PRINT ISSN 1119-8362
Electronic ISSN 2659-1499

Full-text Available Online at
https://www.ajol.info/index.php/jasem
https://www.bioline.org.br/ja

J. Appl. Sci. Environ. Manage.
Vol. 28 (10) 3151-3158 October, 2024

Mechanical Properties of Concrete after Replacing Sand Utilizing Fine Aggregates of Brick Powder

[*1]FILALI, S; [2]NASSER, A; [3]AZOUGAY, A

*[*1]Department of Physics; Laboratory of Materials Waves, Energy, and Environment, Team of Materials, Energy, Civil Engineering and Environment; Faculty of Sciences; Mohammed Premier University; Oujda, Morocco.*
[2]Department of Applied Engineering; Laboratory of Materials, Waves, Energy, and Environment, Team of Materials, Energy, Civil Engineering and Environment; Higher School of Technology; Mohammed Premier University; Oujda, Morocco.
[3]Department of Geology; Laboratory of Applied Geosciences, Mohamed Premier University, Faculty of Sciences, Oujda, Morocco

**Corresponding Author Email: saloua.filali@ump.ac.ma*
[*]ORCID: https://orcid.org/0009-0002-8319-8798
**Tel: +212-618742238*

Co-Author Email: saloua.filali@ump.ac.ma; a1.nasser@ump.ac.ma; a.azougay@ump.ac.ma

ABSTRACT: Infrastructure and urbanization drive the increasing demand for concrete, which strains natural resources and threatens the ecosystem. Incorporating recycled materials into concrete can fulfill this demand without compromising quality. This study therefore examines the mechanical properties of concrete after replacing sand utilizing fine aggregates of brick powder (BP) using appropriate standard techniques of destructive and non-destructive testing methods. Concrete mixtures were developed by incrementally substituting sand with brick powder in ratios from 5% to 25% and evaluated for workability, compressive strength, and split tensile strength in comparison to conventional concrete. The findings indicate that replacing 10% sand with brick powder improves strength by 29.94%, reduces workability by 42.66%, and increases split tensile strength by 8.74%. A strong link was found between compressive strength, ultrasonic pulse velocity (UPV), and rebound number, which was confirmed by regression analysis. Integrating 10% brick powder improves concrete's mechanical properties and promotes sustainable construction practices.

DOI: https://dx.doi.org/10.4314/jasem.v28i10.24

Cite this Article as: FILALI, S; NASSER, A; AZOUGAY, A. (2024). Mechanical Properties of Concrete after Replacing Sand Utilizing Fine Aggregates of Brick Powder. *J. Appl. Sci. Environ. Manage.* 28 (10) 3151-3158

Dates: Received: 07 July 2024; Revised: 15 August 2024; Accepted: 19 August 2024 Published: 05 October 2024

Keywords: Brick powder; workability; strength, Schmidt hammer; ultrasonic velocity.

With an annual production of 5.3 billion cubic meters (Ullah 2022), concrete is the second most used substance after water. It is an essential material for global infrastructure. Kumar Mehta (2014) expects the production to reach 18 billion tons by 2050. Water, aggregate, and cement combine to form versatile, long-lasting, and inexpensive concrete, despite its limitations in tension and cracking. Because of these limitations, the construction industry is increasingly concerned about longevity. About 8% of the world's carbon dioxide emissions come from concrete production (Aruntas 2010), and Portland cement is one of the most polluting ingredients (Anouar 2015). Raw material extraction is a major contributor to resource depletion, which in turn causes ecological and economic problems (Rashad 2013, Sankh 2014). To address these concerns, researchers are looking into alternative materials that are less harmful to the environment and can replace cement. Reducing carbon dioxide emissions from cement production and substituting industrial byproducts for concrete ingredients are the two primary approaches to this problem (Arulmoly 2021). As an example of a byproduct, brick dust is a substantial waste product of brick kilns and building processes. Researchers are studying red brick powder (RBP) as a partial sand

