher load levels." This is quite counter-intuitive, particularly if M2 is intended as a "High-Strength Concrete" beam, which should ideally be stiffer and show less deflection. There are several possible explanations for this phenomenon: first, if the actual concrete strength of M2 is significantly lower than its target strength (and perhaps not much different from M1's actual strength), then the expected superior stiffness would not materialize. Second, differences in reinforcement details, reinforcement ratios, or effective dimensions between M1 and M2, which are not explicitly depicted, could influence stiffness.

## CONCLUSION

This study investigated the viability of using local aggregates from Bundubela, East Sumba, for structural concrete applications. The primary conclusion is that despite passing all initial standardized material quality tests, the Bundubela aggregate is unsuitable for producing concrete that meets the minimum performance requirements for structural use as stipulated by the Indonesian National Standard (SNI 2847:2019). The key findings supporting this conclusion are the concrete's consistent failure to achieve its target compressive strength, its significantly low modulus of elasticity which indicates poor stiffness and a brittle nature, and its inadequate flexural performance characterized by excessive deflection under load. The underperformance is likely attributed to the creation of a weak Interfacial Transition Zone (ITZ) between the aggregate and cement paste, possibly caused by higher-than-optimal fine particle or mud content, even though this content was within basic SNI limits.

This research carries a critical implication for construction practices, particularly in regions relying on local, uncharacterized materials: basic material characterization is not a substitute for comprehensive, performance-based testing. The findings serve as a crucial cautionary tale that adherence to minimum material properties does not guarantee structural performance. For future research, it is recommended to move beyond simple material substitution and instead explore methods of improving the Bundubela aggregate, such as advanced washing techniques to reduce fine particle content or investigating the effects of various pozzolanic admixtures to specifically enhance the ITZ. Such studies could potentially unlock the value of this local resource, turning a currently unsuitable material into a viable asset for sustainable regional development.

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