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Enhancing Concrete Strength through partial substitution of Conventional Materials with Marble Powder, Crushed Marble, and Over-Burnt Bricks

Md. Hamjala Alam, Koyndrik Bhattacharjee, Arijit Kumar Banerji, Chanchal Das and Satabdi Saha[2]

Abstract

Due to modern innovations and developments in the construction industry, the use of natural aggregate is on the rise, and at the same time, solid waste production from the demolition of buildings is on the rise. It is for these reasons that the reuse of demolished constructional waste, such as over-burnt bricks, marble powder and crushed marble, has become a viable option for reducing both solid waste and the shortage of natural aggregates for making concrete. This research investigates the potential enhancement of concrete strength through the partial substitution of conventional constituents, namely cement, sand, and coarse aggregate, with environmentally friendly alternatives. Marble powder, derived from the waste of the marble industry, crushed marble and over-burnt bricks, known for their pozzolanic properties, were used as supplementary materials. The concrete prepared with these alternate products was tested for workability and strength. Experimental results reveal that the incorporation of these sustainable alternatives not only reduces the environmental impact of concrete production but also positively influences its mechanical properties. It was also observed that the properties of the concrete in a fresh and hardened state were impressive, although the results varied drastically from the original properties with the conventional materials. The findings highlight the potential for more resource-efficient and durable concrete mix designs, contributing to the broader goals of sustainable and eco-friendly construction.

Keywords: concrete strength, natural aggregates, over-burnt bricks, marble powder, crushed marble

Introduction

The construction industry is in continual work for innovative and sustainable solutions to address the challenges of urbanization, resource scarcity, and environmental impact. In this context, concrete, as the foundation of modern construction, is undergoing a transformation towards greater sustainability. Concrete is a widely used construction material composed of a mixture of cement, water, fine aggregates (such as sand), and coarse aggregates (such as gravel or crushed stone). When these components are combined and allowed to cure, they form a solid and durable material that is widely used in the construction industry for various applications. Concrete possesses a wide range of properties that make it a popular and versatile construction material. The properties of concrete can be influenced by the mix design, the quality of materials used, curing conditions, and other factors [1]. Concrete gains strength through a chemical reaction called hydration. When water is mixed with cement, a series of complex chemical reactions occur, leading to the formation of a hardened cementitious matrix. This process is what gives concrete its strength and durability over time. Proper consideration of these properties is essential during the design and construction of concrete structures to ensure their safety, longevity, and performance.

Concrete is an incredibly versatile construction material, and its uses are widespread in various sectors of the construction industry. Concrete is extensively used in constructing residential buildings, commercial structures, high-rise buildings, bridges, constructing roads, highways, airport runways, construction of dams, reservoirs, canals, and other water-related structures. The excellent compressive strength and ability to form durable linings make concrete a preferred material for constructing tunnels and underground structures. Concrete is often used to build retaining walls that prevent soil erosion and provide structural support for slopes and embankments. Pre-stressed and post-tensioned concrete is used in bridges, beams, and other structures to enhance their load-carrying capacity and reduce cracking. In coastal areas, concrete is used to construct seawalls and other structures to protect against erosion and flooding. Concrete is popular and widely used in the construction industry for several reasons, including its unique combination of properties and advantages over other construction materials [2]. Concrete production heavily relies on finite natural resources, and its carbon footprint is a significant concern in contemporary construction [3]. By harnessing the properties of waste materials like marble powder, crushed marble, and over-burnt bricks as partial replacements, we can potentially reduce the demand for raw materials and minimize the environmental consequences associated with concrete production. Moreover, such substitutions offer the prospect of not only enhancing concrete performance but also addressing issues related to the disposal of these waste materials.