**Corresponding Author Email: saloua.filali@ump.ac.ma*
**ORCID: https://orcid.org/0009-0002-8319-8798*
**Tel: +212-618742238*

substitute in concrete due to its potential to recycle construction waste and improve mechanical properties. Clay bricks, as an aggregate, have been the subject of numerous investigations. Adamson (2015) demonstrated that, in the absence of steel reinforcements, crushed bricks could substitute natural coarse aggregates in concrete without compromising its durability. As the proportion of bricks in the mix increases (Bektas 2009), the mortar fluidity decreases, but substitutions between 10% and 20% of bricks do not affect the compressive strength. Nunung (2022) observed compressive strengths of 24.45 MPa and 18.03 MPa, respectively, when using lightweight bricks as a 10% and 30% sand substitute. Gaspard (2023) found a negative correlation between compressive strength and crushed brick substitution. A 10% replacement resulted in a 9.63% reduction, and a 75% replacement caused a 50% drop. Compressive strength varied from 24.22 N/mm2 to 37.2 N/mm2 in Momoh's (2015) tests of recycled aggregates and crushed bricks, with the range proportional to the replacement rate. For optimal performance, Srivinas (2016) and Aliabdo (2014) recommended keeping the aggregate content of bricks at 20% and 25%, respectively. Despite extensive field research, the effects of clay brick powder on the mechanical properties of concrete remain poorly understood. It is important to decrease reliance on natural resources and mitigate environmental degradation. Hence, the objective of this paper is to evaluate the mechanical properties of concrete after replacing sand utilizing fine aggregates of brick powder

MATERIALS AND METHODS

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. 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. The sand used in this study was sourced from the Oujda region and is known for its exceptional purity. It has a specific gravity of 2.68, a water absorption rate of 2.5%, and a fineness modulus of 2.85. 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 control concrete moisture. The sand reached a maximum size of 4.75 mm. The NF EN 12620 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. These aggregates' specific gravities are 2.70 and 2.72, respectively, and their water absorption rates are 1.48% and 1.50%, respectively. The NF P-18-560 standard guided the selection of these aggregates. The clay brick powder, derived from fragmented or demolished brick waste during manufacturing, was collected in a brick manufacturing plant (ARGILUX) located in Oujda Morocco. 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 traverse a sieve with a size of 4.75–5 mm 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%, with a specific gravity of 2.18, a water absorption rate of 5.25%, and a fineness modulus of 2.9.

Figure 1 depicts the particle size analysis of the various materials employed. Table 1 displays the chemical constituents of cement, brick powder, and sand.

Table 1: The chemical constitution of Cement, Sand, and Brick Powder.

Constituent (%)	Cement (%) by mass	BP (%) by mass	Sand (%) by mass
CaO	60.06	7,12	5.58
SiO_2	20,90	43,24	77,40
Fe_2O_3	3,90	21,6	2,66
AL_2O_3	5,85	11,92	8,18
MgO	1,85	2,42	0,77
K_2O	2,14	2,15	0,25
TiO_2	0,32	1,86	0,005
SO_3	2,35	6,02	0,018
LOI	21,84	3,42	-

To evaluate the effects of partially replacing natural sand with brick powder on concrete performance, 6 mixtures were prepared. One of these mixtures contained only natural sand (ordinary concrete), while the others incorporated 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 concrete mix design method, with a constant cement dosage of 350 kg per 1 m³ of concrete in all mixtures. Table 2 specifies the proportions of brick powder, sand, coarse aggregates, and cement. The abbreviation SB signifies the substitution of brick powder for natural sand. For instance, the code SB20 signifies a blend where brick powder replaces 20% of the natural sand.

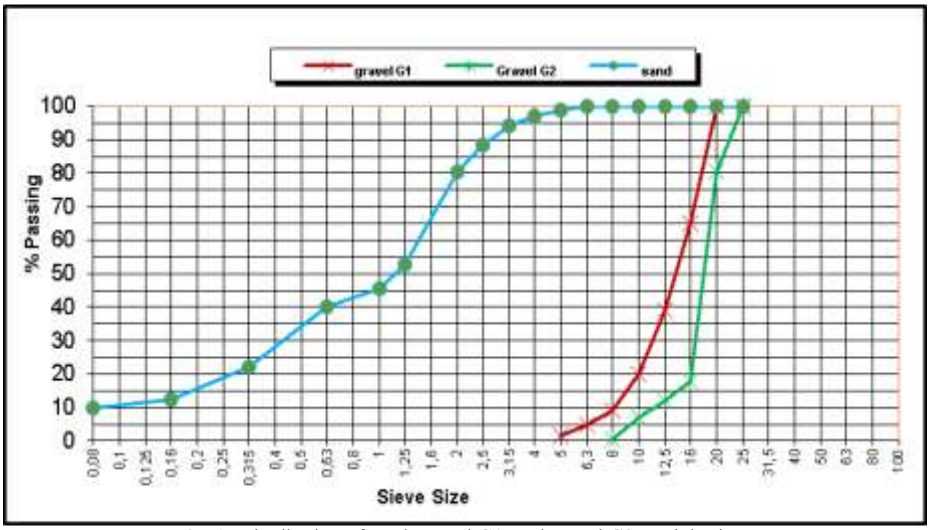

Fig. 1: Distribution of sand, gravel G1, and gravel G2 particle sizes.

