Građevinski materijali i konstrukcije
Building Materials and Structures
journal homepage: www.dimk.rs

https://doi.org/10.5937/GRMK2400010S

**Original scientific paper**

# Improving the mechanical characteristics of environmentally friendly concrete using fly ash and brick powder as partial sand replacements

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*Article history*

*Received:* 21 September 2024
*Received in revised form:* 24 October 2024
*Accepted:* 03 November 2024
*Available online:* 06 December 2024

*Keywords*

fly ash,
brick powder,
workability,
strength,
Schmidt hammer,
ultrasonic velocity

*ABSTRACT*

Infrastructure and urbanization drive the demand for concrete, which puts pressure on natural resources and jeopardizes the ecosystem. Incorporating recycled materials into concrete can fulfill this demand without sacrificing quality. This study examines the mechanical properties of sustainable concrete, employing fly ash (FA) and brick powder as substitutes for sand in fine aggregates. We evaluated rebound hammer strength, ultrasonic pulse velocity (UPV), workability, compressive strength, and split tensile strength using both destructive and non-destructive assessment methods, comparing them to conventional concrete. Concrete mixtures were developed by substituting 10% of natural sand with brick powder and gradually replacing the remaining sand with fly ash at 10% to 50%. The results clearly show that the best mix of 10% brick powder and 40% fly ash increases compressive strength by 64.81%, split tensile strength by 17.78%, and workability by 48%. The identical mixture yields a notable enhancement in ultrasonic pulse velocity (UPV) of 33.15%, achieving a velocity of 4.9 km/s, and a 32.05% increase in rebound number, resulting in a rebound index of 44.92. A regression analysis indicated a significant correlation among compressive strength, UPV, and rebound index. The combination of 10% brick powder and 40% fly ash results in enhanced mechanical performance, reduced costs, and supports sustainable construction practices.

## 1 Introduction

Concrete, a commonly used composite material, plays a crucial role as a structural element in the development of worldwide 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]. Mehta et al. [2] has projected an increase to 18 billion tons by 2050. The composition comprises three fundamental components: water, aggregate, and cement. Cement, the main constituent of concrete, acts as a cohesive substance when mixed with water and aggregates in its powdered form. Concrete is a versatile material that is cost-effective, adaptable, durable, and malleable in various shapes and finishes. It has a high ability to withstand compression, a low ability to withstand tension, a limited ability to deform, and a weak resistance to cracking. Consequently, guaranteeing longevity has increasingly become a significant issue in the construction industry.

The production of concrete accounts for roughly 8% of global $CO_2$ emissions [3]. Portland cement, a major component, plays a significant role in this negative impact on environmental pollution [4]. The extraction of raw materials used in concrete, sourced from the Earth's crust, has contributed to the global depletion of these resources. As a result, the extensive use of concrete has raised significant environmental and economic concerns [5, 6]. This necessitates the replacement of all or part of the cement with an eco-friendly material. In this scenario, we identified two objectives: the first was to reduce the CO2 emissions associated with cement manufacturing. On the other hand, the second approach aimed to reduce environmental impact by using leftover industrial materials as fine or coarse aggregates or as substitutes for cement. Over the past century, researchers have proposed various waste products from industry and agricultural materials as potential substitutes for concrete ingredients. These include rice husk ash, fly ash, sewage sludge ash, bagasse ash, polyvinyl chloride waste powder (PWP), and textile sludge ash (TSA). This approach effectively maintains natural resources, preventing their depletion, and improving the economy and sustainability of concrete production [7]. Fly ash, a by-product of burning pulverized coal in thermal power plants,

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has gained significant attention from researchers as a potential alternative for substitution in concrete. Researchers generally classify fly ash into two categories: Class F and Class C [8]. Class F fly ash contains at least 70% combined silica, aluminum, and iron oxides, with a calcium oxide (CaO) content below 10%. This composition reduces the water demand in concrete mixtures and exhibits pozzolanic properties, improving the material's performance.