Marble, a highly regarded material in the architectural world, has gained attention for its potential as a supplementary material in concrete production. A huge quantity of dust is produced during the cutting process of marble. About 25% of the original mass of marble is rendered into dust in the process of cutting [4]. Crushed marble is a natural stone aggregate produced by crushing marble rocks into smaller fragments. Also from the demolition of marble structures, smaller crushed marbles are obtained. Crushed marble can be used as an aggregate in concrete mixes, contributing to the overall strength and appearance of the concrete. Crushed marble exhibits properties conducive to concrete production, such as excellent compressive strength and durability [4]. The irregular shapes of crushed marble particles create interlocking effects within the concrete matrix, enhancing its strength characteristics. Research suggests that using crushed marble in concrete mixes can lead to improved mechanical properties, making it a sustainable alternative to traditional coarse aggregates [4-6]. Moreover, marble powder, a byproduct of the marble industry, is increasingly recognized for its pozzolanic properties. Researchers have explored its use as a partial replacement for cement in concrete mixes [7-9]. The fine particles of marble powder react with calcium hydroxide in the cement matrix to form additional binding materials. This pozzolanic reaction contributes to improved compressive strength, reduced permeability, and enhanced durability in concrete [8]. Several studies have demonstrated the positive effects of incorporating marble powder in concrete, particularly in terms of increasing strength and reducing the carbon footprint of cement production [7-9]. In addition, over-burnt bricks, also known as clinker bricks are a type of brick that has been subjected to excessive heat during the firing process in the kiln. This intense heat causes the clay to become vitrified, resulting in a darker colour and a distinct appearance. Over-burnt bricks are typically darker shades of red or brown and may have a rough, irregular surface texture. These bricks can be used for partial replacement of coarse aggregates as they also possess strength and density. These bricks, subjected to high temperatures during production, possess remarkable compressive strength and durability properties. Integrating over burnt bricks into concrete mixes has shown promise in enhancing concrete strength and promoting sustainability by reducing waste in the brick industry [10, 11].

From a review of the literature, composite cement displayed better strength at 28 days compared to 7 days, indicating a higher intensity of the material. The increased strength is attributed to the higher marble content, which also correlates with the amount of dust present in the marble. Consequently, the concrete incorporates marble dust, leading to reduced natural resource consumption and a positive impact on mitigating pollution and environmental harm [7-9]. Several researchers have worked on the idea of replacing fine aggregate in concrete with manufactured sand, crushed marble, and crushed basalt. The results have clearly demonstrated that the fine aggregates could be replaced up to a good percentage with these materials which, in other aspects are solid wastes, and the requisite properties and results are also obtained [10]. In a study, Ahmadi et al. [12] explored the use of waste from marble mining byproducts in structural concrete. Substituting marble waste with sand improved compressive and flexural strength. Increased replacement of recycled aggregates improved impact resistance, although no distinct water absorption trend was identified. Overall, research in this field emphasizes the potential advantages of these substitutions in terms of mechanical properties, durability, and environmental impact. However, further investigation and standardization are necessary to fully realize their potential and promote sustainable practices in the concrete industry. This paper explores a novel approach to enhance concrete strength by partially substituting conventional cement, sand, and coarse aggregate with marble powder, crushed marble, and over-burnt bricks. Through a series of experimental analyses and performance assessments, we aim to provide valuable insights into the feasibility of adopting these alternative materials for concrete production.

Materials

Coarse Aggregates and Sand

Coarse aggregates provide the bulk and stability to concrete mixes, enhancing their mechanical properties. The selection of coarse aggregates depends on factors like desired strength, durability, and workability.Sand is a crucial component in concrete mixes, serving as the fine aggregate that fills the voids between larger particles like gravel and contributes to the workability and cohesiveness of the mixture. The quality and characteristics of sand greatly influence the concrete's properties, such as compressive strength, durability, and finishing. The coarse aggregates (Fig. 1a) were obtained from the Pachami stone quarry in Birbhum, West Bengal; and the sand was obtained from Joydev, West Bengal. Table 1 shows the physical parameters of coarse aggregates and sand.

