

# Diminishing Environmental Impact in the Construction Industry: The Use of Brick Coarse Aggregates Instead of Natural Coarse Aggregates

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## ABSTRACT

The rapid growth of infrastructure, urbanization, and industrialization has increased global concrete demand, putting pressure on natural resources and creating ecological challenges. In response, using Brick Waste (BW) as a substitute for natural aggregates in concrete offers a promising solution to enhance sustainability in construction materials. This study specifically investigates the replacement of Natural Coarse Aggregates (NCA) with Brick Coarse Aggregates (BCA) at substitution rates of 25%, 45%, 65%, and 85%. The experimental results show that replacing 25% of NCA with BCA leads to a 12% decrease in workability and a 2.48% reduction in density compared to a control concrete mix. In its hardened state, this substitution results in a slight decrease of 6.45% in compressive strength (fc). At higher substitution rates, such as 85%, the decrease is intensified, with a 32% reduction in workability, 7.93% in density, and 50.32% in compressive strength, all compared to the control concrete after 56 days. The present study also emphasizes a significant correlation between the measured compressive strength and that estimated by non-destructive methods, such as the Schmidt Rebound Hammer Test. Optimizing substitute materials is crucial for achieving high performance while ensuring environmental benefits. This research proposes an innovative approach to sustainable construction, providing a unique opportunity to reconcile performance and sustainability in the construction sector. The importance of this work lies in its potential to transform waste management practices and promote more ecological construction materials.

*Keywords*-brick powder; workability; density; strength; Schmidt rebound hammer test; ultrasonic velocity

## I. INTRODUCTION

Concrete, a commonly used composite material, is an essential structural element in the developing global infrastructure. It is the second most widely used substance after water, with a global production of approximately 5.3 billion cubic meters per year [1], and a projected increase to 18 billion tons by 2050 [2]. Ordinary concrete consists of coarse and fine

aggregates, cement, and water, with aggregates accounting for about 60% to 75% of the total volume, making them a major concrete component [3]. Due to their abundance, these aggregates are extensively exploited for concrete production. However, this intensive exploitation of natural resources raises significant environmental challenges, and thus, searching for substitutes for natural aggregates is inevitable. Concrete is known for its versatility, affordability, adaptability, durability,

and moldability into various shapes and finishes. It has a high capacity to resist compression, but a low capacity to resist tension, limited deformability, and weak resistance to cracking. Therefore, ensuring the longevity of concrete has become a major concern in the construction industry. Concrete production is responsible for about 8% of the global CO<sub>2</sub> emissions [4, 5], with Portland cement being a key factor in this type of pollution [6]. Additionally, the extraction of raw materials from the Earth's crust contributes to the depletion of natural resources, raising significant environmental and economic concerns [7, 8]. Two important goals are the reduction in carbon dioxide emissions associated with cement production, and the increase in the use of industrial by-products as aggregates, either fine or coarse, or cement alternatives could be possible solutions to the aforementioned challenges. Therefore, environmentally friendly materials must be utilized instead of cement and natural aggregates. Research into cement and aggregates made from industrial by-product waste is a novel strategy for improving construction's environmental sustainability. Natural aggregate-containing concrete has been the subject of much research, the findings of which reveal that recycled aggregate concrete can match or exceed the performance of natural aggregate concrete in specific applications [9-11].

BW, a non-hazardous and non-toxic solid by-product, constitutes a large portion of global waste and can be recycled and reused in various construction applications. Its use as fine and coarse aggregates, or as a cement substitute, has proven to be effective, providing an alternative solution to the replacement of natural aggregates, thereby helping reduce the raw material consumption. Several studies have assessed the impact of replacing natural aggregates with Recycled Brick Waste (RBW) in concrete. Authors in [12] evaluated such a substitution at percentages of 20%, 40%, and 60%. The performed compressive strength tests showed that compressive strength could be met by replacing 40% of the natural aggregates with crushed bricks. Authors in [13] found that when 50% and 100% of natural aggregates were replaced with BCA, workability dropped by 21.8% and 44.9%, and compressive strength dropped by 48.72% and 63.14%, respectively. At the 25% level, workability dropped by 16.8% and compressive strength by 17%, which suggests that concrete properties stay the same at this level. Authors in [14] found that using 40%, 80%, or 100% of BW instead of natural aggregates decreased slump by 20%, 48%, and 62%. For 40% and 80% replacements, compressive strength decreased by 20% and 34%, respectively. Density dropped by 2%, 7%, 8%, 9%, and 13% for substitutions of 20%, 40%, 60%, 80%, and 100%, relative to the control mixture. Authors in [15] demonstrated that substituting stone aggregates with brick aggregates at 25%, 50%, 75%, and 100% resulted in compressive strength reductions of 8.11%, 9.61%, 27%, and 32.88%, and tensile strength reductions of 7.81%, 14.4%, 33.74%, and 38.80%, respectively. Authors in [16] documented reductions in compressive strength of 2.35%, 20.72%, and 29.97% for 25%, 50%, and 75% replacements after 28 days, alongside corresponding declines in workability of 5%, 50%, and 55%. Authors in [17] also reported compressive strength reductions of 9.97%, 7.72%, 18.92%, and 22.04%, and a tensile strength