Multiple studies have investigated the implications of substituting sand with fly ash in concrete. Siddique [9] focused his study on the effects of Class F fly ash on the mechanical and physical properties of concrete. The study involved replacing 10 to 50% of fine aggregate (sand) with fly ash. As the proportion of sand substitution increased, the concrete's compressive strength increased due to the pozzolanic effect of fly ash. The concrete exhibited enhanced tensile strength, flexural strength, and modulus of elasticity in comparison to the standard concrete. Even with the addition of a superplasticizer, the ease of handling newly mixed materials decreased, but 50% fly ash proved to be the most effective substitution. Ishimaru [10] performed a study on the use of fly ash as fine aggregates in conventional concrete and determined that it is suitable for constructing concrete structures. Their partial substitution greatly enhances the strength of conventional concrete, enabling their efficient utilization in structural concrete. Rajamane and Ambily [11] investigated the properties of concrete when less calcium fly ash replaced a portion of the sand. The levels of sand replacement were 0%, 20%, 40%, and 60%. The findings indicated that the compressive strengths at 28 days were comparable among all levels of replacement. Furthermore, fly ash concrete showed superior workability compared to control concrete. Bilir et al. [12] undertook a study to examine the impacts of using fly ash as fine aggregates on the mechanical properties of mortar. The results show that using fly ash as a replacement for 30% of the original material enhanced the mortar's ability to withstand deformation and improved its strength through its pozzolanic effect. Deo and Pofale [13] conducted a separate investigation in which he substituted fly ash at weight percentages of 12% and 27% for sand in the concrete compositions. All mixes maintained a water-to-cement ratio of 0.32, demonstrating pozzolanic properties. The findings indicated that the concretes containing fly ash demonstrated superior compressive strength, flexural strength, and workability in contrast to conventional concrete. Moreover, the inclusion of superplasticizers has the potential to enhance these properties even more. In a previous study, Islam and Rashid [14] investigated the effects of partially replacing sand with low-calcium fly ash at various amounts between 0% and 40%. According to the report, concrete with 20% and 30% fly ash showed greater compressive strength than regular concrete when they had the same water/cement ratio. Yin et al. [15] study demonstrated that utilizing both fly ash and river sand results in an optimized particle size distribution of fine aggregates. The concrete mixture containing 30% fly ash demonstrated superior compressive strength in comparison to the conventional concrete, with a notable increase of 28.8%. Mao et al. [16] conducted a study showing that the strength of concrete increases with an increase in fly ash content, as long as it does not exceed 40%.

Fly ash particles are also very small and have a large specific surface area. This lets them fill up more space between the cement and aggregate particles, which makes the concrete denser. While there have been numerous important findings on the use of fly ash in concrete, literature is scarce on its application as a component substitute for fine aggregates.

The landfill disposal of brick dust, a plentiful byproduct from brick kilns and construction sites, raises environmental concerns. Brick kilns are the main contributors to this waste, occupying valuable land and posing significant risks to both health and the environment. Researchers are increasingly interested in using brick powder (BP) as a partial alternative to sand in the composition of concrete mixtures. This is because (BP) has the potential to improve concrete's specific mechanical properties while also recycling construction waste. Researchers have conducted several studies to evaluate the viability of utilizing clay bricks as aggregates in concrete. Adamson et al. [17] showed that it is possible to substitute natural coarse aggregates with crushed bricks in concrete without causing any significant impact on its durability, as long as there are no steel reinforcements present. However, Bektas et al. [18] asserts that increasing the rate of brick substitution results in a decrease in the fluidity of the mortar. However, substituting 10% and 20% of the bricks did not hurt compressive strength and only had a minor effect on mortar shrinkage. In Nunung et al. study [19] the impact of incorporating lightweight bricks as a partial replacement for sand (at levels of 0%, 10%, 20%, and 30%) on the compressive strength of concrete was investigated. The results showed that substituting 10% and 30% of the material achieved the highest and lowest levels of compressive strength, respectively, at 24.45 MPa and 18.03 MPa after 28 days. Gaspard et al. [20] conducted a study to examine how the substitution of fine aggregates with crushed clay bricks affects the concrete's workability and compressive strength. The study examined substitution rates of 10%, 15%, 25%, 50%, and 75%. The findings revealed a negative correlation between the replacement rate and compressive strength. The strength decreased gradually as the replacement rate increased, with a minimal reduction of 9.63% observed at a replacement rate of 10%. However, a replacement rate of 75% recorded a maximum decrease of 50% compared to the control sample, which exhibited a strength of 31.81 MPa. Momoh et al. [21] conducted a study to assess the effectiveness of different amounts of recycled concrete aggregate (15%, 22.5%, and 30%) and crushed clay bricks (10%, 15%, and 20%) as substitutes for coarse and fine aggregates in concrete. The test results indicated that the compressive strength ranged from 24.22 MPa to 27.78 MPa after 7 days, from 27.95 MPa to 37.2 MPa after 18 days, and from 25.15 MPa to 32.48 MPa after 28 days. To achieve optimal performance, the authors suggest keeping the crushed brick content within the range of 15% to 20%. These findings are consistent with Srivinas et al. [22] research, which indicated that the ideal substitution of natural fine aggregates with crushed brick powder was 20%. Similarly, Aliabdo et al. [23] concluded that the amount of clay brick aggregate present in concrete. should not exceed 25% of the total aggregate content. Ibrahim et al. [24] found that lightweight concrete containing 25% used clay bricks reached a maximum strength of 25 MPa and had a density of 1647 kg/m3. This result is consistent with the findings reported by David et al. [25]. The literature review above indicates a dearth of information regarding the impact of adding clay brick powder to concrete's mechanical properties.