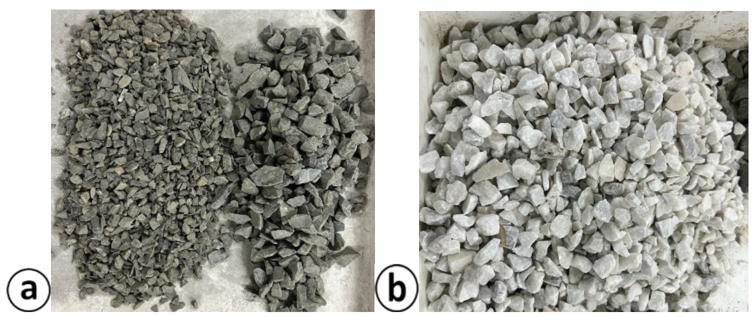

Figure-1: a) Coarse aggregate, b) Crushed marble

Table 1: Physical properties of coarse aggregates and sand

Parameter	Test Result of Coarse Aggregate	Test Result of Sand
Specific gravity	2.42	2.66
Bulk Density (kg/m^3)	1591	1480
Water Absorption (%)	1.29	3.62
Crushing Value (%)	22.60	NA
Impact Value (%)	14.10	NA
Fineness Modulus	NA	2.67

Cement

The cement utilised in this study is ordinary Portland cement of Grade 53.

OPC 53-grade cement (Fig. 2a) is known for its high compressive strength, making it an ideal choice for applications where structural stability is vital. Its superior strength attributes contribute to the durability and load-bearing capacity of concrete structures. Its properties is shown in Table 2.

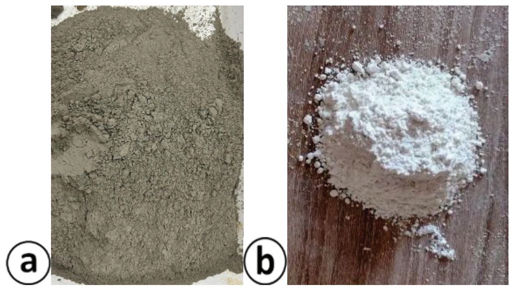

Figure-2: a) Cement, b) Marble powder

Table 2: Physical properties of cement

Parameter	Test Result
Specific gravity	3.08
Density (kg/m^3)	1591
Soundness (mm)	2
Fineness (%)	2
Initial Setting Time (minutes)	110
Final Setting Time (minutes)	240
Consistency (%)	33

Crushed Marble and Marble Powder

Crushed marble refers to marble stone that has been mechanically crushed or broken into smaller pieces. Crushed marble (Fig. 1b), when used as a partial replacement for conventional coarse aggregates in concrete, contributes to improved workability. Its angular and irregular particle shape creates a more interconnected matrix, enhancing the concrete's plasticity and making it easier to place and finish during construction. Marble powder (Fig. 2b) is a fine, dry substance that results from the process of grinding or pulverizing marble into a fine dust or powder. It is obtained as a byproduct during various marble processing operations, such as cutting, polishing, or shaping marble. Marble powder exhibits pozzolanic properties when used as a partial replacement for cement in concrete. This pozzolanic activity contributes to enhanced binding and the development of secondary cementitious compounds, resulting in improved compressive strength and durability.Table 3 shows the physical parameters of crushed marble and marble powder.

Table 3: Physical properties of crushed marble and marble powder

Parameter	Test Result of Crushed Marble	Test Result of Marble Powder
Specific gravity	2.20	2.53
Water Absorption (%)	1.06	0.97
Crushing Value (%)	27.67	NA
Impact Value (%)	17.56	NA
Colour	White	White

Over-Burnt Bricks

Over-burnt bricks are a distinctive type of brick used in the construction industry, known for their unique characteristics resulting from exposure to extremely high temperatures during the firing process. This intense heat treatment alters their physical and chemical properties, resulting in a harder and more durable material compared to regular bricks. Over-burnt bricks (Fig. 3) exhibit a dark, often blackened appearance due to the extreme heat they endure. Table 4 shows the physical parameters of over-burnt bricks.