decrease of 3.56%, 4.65%, 12.33%, and 20% for 25%, 50%, 75%, and 100% brick aggregate substitutions, respectively. These studies exhibit that moderate substitution levels, such as 25% or 40%, maintain adequate concrete properties, whereas higher replacement rates significantly reduce performance.

## II. RESEARCH RELEVANCE AND OBJECTIVES

The primary objectives of the present study are to reduce dependence on natural resources and to mitigate environmental degradation. The analysis carried out in this context aims to thoroughly investigate the characteristics of concrete resulting from replacing a portion of NCA with BCA. To achieve this, the strength properties of the aggregates were tested, and subsequently, an assessment of the concrete in both its fresh and hardened states was performed to evaluate its mechanical properties and durability. For this study, five mixtures were prepared. One of these mixtures contained only NCA, namely ordinary concrete, while in the others, the NCA were replaced by 25%, 45%, 65%, and 85% of BCA. Additionally, various properties of the concrete samples, including workability, density, Schmidt Rebound Hammer Test, Ultrasonic Pulse Velocity (UPV), and compressive strength, were evaluated. Finally, a comprehensive analysis was conducted to assess the viability and environmental benefits of this alternative method, evaluating the effects of these modifications on the composition and performance of the concrete.

## III. MATERIALS AND METHODS

### A. Materials Used

For this project, CPJ 45 Portland cement was selected as the binder, characterized by a minimum clinker content of 65%, and was employed to formulate the concrete mixture. The additional materials consisted of additives provided by Holcim, including fly ash, pozzolans, and fillers. These additives complied with the Moroccan standards NM10.1.004 [18]. This study used sand from the Oujda region, which is known for its exceptional purity. The material's balanced, cubic, and uniform configuration facilitates effortless handling and utilization. To be the moisture content of the concrete controlled, the sand was air-dried for one day at ambient temperature. The maximum particle size attained was 4.75 mm. Sand testing was performed in compliance with the NF EN 12620 standard [19]. G1 and G2 are two types of coarse crushed aggregates utilized in the present study; G1 has particles ranging from 5 mm to 11 mm in size, and G2 has particles ranging from 11 mm to 20 mm. The NF P-18-560 [20] standard served as a guide for selecting these aggregates. The brick factory In Oujda, Morocco, which produces ARGILUX bricks, was the source of the clay brick debris. This debris is a byproduct of the brick manufacturing process, specifically the broken or destroyed bricks. Crushed bricks with a size range of 4.75 mm to 20 mm were employed instead of NCA. BW can be used as an alternative material because it has the right pozzolanic properties, which need at least 70% SiO<sub>2</sub>, CaO, Al<sub>2</sub>O<sub>3</sub>, and Fe<sub>2</sub>O<sub>3</sub>. The concrete was prepared by combining potable water sourced from the Autonomous Intercommunal Agency for Water and Electricity Distribution of Oujda (RADEEO), which adheres to the physical and chemical standards outlined in NM 10.1.353 [21]. Table I illustrates the physical properties of the aggregates and

BW, whereas Figure 1 displays their particle size distribution. Table II presents the chemical composition of cement and sand. The BCA exhibit properties like those of the natural aggregates used in this study, including the fineness modulus. However, the former have a higher water absorption due to their clay content. A minor modification to the Water/Cement (W/C) ratio is required in the mix design. The pre-soaking of the BCA in water for 24 hours before their incorporation into the concrete is a method that diminishes water absorption during the initial mixing phase.

