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Effect of partial replacement of Portland cement with waste marble powder on the workability and mechanical properties of concrete

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Abstract
Cement consumption is rapidly increasing worldwide. As a result, the use of industrial waste in concrete is becoming more common—both as a partial replacement for cement and as part of broader efforts in waste management and conservation of natural aggregates and resources. Waste marble powder (WMP) poses environmental threats not only to ecosystems but also to the physical, chemical, and biological components of the environment. This study investigates the use of WMP as a partial replacement for ordinary Portland cement (OPC) in freshly mixed concrete. Mixes containing 0%, 5%, 10%, 15%, and 20% WMP were evaluated, and their workability was assessed using the slump cone test. Mechanical properties, including compressive strength, flexural strength, and split tensile strength, were measured at curing ages of 7 and 28 days. The results showed that as the WMP content increased, the workability of the concrete decreased. However, mechanical properties improved with the addition of up to 10% WMP, after which a decline in strength was observed. Overall, the findings suggest that replacing OPC with WMP up to 10% offers a sustainable option for concrete production, reducing cement consumption while maintaining acceptable workability and mechanical performance.

Keywords
Waste marble powder, Ordinary Portland cement, Concrete workability, Compressive strength, Sustainable concrete, partial cement replacement.

1.Introduction
Marble is a crystalline metamorphic rock primarily used for monuments, flooring, and ornamental works [1–3]. The significance of the marble industry has increased significantly over the past two decades. A significant quantity of marble is produced in countries such as the US, China, France, and India [4]. About 30% of marble is wasted during processing due to its smaller size and irregular shape. Every year, thousands of tons of waste marble powder (WMP) is processed worldwide during the extraction process. Concrete is currently the most crucial ingredients utilized in the construction industry [5–7]. It plays a vital role in the development of structures worldwide and significantly impacts the overall cost of structure.

Cement is a key ingredient in concrete and requires a substantial amount of energy during its production. Nowadays, the use of industrial waste, such as, in concrete is increasingly being adopted as part of waste management practices.

In recent years, the increase in construction has resulted in higher cement consumption, causing a rapid depletion of accessible natural resources. Excessive costs are incurred when cement is required in large quantities [8]. The production of cement also contributes to CO_2 emissions and excessive environmental pollution [9–12]. A large quantity of WMP is produced during marble quarrying, processing, and polishing. The WMP is often repurposed as an alternative to cement or aggregate in concrete manufacturing, mostly in the dust form [13]. It has been observed that the inclusion of WMP significantly impacts dimensional stability and durability when used as a partial replacement for cement [14–16]. WMP is now being widely used in various structural applications, including reinforced

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cement concrete, owing to its beneficial effects on several concrete properties and its growing popularity in sustainable construction. These components may be used to produce green concrete, which should be encouraged since it directly contributes to energy saving and environmental issues. The introduction of 10-15% WMP in place of cement can provide concrete mixes with satisfactory results based on the marble waste and cement's particle size distribution [17]. The replacement of up to 15% with WMP results in lower emission of CO_2. From the literature, using waste from the mining and processing of marble has led to economies in the manufacturing of concrete while conserving natural resources and lowering environmental hazards related to the unrestricted disposal of discarded materials [18].

The objective of this study is to produce concrete by partially replacing cement with WMP up to 15%. To achieve this, experimental investigations were conducted to evaluate the workability, compressive strength, and split tensile strength of concrete incorporating WMP as a substitute for cement. The effects of varying percentages of WMP and ordinary Portland cement (OPC) on the compressive strength and workability of concrete were systematically analyzed.

The remainder of the paper is organized as follows: Section 2 presents the literature review; Section 3 outlines the methodology; Section 4 discusses the results; and Section 5 provides the conclusions of the study.