Figure-3: Appearance of Over-burnt bricks

Table 4: Physical properties of over-burnt bricks

Parameter	Test Result
Specific gravity	2.67
Water Absorption (%)	10.08
Crushing Value (%)	31.2
Impact Value (%)	20.45
Colour	Dark Black

Composition of concrete and mix design

Concrete and mix design composition is a critical aspect of achieving this universal construction material's desired properties and performance. Concrete is typically composed of four primary components: cement, aggregates (comprising coarse and fine aggregates), water, and admixtures. The ratio of these ingredients, known as the mix design, is accurately determined to meet specific project requirements. The mix design takes into account factors such as desired compressive strength, workability, durability, and environmental conditions. It involves selecting the appropriate type and proportion of cement, aggregates, water-cement ratio, and the addition of admixtures. In this study, the concrete grades M20 is designed with four different combinations of materials. These combinations were determined based on the authors' experience and literature support.

The control sample, which served as a reference, did not include any recycled aggregates and marble powder in its composition. The remaining three mixtures underwent evaluation, with varying percentages of recycled crushed marble, marble powder and over-burnt bricks replacing fine aggregates and coarse aggregate. The replacement percentages for recycled marble aggregates were set at 0%, 5%, 10%, and 15% of the total fine aggregate content. The mix design was calculated in accordance with IS: 456 [13]. In accordance with the mix design calculations, all concrete ingredients were precisely blended together using manual mixing techniques. Once the mixing process was finalized, the concrete casting phase was initiated, and the entire mixing process concluded within a time frame of 10 to 15 minutes. The mixture ratios are detailed in Table 5 and 6.

Table 5: Proportions of the concrete compositions

Items	**Case-1**	**Case-2**	**Case-3**	**Case-4**
Cement	0	5	10	15
Fine Aggregate	0	10	15	5
Coarse Aggregate	0	15	5	10

Table 6: Mix Design of Concrete

Items	Case-1	Case-2	Case-3	Case-4
Cement (kg)	3.2	3.04	2.88	2.72

Marble Powder (kg)	0	0.16	0.32	0.48
Fine Aggregate (kg)	5.73	5.15	4.88	5.44
Crushed Marble (kg)	0	0.57	0.86	0.28
Coarse Aggregate (kg)	10.5	8.92	9.98	9.45
Over burnt bricks (kg)	0	1.57	0.52	1.05

Case 1: C : F.A. : C.A. = 1 : 1.82 : 3.34
Case 2: C : M.P : F.A : C.M : C.A : O.B = 1 : 0.05 : 1.69 : 0.18 : 2.93 : 0.18
Case 3: C : M.P : F.A : C.M : C.A : O.B = 1 : 0.11 : 1.69 : 0.29 : 3.46 : 0.18
Case 4: C : M.P : F.A : C.M : C.A : O.B. = 1 : 0.17 : 2 : 0.10 : 3.47 : 0.38
C: cement; MP: marble powder; FA: fine aggregate; CM: crushed marble; CA: coarse aggregate; OB: over-burnt bricks