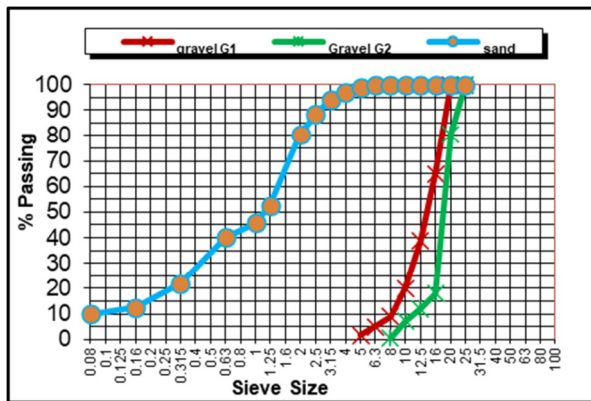


Fig. 1. Distribution of sand, gravel G1, and gravel G2 particle sizes.

TABLE I. PHYSICAL CHARACTERISTICS OF CEMENT, AGGREGATES, AND BW

Property	cement	sand	G1	G2	BCA
Specific gravity	3.15	2.68	2.70	2.72	2.18
Water absorption %	...	2.50	1.48	1.50	12.85
Fineness modulus	...	2.85	6.62	6.82	6.64

TABLE II. CHEMICAL COMPOSITION OF CEMENT AND SAND

Constituent (%)	Cement (%) by mass	Sand (%) by mass
CaO	60.06	5.58
SiO <sub>2</sub>	20.90	77.40
Fe <sub>2</sub> O <sub>3</sub>	3.90	2.66
Al <sub>2</sub> O <sub>3</sub>	5.85	8.18
MgO	1.85	0.77
K <sub>2</sub> O	2.14	0.25
TiO <sub>2</sub>	0.32	0.005
SO <sub>3</sub>	2.35	0.018
LOI	21.84	....

B. Mix Proportions

The effect of using coarse aggregates in place of some of the NCA on concrete performance was studied by making five mixtures for each specimen using a W/C ratio of 0.55. BCA was substituted for 25%, 45%, 65%, and 85% of the NCA. Table III enumerates the concrete mix ratios. For example, BCA25 denotes the composition in which 25% of the sand is substituted with BCA. The mix BCA0 denotes the control concrete. The Dreux-Gorisse method was utilized for the design of the concrete mix [22].

TABLE III. MIXTURE PROPORTIONS WITH W/C=0.55

Mix identification	BCA %	Water (kg/m <sup>3</sup> )	Cement (kg/m <sup>3</sup> )	G1 (kg/m <sup>3</sup> )	G2 (kg/m <sup>3</sup> )	Sand (kg/m <sup>3</sup> )	BCA (kg/m <sup>3</sup> )
BCA0	0	192	350	320	815	763	0
BCA25	25	192	350	240	611.25	763	283.75
BCA45	45	192	350	176	448.25	763	510.75
BCA65	65	192	350	112	285.25	763	737.75
BCA85	85	192	350	48	122.25	763	964.75

C. Testing Procedures

The building materials testing laboratory at the Faculty of Sciences in Oujda, and the LABNORVIDA testing laboratory hosted this study's experiments. The concrete mixes were carefully prepared with an 125-lt pan mixer. This experiment deployed the following method to ensure uniform concrete component distribution. First, the mixer received coarse aggregates and then fine aggregates. Subsequently, a little water from the calculated amount was added. After adding the cement blend, the remaining water was added. Processing persisted until the mixture was uniform.

1) Slump Test

The slump test is frequently employed to assess fresh concrete's workability or consistency and ascertain the necessary W/C ratio for the concrete mixture. This test utilizes the Abrams cone, commonly known as the slump cone, complying with the NF EN 12350-2 [23] standard.

2) Fresh Density

The density of concrete is critical in determining its durability, since denser concrete exhibits superior strength and resilience. The test was performed in compliance with the EN 12350-6 [24] standard. The mold was initially weighed when being empty, it was then filled with concrete, and weighed again. The wet density of all concrete mixtures was ascertained by calculating the average weight of three specimens.

3) Compressive Strength Test

Compressive strength is essential for evaluating the structural integrity of concrete in buildings. Concrete cubes measuring 150 mm × 150 mm × 150 mm are cast to determine the compressive strength of the concrete. NF EN 12390-3[25] assesses compressive strength at ages of 7, 14, 28, and 56 days. Water was used to cure the samples at 100% relative humidity and a constant ambient temperature of 27 ± 2°C. A universal testing machine was utilized to measure both compressive and split tensile strength.