2.Literature review

The latest related work has been discussed in this section. Ma et al. [4] has proposed using marble dust (MD) as cement or aggregate replacement in mortar or concrete, but the benefits are limited. A new method has been developed to use inert waste or fillers as paste replacement. The authors applied this method to mortar mixes, resulting in improved carbonation and water-resistance, reduced shrinkage strain rate, and 33% reduction in cement content. The study demonstrates the potential of WMP in improving cement performance.

Ozkilic et al. [7] has conducted experimental studies on shear-deficient reinforced concrete beams (RCBs) considering the parameter different percentages of WMP and stirrup spacing. The stirrup spacing varied from 160 mm to 200 mm and WMP was taken up to 20% as admixture. It has been seen that the shear strength of RCBs with the stirrups spacing of 160 mm and 200 mm with the MD admixture used up to 20% meets the design regulations and functions exceptionally well with a maximum success rate of 85%. The substitution of 5% WMP in the concrete had negligible effects on the concrete compressive strength while at 10% or above, it has negative impacted.

Ince et al. [9] showed that adding WMP to Pozzolanic concrete enhances its long-term mechanical properties and durability. The study used specimens with cement and silica fume binder and evaluated physical properties over a year. The inclusion of MD significantly improved salt crystallization and freeze/thaw resistance, with small decrease in compressive strength. This highlights the beneficial properties of MD on durability. The cost-efficiency analysis revealed that the use of MD and silica fume in concrete can reduce embodied CO2 emissions, improving the economic and environmental impact.

Suresh and Revathi [10] used WMP to lessen the use of energy sources and natural resources, as well as the environmental pollution load. This study looks considering the potential of utilizing marble sludge dust as a partial substation for cement in concrete preparation. Researchers looked into how the varying WMP contents affected the mechanical and physical characteristics of uncured and cured mixes of hardened concrete.

Chawla et al. [12] replaced river sand with quarry dust and marble waste in concrete to improve strength and durability. The experiment involved six concrete mix proportions and found that the complete substitution of fine aggregate (FA) with marble waste improved compressive strength and flexural strength by 84% and 18.6%, respectively. The mixes were less reactive to aggressive agents, attributed to the ability of marble fines to impart cohesiveness even at lower water content.

Chaudhary and Sinha [19] investigated the impact of Nano-silica (NS) and water-binder (W/B) ratio on concrete's durability in an aggressive chemical environment. It conducted acid, sulphate, and chloride resistance tests on concrete specimens exposed to varying concentrations of NS. Results showed NS inclusion significantly improved concrete resistance, with NS inclusion having a more significant effect than the W/B ratio. Further tests were conducted to assess mix durability and morphology.

Khan and Dhanoa [20] used WMP in concrete instead of sand to recycle natural resources. Concrete's mechanical properties and durability are enhanced by this process, giving it more strength and longevity. Destructive and non-destructive testing were employed in the study to evaluate the findings.
Hussain et al. [21] in their study investigated the use of porcelain powder (P) and marble (M) as cement substitutes in the manufacturing of cement mortar. Thirteen mixes with varying cement quantities were substituted in the study, which looked at the mechanical and microstructural properties of the combinations. The mixes of 10% M, 10% P, and 5% M+5% P produced the best results. According to the study, M and P can be utilised as substitute resources to create sustainable and high-performing concrete. Because both the C-H and M-P phases formed, the investigation also showed a dense and compacted microstructure.

Rajesh et al. [22] Used WMP for their investigated as a sustainable alternative in the manufacturing of concrete. According to the study, adding WMP to concrete formulations can result in more affordable, high-strength concrete, improving sustainability in building methods. This study emphasizes the significance of environmentally friendly building material advances and the requirement for sustainable substitutes to satisfy the demands of infrastructure expansion.

Liu et al. [23] studied explored using WMP as a precursor in alkali-activated binders. It uses WMP as the only precursor and conducts macroscopic and microscopic characterization tests. Variables include the alkali activator modulus, Na_2O dosage, and curing conditions. Results show that increasing Na_2O dosage shortens the setting time, reduces fluidity, and improves strength. The alkali activator modulus prolongs the setting time, fluidity increases and decreases, and strength decreases. High-temperature curing is beneficial for early strength development.