Test Methods

The need for assessing the workability of concrete through the slump cone test arises from its fundamental importance in construction. Workability refers to the ease with which concrete can be mixed, placed, compacted, and finished while maintaining its desired properties. The workability of concrete is a critical aspect evaluated through the slump cone test in the context of enhancing concrete strength by partially substituting conventional materials. During the test, a slump cone is filled with freshly mixed concrete in layers and compacted. Subsequently, the cone is carefully lifted, and the amount by which the concrete settles or slumps is measured. It ensures that while following improvements in concrete strength, the material remains practical for construction purposes. The slump cone test, in this case, aids in promoting the right balance between enhanced strength and workability, ultimately contributing to the successful and efficient execution of construction projects. In addition, in the context of enhancing concrete strength through the partial substitution of conventional materials with marble powder, crushed marble and over-burnt bricks, conducting a compressive strength test is crucial. The need for this test arises from the fundamental requirement of ensuring that the modified concrete mixture maintains or exceeds the minimum strength standards expected for the intended application. By incorporating unconventional materials such as marble powder, crushed marble, and over-burnt bricks into the mix, it becomes imperative to validate the structural competence of the resulting concrete. The compressive strength of cubes (Fig. 4), with dimensions of 15 × 15 × 15 cm, was determined according to the IS 516 standard at a curing period of 28 days. The specimens are placed in a compression testing machine, commonly known as the universal testing machine. The test machine applies a gradually increasing axial load to the specimen in a controlled manner until the concrete fails. Compressive strength testing assists in optimizing the mix design by modifying the proportions of conventional and unconventional materials to achieve the desired strength characteristics.

Figure-4: Compressive strength test

Results and Discussions

The effect of partial replacement of cement with marble powder has been observed. The table below depicts the effect of partial replacement of cement with marble powder.

Table 7: Effect of partial replacement of cement with marble powder

Percentage replacement by weight	Compressive strength (MPa)	
	7 days	28 days
0%	11.35	26.9
5%	12.93	29.62
10%	13.09	30.4
15%	12.50	26.1

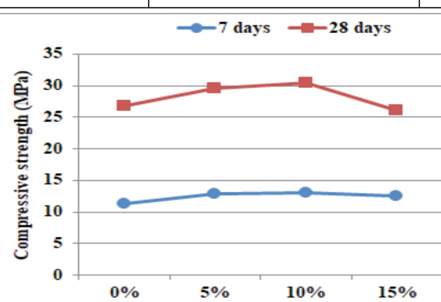

Figure-5: Compressive strength at various percentage replacement of cement with marble powder

When fine aggregate was partially replaced with crushed marble, then it was seen that maximum compressive strength was obtained at 15% replacement of fine aggregate with crushed marble. The data has been presented in tabular form below. The same data was plotted in graphical form in Figure 5. Both curves for 7 days and 28 days compressive strength, the natures of curves are increasing. So 15% replacement of crushed marble with the fine aggregates gives the maximum strength.

Table 8: Effect of partial replacement of fine aggregate with crushed marble

Percentage replacement by weight	Compressive strength (MPa)	
	7 days	28 days
0%	9.45	23.5
5%	11.65	26.4
10%	12.10	27.85
15%	12.90	28.4

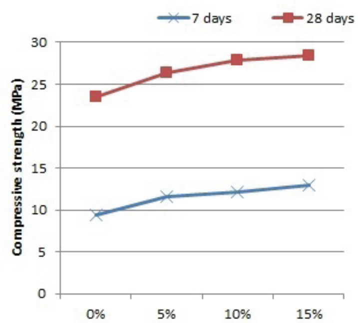

Figure-6: Compressive strength at various percentage replacement of fine aggregate with crushed marble

As it is evident from the above table that 7 day compressive strength test, up to 10% replacement of cement with crushed marble powder. Beyond this the compressive strength shows a down fall. So, the partial replacement of cement with 10% crushed marble powder is considered the optimum mix.

Coarse aggregates were partially replaced with over burnt bricks. Also the compressive strength was obtained for various percentage replacement of fine aggregate with crushed marble. Both curves for 7 days and 28 days compressive strength, the natures of curves are decreasing beyond 5%. So 5% replacement of coarse aggregates with over burnt bricks gives the optimum result.