4) UPV Test

UPV testing, a non-destructive technique, evaluates concrete quality in situ. The concrete quality of all samples was assessed using the NF EN 12504-4 [26] standard procedure for ultrasonic testing, following 28 days of curing. The device features a processing unit that emits and detects ultrasonic pulses, simultaneously measuring the interval between these actions. In this research, the direct method was deployed to generate the pulse for this process. The pulse velocity is independent of the material's geometry. The medium through which it propagates is contingent upon the material's elastic properties.

5) Schmidt Rebound Hammer Test

The Schmidt rebound hammer is an instrument that assesses the compressive strength of concrete by measuring the rebound of a spring-driven hammer when it strikes the surface. This non-destructive testing method provides a concrete strength estimation following NF EN 12504-2 [27]. The rebound hammer measurements are linked to concrete compressive strength using conversion charts provided by the manufacturer. The comprehensive testing and correlations between the rebound values and actual concrete compressive strength can be derived from these charts.

IV. RESULTS AND DISCUSSIONS

A. Workability Test Results

The present study assessed the feasibility of replacing NCA with BCA in concrete mixtures at rates of 25%, 45%, 65%, and 85%. Figure 2 presents the corresponding slump values and demonstrates that as the proportion of NCA replaced by BCA increases, the workability of the concrete gradually decreases. The slump values range from 51 mm to 75 mm. The results show that with a 25% brick substitution (BCA25), the slump decreases by 12%, indicating a slight reduction in fluidity. Substitution rates higher than 25% lead to reductions of 20%, 26.67%, and 32% compared to conventional concrete (BCA0). This means that the concrete becomes less workable, being, thus, harder to handle. This decrease is likely to occur due to the increased porosity and higher absorption capacity of the BW, which reduces the available water in the mixture and affects the consistency of the concrete. To mitigate the decrease in workability while maintaining the mechanical properties of concrete by incorporating brick waste as coarse aggregates, the aggregates should be used in a saturated surface dry state, or high-efficiency water-reducing admixtures should be applied. These findings comply with those reported in [28].

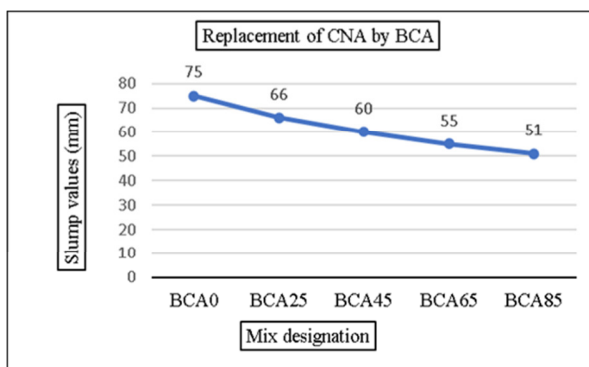


Fig. 2. Workability of BCA concrete.

B. Concrete Density Test Results

Figure 3 depicts the concrete density for different ratios, with NCA being replaced by BCA, emphasizing the effect of integrating BCA on the density of concrete.

The findings indicate a progressive reduction in concrete density as the proportion of NCA replaced by BCA rises. The control concrete exhibits the highest density at 2465.8 kg/m<sup>3</sup>. The mixes BCA25, BCA45, BCA65, and BCA85 demonstrate

densities of 2404.6 kg/m<sup>3</sup>, 2358.1 kg/m<sup>3</sup>, 2315 kg/m<sup>3</sup>, and 2270.2 kg/m<sup>3</sup>, reflecting reductions of 2.48%, 3.27%, 6.11%, and 7.93%, respectively. The specific gravities of both materials, evidenced in Table I, demonstrate the lighter weight of BCA compared to NCA, resulting in a reduced overall concrete density. Furthermore, the abrasive texture of the BW is likely to enhance the porosity of the mixture, thereby marginally decreasing its density. Such a decrease may be advantageous in applications requiring a lightweight structure although it may impact other mechanical properties of concrete, including strength. The results show that adding BCA to concrete mixtures lowers their density. This calls for a thorough investigation of how these substitutions affect the performance of the materials, while also considering the environmental benefits of using recycled materials.

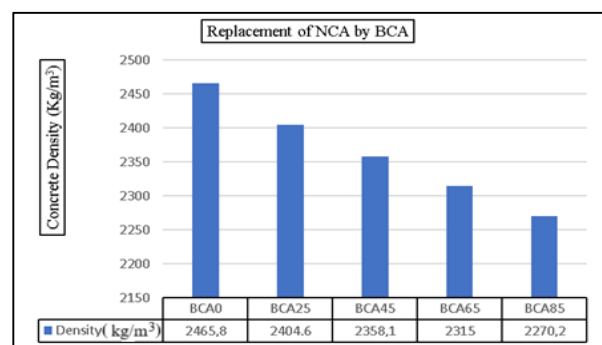


Fig. 3. Density results of BCA concrete.