## 2 Research relevance and objectives

Reducing dependency on natural resources and mitigating environmental degradation are the primary goals of this study. The purpose of this analysis is to look closely at the properties of concrete that has had some of its natural sand replaced with fly ash and brick powder. To accomplish this, several different mixes were prepared. Brick powder replaces 10% of the sand in all the mixes, while fly ash gradually replaces the remaining sand, increasing the percentage from 10% to 50% in 10% increments. The study examines several concrete samples, including workability, compressive strength, split tensile strength, ultrasonic pulse velocity, and Schmidt rebound hammer index. We conduct an in-depth analysis to assess the feasibility and environmental benefits of this alternative method by examining the effects of these modifications on the composition and functionality of the concrete.

## 3 Experimental study

### 3.1 Characterization of materials

The binding material chosen for this project is Portland cement CPJ 45, which has a minimum clinker content of 65% and will be used to create the concrete mixture. The remaining materials consisted of additives, including fly ash, pozzolans, and fillers provided by Holcim. These additives complied with the Moroccan specifications NM10.1.004 [26]. The concrete was prepared by mixing potable water sourced from Oujda's autonomous intercommunal water and electricity distributing agency (RADEEO), which meets the physical and chemical requirements specified in NM 10.1.353 [27]. The sand used in this study was sourced from the Oujda region (Morocco) and is known for its exceptional purity. The substance's streamlined, balanced, and cuboid shape enables effortless manipulation and handling. The sand underwent a full day of air drying at room temperature to regulate the moisture content of the concrete. The sand reached a maximum size of 4.75 mm. The NF EN 12620 [28] standard guided the sand tests. This study utilized two distinct types of crushed coarse stone aggregates: G1, which had a sieve range of 5-11 mm, and G2, which had a sieve range of 11-20 mm. The NF P-18-560 [29] standard guided the selection of these aggregates. This study uses F-class fly ash from Morocco's Jerada thermal power plant. Electrostatic methods collect the fly ash from the powdery particles in the flue gas stream of boilers powered by pulverized coal. These measurements are per the NM 10.1.004 [26] standard.

The clay brick powder, derived from fragmented or demolished brick waste during manufacturing, was collected in a brick manufacturing plant (ARGILUX) located in Oujda. It was pulverized into fine particles using a ball mill until all particles were reduced to a size smaller than 4.75 mm. The particles utilized as a replacement for sand are those that can pass through a 4.75–5 mm sieve and are captured by a sieve with a size of 75–90 microns. The choice to use brick powder as a substitute material is justified by its pozzolanic properties, which require a minimum composition of SiO2, CaO, $Al_2O_3$, and $Fe_2O_3$ that exceeds 70%. Figure 1 depicts the particle size analysis of the various materials employed. Table 1 presents the physical characteristics of cement, sand, coarse aggregates, fly ash, and brick powder. Table 2 displays the chemical constituents of cement, brick powder, sand, and fly ash.

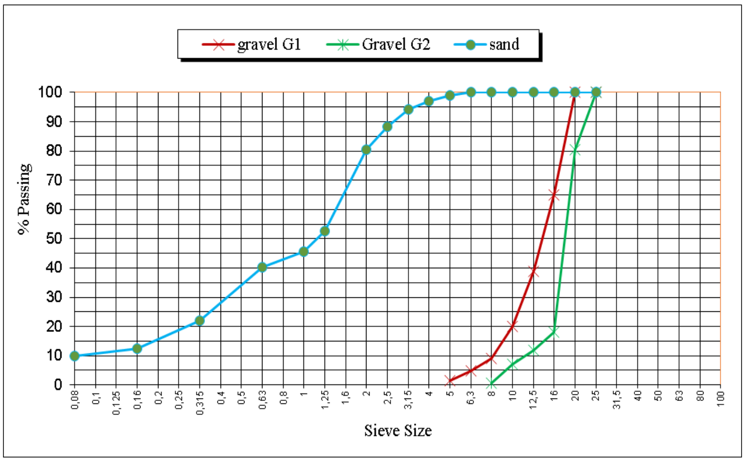


*Fig. 1. Particle size distribution of aggregates*

*Table 1. Physical properties of constituent materials*

| Property | cement | fly ash | sand | G1 | G2 | BP |
|---|---|---|---|---|---|---|
| Specific Gravity | 3.15 | 2.52 | 2.68 | 2.70 | 2.72 | 2.18 |
| Water absorption % | | 3.01 | 2.50 | 1.48 | 1.50 | 5.25 |
| Fineness modulus | | 0.96 | 2.85 | 6,62 | 6,82 | 2.87 |
| Initial setting time (min) | 180 | | | | | |
| Final setting time (min) | 210 | | | | | |
| Fineness Blaine cm2/gm) | 3100 | 3360 | | | | |