Table 2: Mixture proportions with w/c= 0. 55.

Mix identification	BP %	Water (Kg/m^3)	Cement (Kg/m3)	G1 (Kg/m3)	G2 (Kg/m3)	Sand (Kg/m3)	BP (Kg/m3)
SB0	0	192	350	320	815	763	0
SB5	5	192	350	320	815	725	38
SB10	10	192	350	320	815	687	76
SB15	15	192	350	320	815	649	114
SB20	20	192	350	320	815	610	153
SB25	25	192	350	320	815	572	191

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. *Workability:* The study aimed to assess the impact of substituting a portion of natural sand with brick powder 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. The slump cone had conventional measurements: 300 mm in height, with a 200 mm base diameter and a 100 mm top diameter. All of the mixtures were tested for their workability by performing slump tests and measuring the slump values for the various concrete compositions.

Determination of Compressive and Split Tensile Strength of Concrete with Brick Powder as a Partial Sand Substitute: The concrete test specimens are prepared using the identical concrete utilized in the construction site. Cubes measuring 15 cm are ready for the cube test. Cylinders with 300 mm in height and 150 mm in diameter are produced for the cylinder test. Compressive strength is evaluated at ages 7, 14, 28, and 56 days according to NF EN 12390-3. Similarly, tensile strength is assessed at the same curing intervals, following the guidelines of NF EN 12390-6. The samples were cured under 100% relative humidity and a constant ambient temperature of 27 ± 2°C with water. Mix cement, fine aggregate, and brick powder on a watertight, non-absorbent surface until uniform. Next, distribute the coarse aggregate evenly and add water until the mixture becomes homogeneous and reaches the desired consistency. Molds must be cleaned and oiled before being filled with 5 cm-thick concrete for sampling. The test specimens are stored in a moist environment for 24 hours, after which they are marked, removed from the molds, and submerged in clear freshwater until shortly before the test. *Apparatus for Concrete Cube Test:* A compression testing machine (Figure 2), commonly known as a compressive strength testing machine, is a crucial device utilized to assess the compressive strength of materials, especially concrete and other construction materials. This machine applies axial loads to test specimens in a controlled and gradual manner to assess their ability to withstand compression forces without failing or deforming. It plays a crucial role in quality control and design in construction and material industries, ensuring that structures and materials meet the required strength standards. The load is applied gradually at a rate of 140 kg/cm2 per minute until the specimens fail. The compressive strength of the concrete is determined by dividing the load at failure by the specimen's area.

Fig. 2: CompressionTesting Machine

To test the concrete cube after curing, remove it from the water and wipe off excess water. After measuring the specimen to the nearest 0.2 mm, clean the testing machine's bearing surface. Place the specimen in the machine with opposite sides loaded and centrally aligned on the base plate. Start by gently rotating the movable portion to contact the specimen's top surface. Note the maximum load and unusual failures. Each age should test at least three specimens, and reject any that deviate more than 15% from the average. Concrete crushing strength must meet requirements based on the average strength of the three specimens.

The formula in equation 1 for calculating the compressive strength (f_c) of a material, such as concrete, is:

$$f_c = \frac{F}{A} \qquad (1)$$

Where: F is the applied force (in Newtons, N), A is the cross-sectional area over which the force is applied (in square meters, m²).

Compressive strength is typically expressed in megapascals (MPa).

Measurement of Ultrasonic pulse velocity with Brick Powder as a Partial Sand: Substitute: 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 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. The researchers in this study generated the pulse using a direct method to carry out this process. The pulse velocity is unaffected by the material's geometry and the form it travels through, but it does depend on the material's elastic properties. The receiver detects the beginning of longitudinal waves, 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.

RESULTS AND DISCUSSION

Impact of Brick Powder on Concrete Compressive Strength: Concrete samples were subjected to compressive strength tests. 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 3 displays the compressive strength values for each specimen. The results show the results for various sand substitutions, including brick powder at rates of 5%, 10%, 15%, 20%, and 25%.