C. Compressive Strength Test Results

TABLE IV. COMPRESSIVE STRENGTH OF CONCRETE WITH BCA REPLACEMENT

Mix designation	Concrete's Compressive Strength (MPa)			
	7 days	14 days	28 days	56 days
BCA0	18,50	23,88	27,94	30,72
BCA25	17.12	20.74	25.92	28.74
BCA45	13.83	16.16	20.73	25.26
BCA65	10.82	12.74	16.37	20.46
BCA85	8.22	10.12	12.27	15.62

The research findings indicate that replacing 25% of NCA with BCA25 results in a minor decrease in compressive strength of 7.45%, 13.14%, 7.22%, and 6.45% at 7, 14, 28, and 56 days, respectively, suggesting a moderate decline in quality. When substitution exceeds 25%, the strength continues to decrease over time. At 56 days, reductions of 17.77%, 33.39%, and 50.32% were observed, demonstrating that BCA negatively affects the mechanical properties of concrete. Figure 4 displays moderate substitution levels, such as 25%, which are acceptable. However, higher substitution rates significantly reduce concrete quality due to the increased porosity and lower strength of the BCA.

D. UPV Test Results

The data displayed in Table V illustrate the compressive strength and UPV after 28 days for various concrete mixtures. These mixtures substitute BCA for NCA at 25%, 45%, 65%, and 85% replacement rates.

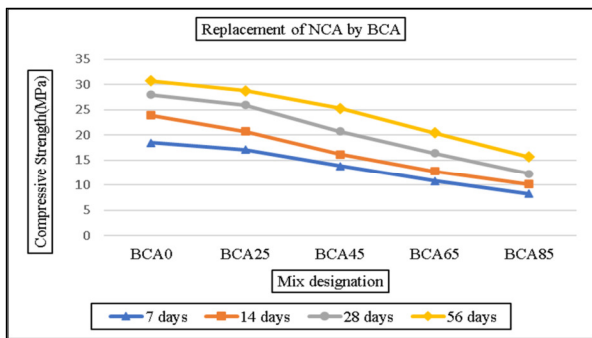


Fig. 4. Compressive strength of BCA concrete.

TABLE V. COMPRESSIVE STRENGTH AND UPV OF CONCRETE WITH BCA

Mix designation	UPV (Km/s)	Compressive Strength (MPa) at Day 28
BCA0	3.68	27.94
BCA25	3.64	25.92
BCA45	3.56	20.73
BCA65	3.45	16.37
BCA85	3.32	12.27

Figure 5 demonstrates that this substitution leads to a gradual drop in UPV values. This is mostly because BCA are of lower quality and have more holes in them. This decline is typically associated with a decrease in the compressive strength of concrete. Nonetheless, most mixtures, except BCA65 and BCA85, exhibit values exceeding 3.5 km/s signifying acceptable quality. Reductions of 1.08%, 3.26%, 6.25%, and 9.78% for the different substitution rates show that moderate substitutions of BCA up to 45% do not have a big effect on concrete quality. On the contrary, higher proportions make the mechanical properties and material homogeneity much worse. The compressive strength and UPV of concrete incorporating BCA were evaluated by comparing the experimental results and empirical data, as depicted in Figure 5.

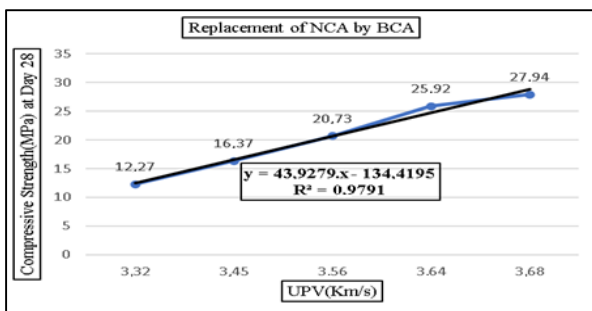


Fig. 5. UPV and compressive strength correlation in concrete with BCA replacement.