*Table 2. The chemical constitution of cement, sand, fly ash, and brick*

| Constituent (%) | cement (%) by mass | BP (%) by mass | sand (%) by mass | fly ash (%) by mass |
|---|---|---|---|---|
| CaO | 60.06 | 7,12 | 5.58 | 1,12 |
| $SiO_2$ | 20,90 | 43,24 | 77,40 | 55,2 |
| $Fe_2O_3$ | 3,90 | 21,6 | 2,66 | 11,2 |
| $AL_2O_3$ | 5,85 | 11,92 | 8,18 | 28,3 |
| MgO | 1,85 | 2,42 | 0,77 | 0,68 |
| $K_2O$ | 2,14 | 2,15 | 0,25 | 1,45 |
| $TiO_2$ | 0,32 | 1,86 | 0,005 | 1,5 |
| $SO_3$ | 2,35 | 6,02 | 0,018 | 0,44 |
| LOI | 21,84 | 3,42 | …….. | 1,06 |

In order to evaluate the effects of partially replacing natural sand with brick powder and fly ash on concrete performance, six mixtures were prepared. One of these mixtures contained only natural sand (ordinary concrete), while the others incorporated fly ash and brick powder as partial replacements for natural sand, using a water-to-cement ratio of 0.55. The concrete mixtures were prepared using the Dreux-Gorisse [30] concrete mix design method, with a constant cement dosage of 350 kg per 1 m³ of concrete in all mixtures. Table 3 specifies the proportions of fly ash, brick powder, sand, coarse aggregates, and cement. The abbreviation SFS denotes the substitution of fly ash for natural sand, while SB signifies the substitution of brick powder for natural sand. For instance, the code SB10-SFS10 signifies a blend where brick powder replaces 10% of the natural sand and fly ash replaces the remaining 10%.

## 3.2 Test Parameters

The Oujda Faculty of Science's building materials laboratory and the LABNORVIDA testing laboratory in Oujda were the sites of the study's experimental program. A 125-liter pan mixer was used to meticulously prepare the concrete mixes. The procedure started with adding big aggregates to the mixer, then fine aggregates. Next, a small amount of water, equal to a fraction of the total amount, was added. Following this, the remaining water was added to the cement, fly ash, and brick powder mixture. We considered the mixture complete only after running the mixer continuously.

### 3.2.1 Workability

The research objective was to assess the impact of substituting a portion of natural sand with a combination of brick powder and fly ash on the workability of fresh concrete. The consistency of the concrete was evaluated by conducting slump tests using the Abrams cone method, as specified in NF EN 12350-2 [31]. The slump cone had conventional measurements: 300 mm in height, with a 200 mm base diameter and a 100 mm top diameter. The workability of each mixture was evaluated by performing slump tests and measuring the slump values for the various concrete compositions. The average result was calculated using three specimens.

### 3.2.2 Compressive, split tensile, and flexural strength

The assessment of the structural capacity of concrete in buildings relies heavily on the measurement of compressive strength. Concrete cubes with dimensions of 150 mm on each side were created to determine the concrete's compressive strength. The NF EN 12390-3 [32] standard mandates evaluating the compressive strength at various curing ages, specifically on days 7, 14, 28, and 56. The samples were subjected to a curing process in an environment with 100% relative humidity and a constant ambient temperature of 27 ± 2°C using water. Cylinders with dimensions of 300 mm in height and 150 mm in diameter were manufactured to measure the split tensile strength of the concrete. Under the specifications outlined in NF EN 12390-6 [33], the evaluation of tensile strength was performed after curing has lasted until the day of the test.