Mascarin et al. [24] study explores the production of low-CO_2, Portland-free cement binders by reacting calcined clays in alkaline solutions. The study found that replacing calcined clay with 30% waste marble can reduce the amount of alkaline activator and its embodied CO_2. This approach can reduce the CO_2 footprint of cement and upcycle hazardous waste from the dimension stone industry. The study also discussed the role of calcium carbonate and carbonation reactions occurring through atmospheric CO_2 uptake.

Messaoudene et al. [25] performed an experimental endeavor that aims to investigate how the fineness of the marble affects the rheological behavior of regular concrete in both its fresh and hardened states. The International Center for Aggregate Research (ICAR) rheometer was used to measure the concrete's rheological characteristics and calculate its compressive and flexural strengths. The outcomes demonstrated that the ideal level of marble powder (MP) was 5% and did not require a high level of grinding. The concrete maintained its mechanical and rheological qualities while it was still its fresh state.

A study by Kuoribo and Mahmoud [26] was conducted to fill a gap in research on WMP in sustainable concrete production by scientometrically reviewing existing documents in the Scopus database. The analysis identifies key areas, publications, keywords, scholars, and citations. It also discusses the use of WMP in sustainable construction, determining the optimal percentage replacement and performance of other recycled aggregates. The study also identifies knowledge gaps and future research directions, enhancing the motivation for in-depth knowledge on WMP reuse in sustainable construction applications.

Sufian et al. [27] studied that WMP was intensively used in the construction industry and contributes to environmental degradation due to its irregular geometry and small dimensions. They utilized different percentages of WMP to make of clay bricks.105 samples were prepared to assess the performance of the marble clay bricks, including water absorption, bulk density, apparent porosity, salt resistance, and compressive strength. The bricks were found to be 1.3-19.9% lighter than conventional bricks and had adequate compressive strength. The empirical equations showed good agreement with the experimental results, suggesting that the use of WMP in construction not only lowers project costs but also reduces soil erosion and water contamination.

An update on the utilization of WMP in concrete and the enhancement of concrete strength in a cost-effective manner was provided by Pal et al. [28]. WMP was incorporated into M20 grade concrete at varying percentages - 0%, 5%, 10%, 15%, 20%, 25%, and 30% to partially substitute cement by weight. Each concrete mixture maintained a consistent water-to-cement ratio of 0.50. The concrete specimens, both cubes and cylinders, were tested for split tensile and compressive strengths after

7 and 28 days of proper curing. The experimental results indicated that the inclusion of WMP in cement can elevate the compressive and split tensile strengths of concrete by as much as 10%.

Khaliq et al. [29] conducted a series of laboratory tests to assess permeability, along with physical and mechanical characteristics. Concrete specimens were prepared with varying proportions of WMP, ranging from 5% to 30% of cement, sourced from two different locations. A 5% substitution of cement with WMP resulted in a reduction of compressive strength by 6% and tensile strength by 12%. These parameters continued to decline as the WMP content increased to 30%. The most favorable outcomes were achieved with a 10% replacement of cement with WMP. Notable enhancements in consistency and permeability were noted and the use of WMP as a substitute for cement. The literature review focuses on the replacement of marble waste as a substitute for various ingredients in the production of cement concrete, aiming to enhance the properties of both fresh and hardened concrete under different strength and durability parameters. It was found that waste marble can be effectively utilized as a filler in concrete; however, further research has been recommended to assess the need for incorporating pozzolanic materials to achieve high durability. A statistical model was developed using the response surface methodology (RSM) for optimization. To the best of the authors' knowledge, no similar study is currently available in the public domain.

3.Materials and methods

In this section, the study was carried out at NSIT, Bihta, Patna to determine physical properties and the chemical composition of materials used in concrete has been discussed. Moreover, experimental procedure, mix design and environmental conditions has also been mentioned in this part [30].