Table 3: Compressive Strength of Concrete with Brick Powder Replacement.

Mix designation	Concrete's Compressive Strength (MPa)			
	7 days	14 days	28 days	56 days
SB0	18,50	23,88	27,94	30,72
SB5	19,26	24,06	29,16	32,04
SB10	23,47	27,46	35,08	36,84
SB15	22,73	26,95	34,56	36,34
SB20	22,44	25,14	33,58	35,28
SB25	20,18	23,36	31,48	33,34

As shown in Figure 3, the compressive strength typically rises as the percentage of brick powder increases. When compared to the control concrete, the mixture with 10% substitution (SB10) exhibited the best performance in terms of compressive strength, increasing by 26.66%, 14.99%, 25.55%, and 19.92% at 7, 14, 28, and 56 days, respectively. The pozzolanic reaction results in improved density and efficient pore filling, which explains this. As the substitution rate rises above 10%, cement's compressive strength decreases. This is probably because there is either an inadequate reaction or an excess of inert material that increases the porosity of the cement matrix. For optimal mechanical properties, a moderate replacement rate is recommended.

Impact of Brick Powder on Concrete Workability: The study assessed the feasibility of replacing natural sand with brick powder in concrete mixtures, starting with a

5% substitution and increasing in 5% increments up to a maximum of 25%. Figure 4 presents the substitution rates alongside the corresponding slump values, ranging from 43 to 75 mm, and demonstrates that as the proportion of sand replaced with brick powder (sb) increases, the workability of the concrete gradually decreases. The slump values range from 43 to 58 mm. The SB25 mix exhibits the most notable decrease, with a reduction of 42.66% in comparison to the control concrete. The irregular and angular shape of the particles in the concrete is responsible for increasing the water demand and decreasing the air content in the mixture. This hinders the movement of the fresh mixture by blocking the particles, ultimately reducing the slump of the concrete. The uneven surface of the concrete may also contribute to this, as it increases the resistance between the particles and requires more energy to promote movement and achieve the desired slump. Therefore, we recommend mitigating this impact by incorporating additional water or employing superplasticizers. Hebhoub (2011), Aliabdo (2014), Ashish (2018), and Vardhan (2019) all made identical observations.

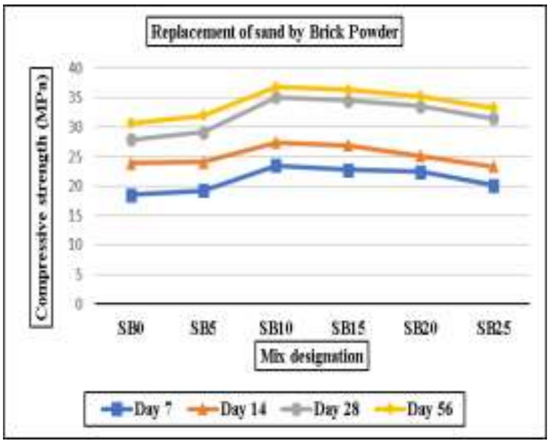

Fig. 3: Compressive Strength of Brick Powder Concrete

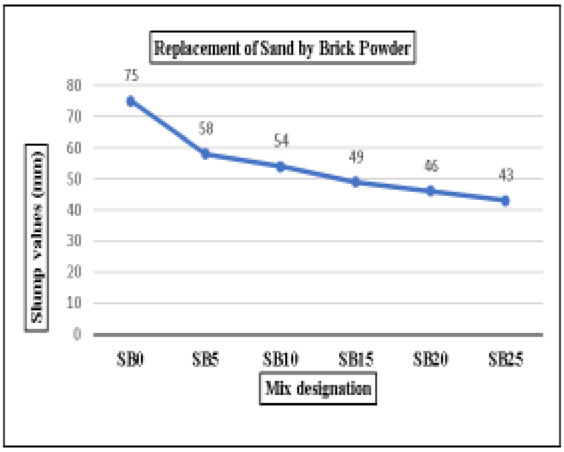

Fig.4: Workability of Brick Powder Concrete

Impact of Brick Powder 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 average result was obtained using three specimens. The splitting tensile strength results were obtained using the universal testing machine. Table 4 displays the splitting tensile strength values for each test specimen under various sand substitutions. The set of substitutions includes brick powder at rates of 5%, 10%, 15%, 20%, and 25%.