### 3.2.3 Ultrasonic pulse velocity

Ultrasonic pulse velocity testing, a non-destructive method, can assess concrete quality on-site. The quality of concrete on all samples was evaluated using the NF EN 12504-4 [34] standard procedure for ultrasonic testing after 28 days of curing. The experiment was carried out using a voltage of 500 V and a frequency of 54 kHz. The device incorporates a processing unit that transmits and receives ultrasonic pulses while also measuring the time duration between these two operations. The device transmits sound energy through two probes. The time interval between the transmitting probe's transmission of sound energy into the concrete and the receiving probe's detection of this energy determines the pulse velocity. This study used a direct method to generate the pulse to carry out this process. The pulse velocity is unaffected by the substance's form and structure as it passes through, but it does depend on the

*Table 3. Mixture proportions with w/c=0,55.*

| Mix identification | BP % | fly ash % | water (Kg/m$^3$) | cement (Kg/m$^3$) | G1 (Kg/m$^3$) | G2 (Kg/m$^3$) | sand (Kg/m$^3$) | fly ash (Kg/m$^3$) | BP (Kg/m$^3$) |
|---|---|---|---|---|---|---|---|---|---|
| SB0SFS0 | 0 | 0 | 192 | 350 | 320 | 815 | 763 | 0 | 0 |
| SB10-SFS10 | 10 | 10 | 192 | 350 | 320 | 815 | 611 | 76 | 76 |
| SB10-SFS20 | 10 | 20 | 192 | 350 | 320 | 815 | 534 | 153 | 76 |
| SB10-SFS30 | 10 | 30 | 192 | 350 | 320 | 815 | 458 | 229 | 76 |
| SB10-SFS40 | 10 | 40 | 192 | 350 | 320 | 815 | 382 | 305 | 76 |
| SB10-SFS50 | 10 | 50 | 192 | 350 | 320 | 815 | 305 | 382 | 76 |

material's elastic properties. Longitudinal waves are detected by the receiver, which are the fastest. When the concrete's density, homogeneity, and uniformity are high, we observe greater velocity values. Compromise in quality results in reduced values.

#### 3.2.4 Schmidt rebound hammer

For a non-destructive way to find out how strong concrete is under compression, engineers use the rebound hammer (Figure 2). This control technique, in line with NF EN 12504-2 [35], allows for the estimation of concrete strength. This technique is based on the idea that the rebound of an elastic mass is proportional to the surface hardness of the concrete it hits. The design checks the consistency and quality of the concrete, providing a quick and easy indication of its compressive strength. As the apparatus operates, a spring-loaded mass moves along a plunger within a tube. Lower rebound values are associated with lower-strength concrete due to the increased energy absorption observed in this material. After obtaining the rebound number, the manufacturer's supplied chart displayed the compressive strength for each rebound value. The rebound measurement of the sclerometer is the average of 10 measurements taken at different points on the same sample. These points must be spaced at least 20 mm apart.

## 4 Results and conversational analysis

### 4.1 The influence of brick powder and fly ash on concrete compressive strength

The compressive strength of concrete samples was measured. Throughout the process, the specimens were water-cured. On days 7, 14, 28, and 56, after allowing samples to dry for one full day, each concrete specimen was analyzed. The average result was calculated using three specimens. The results of the compressive strength were obtained using the universal testing machine. Table 4 displays the compressive strength values for each specimen.

Figure 3 shows that replacing 10% of sand with brick powder significantly improves the compressive strength by increasing the fly ash content from 10% to 40%. Compared to the conventional, the SB10SFS40 mix has better compressive strength, increasing 64.81%, 34.84%, 60.77%, and 45.80% at 7, 14, 28, and 56 days. Furthermore, the study's results indicate that the gradual improvement in compressive strength is particularly significant at the 28 and 56-day marks. This is due to the slow reaction of calcium hydroxide released during cement hydration with fly ash. The findings indicate that a blend of 10% brick powder and a maximum of 40% fly ash is optimal for improving the compressive strength of concrete mixtures. Utilizing these

*Fig. 2. Schmidt rebound hammer*

*Table 4. Compressive strength of concrete with brick powder and fly ash*

| Mix designation | Concrete's compressive strength (MPa) | | | |
|---|---|---|---|---|
| | 7 days | 14 days | 28 days | 56 days |
| SB0SFS0 | 18,50 | 23,88 | 27,94 | 30,72 |
| SB10-SFS10 | 24,62 | 27,04 | 38,74 | 37,37 |
| SB10-SFS20 | 26,01 | 28,18 | 40,90 | 40,22 |
| SB10-SFS30 | 28,80 | 31,19 | 43,16 | 42,82 |
| SB10-SFS40 | 30,49 | 32,20 | 44,92 | 44,79 |
| SB10-SFS50 | 28,68 | 29,94 | 39,87 | 38,95 |