Table 9: Effect of partial replacement of coarse aggregate with over burnt bricks

Percentage replacement by weight	Compressive strength (MPa)	
	7 days	28 days
0%	8.35	22.50
5%	11.25	24.30
10%	9.10	21.85
15%	9.50	21.40

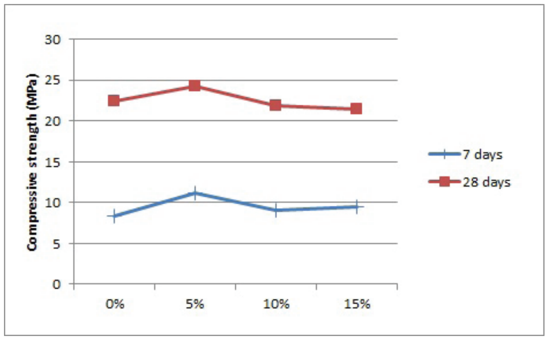

Figure-7: Compressive strength at various percentage replacement of coarse aggregate with over burnt bricks

The results obtained after mixing marble powder, crushed marble and over burnt brick is being presented here. The table below shows results from slump cone test for measurement of workability in mm.

Table 10: Test results from slump cone test for workability in mm

Items	% replacement (MP + CM + Over burnt Brick)	Over burnt bricks (kg)
Case 1	0 + 0 + 0	100
Case 2	5 + 10 + 15	90
Case 3	10 + 15 + 5	105
Case 4	15 + 5 + 10	96

The plot of slump height (mm) for various cases of mix design viz. case 1 , case 2, case 3 and case 4 have been depicted in the graph below.

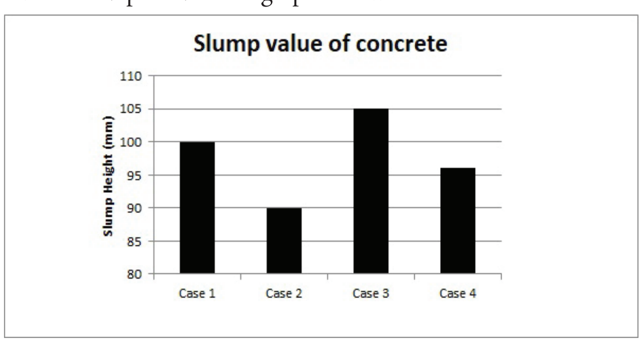

Figure-8: Slump values of concrete

Table 11: Compressive strength test results for different cases at 7 days and 28 days

Items	7 day	28 day
Case 1	11.35	26.9
Case 2	12.93	29.62
Case 3	13.09	30.4
Case 4	12.5	26.1

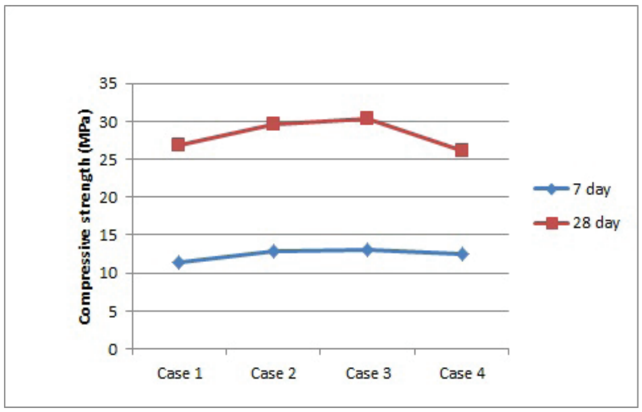

Figure-9: Compressive strength at test results for different cases at 7 days and 28 days

So, it is observed that for Case 3, the compressive strength is maximum at 7 days as well as 28 days which is 15.33 % and 13.01% more than original strength respectively.