Table 4: Split Tensile Strength of Concrete with Brick Powder

Mix designation	Concrete's Split Tensile Strength (MPa)			
	7 days	14 days	28 days	56 days
SB0	2,76	3,09	3,43	3,60
SB5	2,74	3,04	3,39	3,48
SB10	2,85	3,12	3,73	3,82
SB15	2,82	3,02	3,58	3,67
SB20	2,78	2,95	3,52	3,56
SB25	2,66	2,85	3,37	3,45

According to Figure 5, substituting sand with 10% brick powder improves splitting tensile strength. We observe this improvement at different time intervals, showing increases of 3.26%, 0.97%, 8.74%, and 6.11% at 7, 14, 28, and 56 days, respectively, in comparison to conventional concrete.

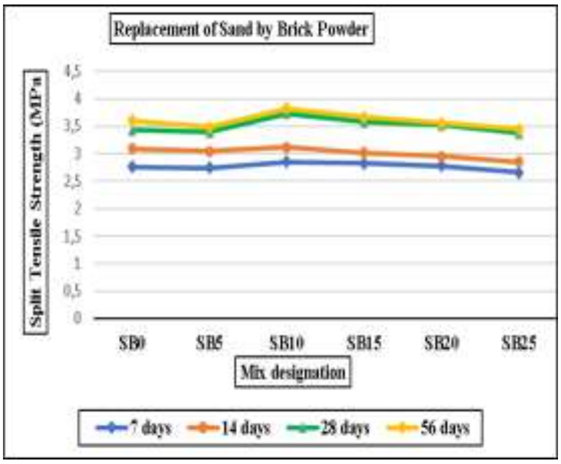

Fig .5: Split Tensile Strength of Brick Powder Concrete

Nevertheless, when the proportion of brick powder in the mixture rises from 15% to 25%, the tensile strength experiences a decline. Specifically, there are decreases of 3.62%, 7.76%, 1.74%, and 4.16% at 7, 14, 28, and 56 days, respectively, compared to the standard mixture. The findings indicate that substituting 10% of sand with brick powder can improve the splitting tensile strength of concrete at later stages, possibly because of enhanced cohesion within the concrete structure and higher compactness. Nevertheless, once the replacement rate reaches 25%, the strength of the concrete decreases at all ages tested, potentially due to heightened porosity or a deterioration in the bond quality among the concrete particles.

Impact of Brick Powder on the velocity of ultrasonic pulses: Table 5 displays data illustrating the compressive strength and ultrasonic pulse velocity (UPV) after 28 days for various concrete mixtures. These mixtures substitute brick powder (SB) for sand in varying proportions, ranging from 5% to 25%.

Table 5: Compressive Strength and UPV of Concrete with Brick Powder

Mix designation	UPV (Km/s)	Compressive Strength (MPa) at Day 28
SB0SFS0	3,68	27,94
SB5	3,64	29,16
SB10	3,62	35,08
SB15	3,54	34,56
SB20	3,46	33,58
SB25	3,38	31,48

As the proportion of brick powder replacing sand increases from 5% to 25%, the ultrasonic pulse velocity steadily decreases without impacting the concrete's quality. The ultrasonic pulse velocity values range between 3.38 km/s and 3.68 km/s. Brick powder, which is typically more porous and less dense than natural sand, causes a rise in porosity or a decrease in concrete density, resulting in a decrease in UPV. The compressive strength and ultrasonic pulse velocity of concrete incorporating fly ash were evaluated by comparing experimental results and empirical data, as depicted in Figure 6.

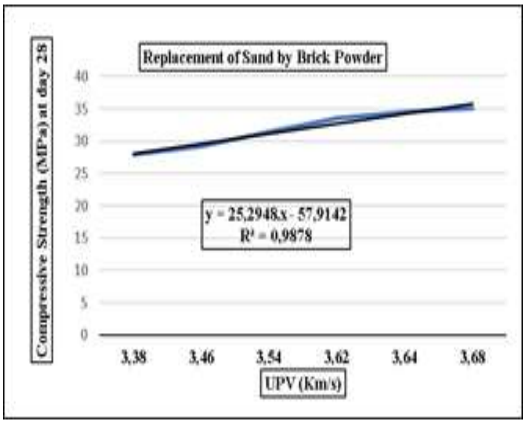

Fig.6: UPV and Compressive Strength Correlation in Concrete with Brick Powder Replacement