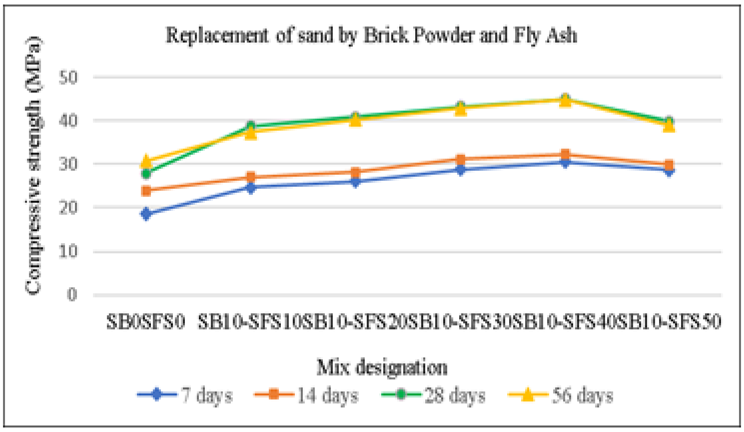


*Fig. 3. Compressive strength of brick powder and fly ash concrete*

materials in moderate amounts appears to enhance the density and overall strength of the concrete by promoting a more efficient pozzolanic reaction and effective pores filling. However, going over these recommended replacement rates, especially for fly ash levels above 40%, could lower the compressive strength. This could be because the mixture will have more voids in it.

### 4.2. The influence of brick powder and fly ash on the workability of concrete

Figure 4 shows workability values, indicating a significant decline in mixtures containing brick powder (SB) and fly ash (SFS). The lowest slump measured is 39 mm, while the highest is 75 mm. When compared to the control concrete, this combination yields a reduction of about 48%. This is because the brick powder particles are angular and irregular in shape, which has a direct impact on workability. This is because the particles are more difficult to mobilize, leading to a growth in water demand and a reduction in the mix's air content. More energy is required to overcome this internal resistance and bring about the intended collapse. Fly ash's higher water requirements for particle coating further impede mixture flow and complicate handling. Hebhoub et al. [36], Aliabdo et al. [37], Ashish [38], and Vardhan et al. [39] research recommends incorporating water or using superplasticizers to address this limitation.

### 4.3 The influence of brick powder and fly ash on the split tensile strength of concrete

Concrete samples were subjected to tests to determine their splitting tensile strength. The procedure involved subjecting the specimens to water curing. We allowed the concrete specimens to dry for a full day before analyzing them on days 7, 14, 28, and 56. The splitting tensile strength results were obtained using the universal testing machine. Table 5 displays the splitting tensile strength values for each test specimen under various sand substitutions. The average result was calculated using three specimens. The set of substitutions combines 10% brick powder and fly ash at rates of 10%, 20%, 30%, 40%, and 50%.

The results presented in Figure 5 indicate that replacing sand with 10% brick powder and combining it with fly ash in proportions of 10% to 40%, enhances tensile strength. The SB10-SFS40 mixture exhibits enhanced tensile strength relative to conventional concrete at 7, 14, 28, and 56 days, with improvements of 17.75%, 8.09%, 17.78%, and 17%, respectively. Adding 50% more fly ash (SB10-SFS50) lowers the tensile strength slightly at all testing ages. This could be because the concrete particles become less tightly connected or more voids are in the mix. This highlights the importance of determining an optimal substitution rate to improve concrete's mechanical efficiency.

Brick powder and fly ash synergistically enhance the strength of the concrete matrix by effectively occupying the pores and increasing density, resulting in improved strength. This approach enhances mechanical properties, minimizes expenses, and mitigates environmental impact, rendering this strategy appealing for sustainable construction applications.

### 4.4 The influence of brick powder and fly ash on the velocity of ultrasonic pulses

Figure 6 presents data on the ultrasonic pulse velocity (UPV) and compressive strength after 28 days for various concrete mixtures. The UPV values, ranging from 3.68 km/s to 4.9 km/s, with an average of 4.21, indicate high-quality cement paste. This suggests that adding brick powder and fly ash to the concrete has a positive impact on its UPV. Compared to conventional concrete (mix SB0-SFS0), the UPV increases by 7.88%, 14.40%, 20.92%, and 33.15%, respectively, when replacing 10% of the sand with brick powder and gradually increasing the amount of fly ash from 10% to 40%.