Conclusions

This study explores the potential of enhancing concrete strength by partially substituting conventional materials with three alternative components: marble powder, crushed marble, and over-burnt bricks. These materials, often overlooked or considered waste, are repurposed to create a more robust and environmentally friendly concrete mixture. The research investigates their impact on workability and compressive strength, providing valuable insights into optimizing concrete mix designs for both performance and sustainability. The incorporation of these alternative materials into concrete mixtures has shown a positive impact on workability. Despite concerns about potential irregularities in particle size and shape, the concrete remains highly workable, allowing for efficient placement and construction processes. Furthermore, one of the most significant findings of this study is the substantial increase in compressive strength. Concrete specimens with partial substitutions consistently exhibited higher compressive strength values compared to the control group, demonstrating the effectiveness of these materials in improving structural performance. Beyond the technical aspects, this research highlights the sustainability benefits of utilizing waste materials like marble powder and over-burnt bricks in concrete production. By repurposing these materials, we reduce waste disposal and resource consumption, contributing to more eco-friendly construction practices.

REFERENCES

1. Yucel H.E., Dutkiewicz M., and Yildızhan F., The Effect of Waste Ballast Aggregates on Mechanical and Durability Properties of Standard Concrete, Materials, Vol. 16, Issue 7, 2023, pp. 2665.
2. Sharma A., Chauhan A.S., Jain A., and Jangid, J.B., Utilization of Waste Material to Make Green Concrete, Int. Res. J. Eng. Technology, Vol. 7, 2020, pp. 2666-2669.
3. Banerji A.K., Topdar P., and Datta A.K., Structural Performance of Cement-treated Base Layer by Incorporating Reclaimed Asphalt Material and Plastic Waste, Jordan Journal of Civil Engineering, Vol. 17, Issue 2, 2023, pp. 259-271.
4. Basaran B., Kalkan I., Aksoylu C., Özkılıç, Y.O., and Sabri, M.M.S., Effects of waste powder, fine and coarse marble aggregates on concrete compressive strength, Sustainability, Vol. 14, Issue 21, 2022, pp. 14388.
5. Kumar M.A., Balaji S., Selvapraveen, S., and Kulanthaivel, P., Laboratory study on mechanical properties of self compacting concrete using marble waste and polypropylene fiber, Cleaner Materials, Vol. 6, 2022, pp. 100156.
6. Ulubeyli G.C., Bilir T., and Artir R., Durability properties of concrete produced by marble waste as aggregate or mineral additives, Procedia engineering, Vol. 161, 2016, 543-548.
7. Singh M., Choudhary K., Srivastava A., Sangwan K.S., and Bhunia D., A study on environmental and economic impacts of using waste marble powder in concrete, Journal of Building Engineering, Vol. 13, 2017, pp. 87-95.
8. Wang Y., Xiao J., Zhang J., and Duan Z., Mechanical behavior of concrete prepared with waste marble powder, Sustainability, Vol. 14, Issue 7, 2022, pp. 4170.
9. Khan K., Ahmad W., Amin M.N., Ahmad A., Nazar S., Alabdullah A.A., and Arab A.M.A., Exploring the use of waste marble powder in concrete and predicting its strength with different advanced algorithms, Materials, Vol. 15, Issue 12, 2022, pp. 4108.
10. Apebo N.S., Shiwua A.J., Agbo A.P., Ezeokonkwo J.C., and Adeke P.T., Effect of

Water-Cement Ratio on the Compressive Strength of gravel-crushed over burnt bricks concrete, Civil and Environmental Research, Vol. 3, Issue 4, 2013, pp. 74-81.

11. Praveen K., Sathyan D., and Mini K.M., Study on performance of concrete with over-burnt bricks aggregates and micro-silica admixture, In IOP Conference Series: Materials Science and Engineering, Vol. 149, Issue 1, 2016, pp. 012061.
12. Ahmadi M., Abdollahzadeh E., and Kioumarsi M., Using marble waste as a partial aggregate replacement in the development of sustainable self-compacting concrete, Materials Today: Proceedings (2023).
13. IS 456. (2000). Indian Standard Plain and Reinforced concrete-code of conduct, Bureau of Indian Standards, New Delhi.
14. IS 516. (2004). Indian Standard Code for Methods of Tests for Strength of Concrete, Bureau of Indian Standards, New Delhi.

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