The study utilized the least squares method to examine the correlation between compressive strength (Rc) and the ultrasonic pulse velocity. An Equation 2 for determining compressive strength was derived from the obtained results, as shown below:

$$Rc = 25948.(uvp) - 57,9142 \quad \text{with} \quad R^2 = 0,9878 \quad (2)$$

Impact of Brick Powder on the Schmidt Rebound Hammer: By measuring the rebound of a spring-driven hammer that impacts the concrete surface, the Schmidt Rebound Hammer (Figure 7) assesses the compressive strength of concrete. This non-destructive testing method estimates concrete strength per NF EN 12504-2. Concrete cube specimens underwent testing on day 28.

Fig.7: Schmidt Rebound Hammer

The results of the rebound number for concrete mixtures with various sand substitutions are shown in Figure 8. Compared to the reference concrete SB0SFS0, the rebound number increased by 3.01%, 13.97%, 11.50%, 8.49%, and 6.58% for the SB5, SB10, SB15, SB20, and SB25 mixtures, respectively. The substitution of 10% of sand with brick powder resulted in the highest rebound number, which reached 41.6.

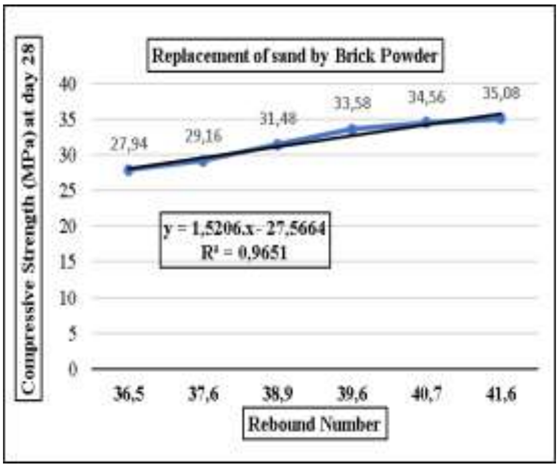

Fig .8: Rebound Number and Compressive Strength Correlation in Concrete with Brick Powder Replacement

These findings suggest that using substitute materials like brick powder instead of sand can improve the hardness and potentially prolong the lifespan of concrete within a specific range. The data suggests that a balanced approach, with moderate replacement levels, such as 10% brick powder, is most advantageous. Once the levels go beyond a certain point, the improvements either stop increasing or decrease slightly. This emphasizes the significance of accurately proportioning materials to achieve the desired mechanical performance in concrete applications. The method of least squares, a mathematical concept, was employed to conduct a regression analysis on the correlation between compressive strength and rebound number as measured by the Schmidt hammer when substituting sand with fly ash. The aim was to gather data that closely reflected the actual situation. The data in Figure 8, as well as Equation 3, were used to formulate the following formulas for determining compressive strength:

$$Rc = 1{,}5201.\ (Rn) - 27{,}5664 \quad \text{with} \quad R^2=0{,}9651 \quad (3)$$

Conclusion: The findings indicate that substituting 10% of sand with brick powder (BP) markedly enhances the mechanical properties of concrete. The compressive strength increases by approximately 29.94%, whereas the split tensile strength escalates by 8.74%. Nonetheless, despite these enhancements, workability diminishes by 42.66%. This situation shows a clear link between compressive strength, ultrasonic pulse velocity (UPV), and rebound number. This shows that non-destructive testing can accurately predict the quality of BP-modified concrete. In the future, it will be pertinent to enhance the workability of BP-based concrete without sacrificing its strength. Integrating additional recycled materials, such as fly ash or glass powder, may yield further insights into sustainable alternatives for concrete manufacturing. These findings highlight the necessity for concrete manufacturers to balance performance and sustainability. Construction techniques employing recycled materials, such as BP, are more ecologically sustainable as they diminish waste and the consumption of natural sand.

Acknowledgment: 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.

Declaration of Conflict of Interest: The authors declare no conflict of interest.

Data Availability Statement: Data are available upon request from the corresponding author.

REFERENCES

Adamson, M; Razmjoo, A; Poursaee, A (2015). Durability of concrete incorporating crushed brick as coarse aggregate. *Construct. Build. Mat.* 94: 426-432.

Aliabdo, AA; Abd-Elmoaty, AM; Hassan, HH (2014). Utilization of crushed clay brick in concrete industry. *Alexandria Engineer. J.* 53(1): 151–168.