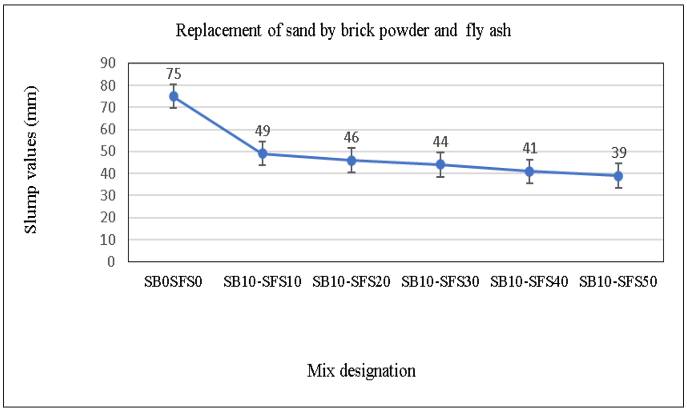


*Fig. 4. Workability of brick powder and fly ash concrete*

*Table 5. Split tensile strength of concrete with brick powder and fly ash*

| Mix designation | Concrete's split tensile strength (MPa) | | | |
|---|---|---|---|---|
| | 7 days | 14 days | 28 days | 56 days |
| SB0-SFS0 | 2,76 | 3,09 | 3,43 | 3,60 |
| SB10-SFS10 | 2,92 | 3,01 | 3,58 | 3,79 |
| SB10-SFS20 | 3,01 | 3,13 | 3,90 | 3,88 |
| SB10-SFS30 | 3,16 | 3,29 | 3,96 | 4,05 |
| SB10-SFS40 | 3,25 | 3,34 | 4,06 | 4,14 |
| SB10-SFS50 | 3,14 | 3,16 | 3,73 | 3,81 |

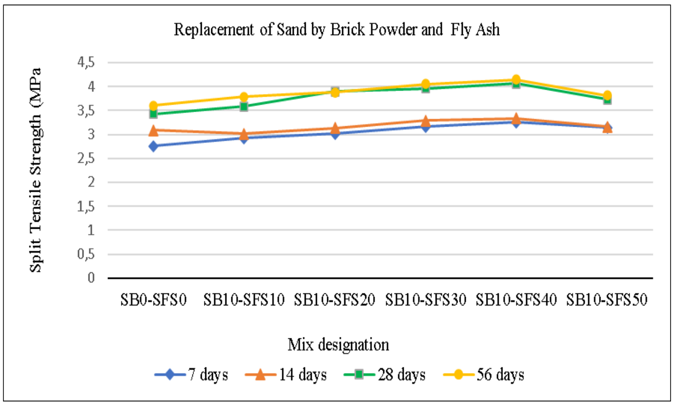


*Fig. 5. Split tensile strength of brick powder and fly ash concrete*

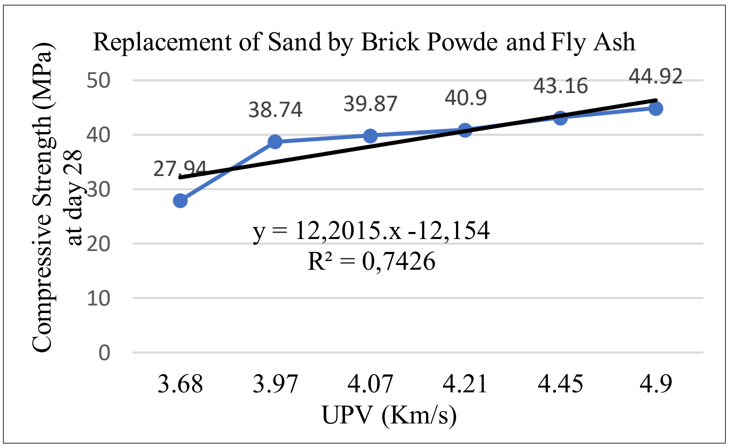


*Fig. 6. UPV and compressive strength correlation in concrete with brick powder and fly ash replacement*

To assess the UPV and compressive strength ($f_C$) of concrete containing brick powder and fly ash, a correlation between UPV and $f_C$ was examined using a least squares regression analysis. Equation (1) presents the derived formula for calculating compressive strength, based on the acquired data.

$$f_c = 12{,}2015.(\text{uvp}) - 12{,}154 \quad \text{with} \quad R^2 = 0{,}7426 \quad (1)$$

To maximize the advantages of brick powder and fly ash while preserving the mechanical and physical properties of concrete, it is essential to ascertain the optimal substitution rate. In this context, incorporating 10% brick powder into mixtures with 10%, 20%, 30%, or 40% fly ash has been shown to improve ultrasonic pulse velocity. Factors such as the enhanced density of the concrete matrix, elevated pozzolanic reactivity, the filler effect, and a decrease in imperfections and fissures all contribute to this improvement in ultrasonic wave transmission.