The study utilized the least squares method to examine the correlation between compressive strength and the UPV. From the obtained results, the compressive strength is determined as:

$$f_c = 43.9279 (uvp) - 134.4195, R^2 = 0.9791 \quad (1)$$

E. Schmidt Rebound Hammer Test Results

Cubic concrete specimens underwent Schmidt rebound hammer testing after 28 days. Table VI illustrates the rebound-

number results for concrete mixtures with different substitutions.

TABLE VI. COMPRESSIVE STRENGTH AND REBOUND NUMBER OF CONCRETE WITH BW

Mix designation	Rebound number	Compressive strength (MPa) at Day 28
BCA0	36.5	27.94
BCA25	36.1	25.92
BCA45	35.3	20.73
BCA65	34.2	16.37
BCA85	33.6	12.27

Figure 6 shows that the rebound number decreases as the amount of BCA increases compared to regular concrete SB0-BCA0. The numbers go down by 1.09%, 3.28%, 6.33%, and 7.94% for substitution rates of 25%, 45%, 65%, and 85%, respectively. This reduction is ascribed to the elevated porosity of BCA, which absorb greater amounts of water than natural aggregates, compromising the cement matrix and diminishing the internal cohesion of the concrete.

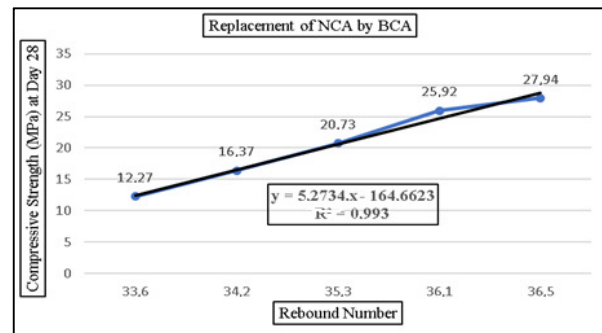


Fig. 6. Rebound number and compressive strength correlation in concrete with BCA replacement.

The data evidenced in Figure 6 were used to formulate (2) which can be used for determining compressive strength:

$$f_c = 5.2734. (Rn) - 164.6623 \text{ with } R^2 = 0.993 \quad (2)$$

V. CONCLUSION

Research on the utilization of Brick Waste (BW) as a substitute for natural aggregates in concrete has demonstrated variability in the findings. These discrepancies are due to variations in the recycled materials, mixture proportions, and testing methodologies employed. Certain researchers report enhancements in concrete performance, whereas others indicate the existence of a deterioration, underscoring the necessity to optimize parameters for more consistent and reliable outcomes. The present study introduces an innovative approach by employing BW as partial coarse aggregates in concrete, a material that remains largely underexplored. Unlike previous research on recycled materials, this work investigates the effects of BW at high substitution levels, up to 85%, uncovering new insights into its potential. The conducted analysis reveals synergistic interactions between BW and traditional aggregates, enhancing the mechanical properties of concrete. To assess durability, the current study integrates advanced non-destructive testing techniques, including

Ultrasonic Pulse Velocity (UPV) and Schmidt rebound hammer tests. These methods enable a novel and accurate prediction of compressive strength while offering a dependable alternative to conventional testing. By merging these techniques, this research presents a robust framework for evaluating their performance, paving the way for optimized waste management practices in construction while reducing the environmental footprint. This study also elucidates the potential of industrial by-products, specifically BW, as a sustainable substitute for traditional materials. The incorporation of these materials enhances the properties of concrete while promoting more sustainable waste management practices. It is demonstrated that when 25% of the natural aggregates are replaced with Brick Coarse Aggregates (BCA), the fresh concrete becomes 12% less workable and 2.48% less dense than the control concrete (BCA0). In its hardened state, this identical substitution rate results in a marginal decrease of 6.45% in compressive strength while concurrently enhancing tensile strength by 11.38% compared to BCA0. When the BCA proportion reaches 85%, the decline becomes more noticeable. The workability drops by 32%, density by 7.93%, compressive strength by 50.32 %, and tensile strength by 33.88% compared to the control concrete after 56 days. The present research demonstrates that elevating the substitution rate to 45% leads to a gradual reduction in UPV, yet it remains above 3.5 km/s, thereby, maintaining acceptable concrete quality. The rebound index diminishes as the ratio of BCA increases, relative to BCA0. Based on the recorded rebound number, there was a strong link between the compressive strength measured by a universal testing machine and that predicted by the Schmidt rebound hammer test. These findings reveal that the optimization of substitute materials can significantly improve concrete performance and offer significant environmental benefits. Finally, this study's findings suggest a novel approach to environmentally responsible building practices that combines performance and durability.

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