Aliabdo, AA; Abd-Elmoaty, AM; Hassan, HH (2014). Utilization of crushed clay brick in cellular concrete production. *Alexandria Engineer. J.* 53: 119–130.

Anwar, A; Mohd, S; Husain, A; Ahmad, SA (2015). Replacement of cement by marble dust and ceramic waste in concrete for sustainable development. *Intern. J. Innov. Res. Sci. Engineer. Technol.* 2: 496–503.

Aruntas, HY; Gürü, M; Dayi, M; Tekin, I (2010). Utilization of waste marble dust as an additive in cement production. *Mat. Design.* 31: 4039–4042.

Arulmoly, B; Konthesingha, C; Nanayakkara, A (2021). Performance evaluation of cement mortar produced with manufactured sand and offshore sand as alternatives for river sand. *Construct. Build. Mat.* 297: 297(7):123784. DOI:10.1016/j.conbuildmat.2021.123784.

Ashish, DK (2018). Concrete made with waste marble powder and supplementary cementitious material for sustainable development. *J. Cleaner. Product.* 211: 716-729.

Belaïd, F (2022). How does concrete and cement industry transformation contribute to mitigating climate change? *Challenges*. https://doi.org/10.1016/j.rcradv.200084.

Bektas, F; Wang, K; Ceylan, H (2009). Effects of crushed clay brick aggregate on mortar durability. *Construct. Build. Mat.* 23: 1909–1914.

Binici, H; Shah, T; Aksogan, C; Kaplan, H (2008). Durability of concrete made with granite and marble as recycle aggregate. *J. Mat. Process. Technol.* 299–308.

David, D; Sebastian, B; Johny, MA (2017). Partial replacement of fine aggregate with crushed clay brick in cellular concrete. *Intern. J. Innov. Res. Sci. Engineer. Technol.* 6(5): 8218–8226.

Gaspard, U; Bienvenu, N; Habimana, UGB (2023). Effect of crushed clay brick as partial replacement of fine aggregate in concrete. *Mediterranean J. Basic. Appl. Sci.* 7(1): 90–99.

Hebhoub, H; Aoun, H; Belachia, M; Houari, H; Ghorbel, E (2011). Use of waste marble aggregates in concrete. *Construct. Build. Mat.* 25: 1167–1171.

Ibrahim, NM; Salahuddin, S; Amat, RC; Rahim, NL; Izhar, TNT (2013). Performance of lightweight concrete with waste clay brick as coarse aggregate. *APCBEE Procedia*, 5: 497–501.

Mehta, PK; Monteiro, PJM (2014). *Concrete: Microstructure, Properties, and Materials*, 4th edition.

Momoh, GO; Sundaram, H; Shanmugam, T; Jada, DT (2015). Influence of recycled concrete aggregate and crushed clay brick on mechanical properties of concrete. *Civil. Environ. Res.* 7(7): 67–72.

Nunung, M; Rizka, N; Muhammad, FRH; Putera, AMA; Yanuar, S (2022). Compressive strength of concrete using lightweight brick waste as the substitute for fine aggregate. *Intern. J. GEOMATE*, 23(98): 189–196.

Rashad, AM (2013). Metakaolin as cementitious material: History, sources, production and composition, a comprehensive overview. *Construct. Build. Mat.* 41: 303–318.

Sankh, AC; Biradar, PM; Naghathan, SJ; Ishwargol, MB (2014). Recent trends in replacement of natural sand with different alternatives. *J. Mech. Civil. Engineer.* 59–66.

Seeni, S; Madasamy, M; Chellapandian, M; Arunachelam, N (2023). Effect of silica fume on the physical, hydrological, and mechanical properties of pervious concrete. *Materials Today: Proceedings*, available online 3 April 2023.

Srivinas, P; Prasad, ASSV; Kumar, SA (2016). Experimental study on strength of concrete with partial replacement of fine aggregate with waste clay brick powder. *Intern. J. SART*, 2(8): 250–253.

Ullah, K; Qureshi, MI; Ahmad, A; Ullah, Z (2022). Substitution potential of plastic fine aggregate in concrete for sustainable production. *Struct.* 35: 622–637.

Vardhan, K; Siddique, R; Goyal, S (2019). Influence of marble waste as partial replacement of fine aggregates on strength and drying shrinkage of concrete. *Construct. Build. Mat.* 228, Article 116730.