### 4.5 The influence of brick powder and fly ash on the Schmidt rebound hammer

Tests were performed on concrete cube specimens at the 28-day mark using a Schmidt hammer. The results of the rebound number for the cement paste with various sand substitutions are shown in Figure 7. The results show that replacing 10% of the sand with brick powder and increasing the fly ash (SFS) content from 10% to 40% raises the rebound number by 20%, 25.48 %, 26.33 %, and 32.05 %, respectively. Despite a minor reduction at a fly ash percentage of 50% (SB10-SFS50), the rebound number continues to exceed that of the control mixes. The data suggests that a balanced approach, with moderate replacement levels, such as 40% fly ash and 10% brick powder, is most advantageous.

The method of least squares was utilized to perform a regression analysis of the correlation between rebound number and compressive strength, as measured by the Schmidt hammer when substituting sand with fly ash and brick powder. We used the data from Figure 7 and Equation (2) to derive the following formula for calculating compressive strength:

$$f_c = 1{,}471.(\text{Rn}) - 25{,}7143 \quad \text{with} \quad R^2 = 0{,}9\text{9} \quad (2)$$

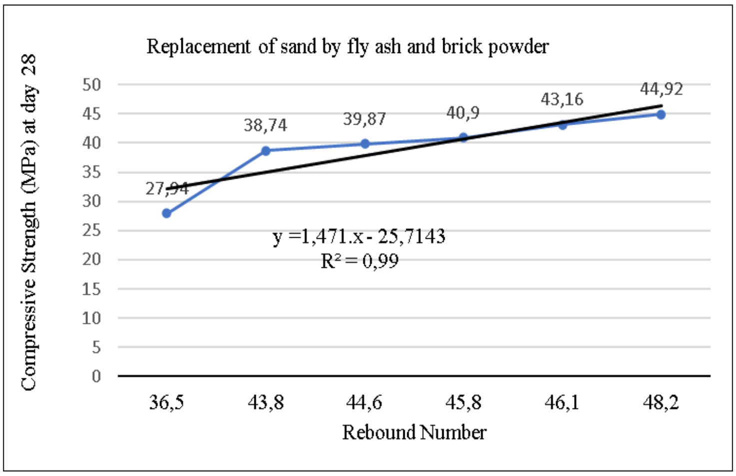


*Fig.7. Rebound number and compressive strength correlation in concrete with brick powder and fly ash replacement*

## 5 Conclusion

Investigations into sustainable substitutes for natural sand in concrete, including fly ash and brick powder, have revealed a significant deficiency in comprehending the synergistic interactions of these materials. Previous studies have examined individual substitutes, but none have thoroughly investigated the synergistic effects of fly ash and brick powder. This study sought to address that gap by assessing the effects of these alternatives on concrete's workability, rebound number, ultrasonic pulse velocity, split tensile strength, and compressive strength.

Using 40% fly ash and 10% brick powder instead of sand increased the compressive strength by 64.81% and the split tensile strength by 17.78%. However, the workability decreased by 48% compared to the control mix (SB0-SFS2). The SB10-SFS40 mix achieved an ultrasonic pulse velocity of 4.9 km/s, indicating a 33.15% improvement. Additionally, it increased the rebound number by 32.05%, reaching a maximum of 48.2 on the Schmidt hammer test. We used least squares regression to find strong links between compressive strength, rebound number, and ultrasonic pulse velocity. These links led to reliable formulas for estimating compressive strength based on these variables. Significantly, when fly ash replacement exceeded 40%, it only slightly reduced mechanical performance.

In summary, the ideal equilibrium for improving the mechanical properties of concrete, lowering expenses, and mitigating environmental effects entails the incorporation of 10% brick powder with a maximum of 40% fly ash. Better pozzolanic reactions and good pore filling enable this synergy, resulting in stronger and denser concrete. The results underscore a substantial advancement in sustainable construction, providing an environmentally friendly solution that alleviates strain on natural resources while enhancing concrete performance.

### Declarations:

**Funding**: No financial assistance, grants, or additional support was obtained.

**Declaration of competing interest**: The authors declare that there is no conflict of interest regarding the publication of this paper.

### Credit authorship contribution statement:

**Filali. S**: Investigation. Original draft. Planning, and execution of experiments Design. Data analysis and final manuscript writing.

**Nasser. A**: Project administration, Supervision, Validation.

**Azougay. A**: Supervision, Revision.

### Acknowledgments

The authors express gratitude to the testing laboratory LABNORVIDA in Oujda and the laboratory of the Department of Geology at the Faculty of Sciences in Oujda for their assistance in conducting this research.

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