3.1Cement

OPC is utilized for all proportions of concrete mixes. The chemical composition of OPC given in *Table 1* has been used for the preparation of concrete mix. It was found that oxides of various key minerals like calcium (CaO), silica (SiO_2), aluminium (AL_2O_3), ferrous (Fe_2O_3) and magnesium (MgO) are within the stipulated range. The physical properties of OPC have been calibrated in the laboratory and presented in *Table 2*.

Table 1 Chemical composition of OPC

Chemical Component of Cement	LOI	SO_3	K_2O	Na_2O	MgO	CaO	Fe_2O_3	Al_2O_3	SiO_2
% Value of Component	1.90	2.36	0.53	0.28	1.76	62.85	3.92	5.42	20.98

Table 2 Physical properties of OPC

Setting time		Expansion (mm)	Normal consistency (%)	Specific gravity	Color
Initial (min)	**Final (min)**				
110	260	4	28	3.15	Gray

3.2Marble powder (MP)

Dolomite $\{CaMg(CO_3)_2\}$ or calcite $(CaCO_3)$ make up the majority of marble. It frequently includes impurities such as iron oxides, silica, graphite and pyrite [31–33]. Marble interacts with acids including hydrochloric acid to form soluble calcium salts, CO_2 gas, and water. MP exists in a variety of colours, although its most frequent colour is white [16, 34]. There are interconnecting calcite crystals and medium-sized grains in the MP. Marble is surprisingly hard for a material consisting of a soft mineral calcite ($CaCO_3$). Marble has a unique appearance due to its granoblastic and granular texture [35]. The waste marble was collected from various construction sites in Bihta (Patna), India, and ground into powder form using the Los Angeles Abrasion machine. The resulting material was then sieved through mesh sizes of 90, 80, 75, 63, and 53 microns before being added to the concrete mix. The fineness of the powder was determined using the Air Blaine Permeability test to calculate the Fineness Modulus (FM). The FM of different percentages of WMPs was found to be 1735 cm^2/g, 1957 cm^2/g, 2092 cm^2/g, 2396 cm^2/g, and 2667 cm^2/g respectively. The chemical composition and physical properties of WMP have been calibrated in the laboratory by the author. The percentage of oxides of chemical components and physical properties of WMP has been presented in *Table 3* and *Table 4* respectively.

Table 3 Chemical composition of WMP

Component of WMP	SiO_2	CaO	SO_3	K_2O	Na_2O	MgO	Fe_2O_3	Al_2O_3	LOI
Percentage	3.90	31.23	0.10	1.91	1.64	17.94	2.05	1.06	39.68

Table 4 Physical properties of WMP

Specific gravity	Color	Form	Retained on IS sieve (90µ) (%)	Hardness (Mohr's scale)	Water absorption (%)
2.68	White	Powder	2.9%	3	0.98

3.3Aggregate

The normal river sand termed FA is readily available at the store and conforms to Zone II. In terms of weight, CA contributes 65 % of 20 mm passing aggregate and 35 % of 10 mm passing aggregate. The physical properties of CA and FA is given in *Table 5*. Also, the grading of FA is given in *Table 6*. This table represents a sieve analysis of FAs, which is used to determine the particle size distribution of a sample. The pan at the bottom of the sieve stack collects the finest particles that pass through all the sieves. Fineness modulus (286.6/100=2.86) is one of the most important factors in the construction business. It assists engineers in determining the degree of fineness or coarseness of FA which influences the strength and workability of concrete mixtures [36].

Table 5 Physical properties of CA and FA

Properties	Specific gravity	Bulk density	Water absorption	Flakiness index	Elongation index	Fineness modulus
FA	2.68	1.617	0.97	-	-	2.86
CA	2.79	1.85	0.54	11.7	9.8	6.75

Table 6 Grading of FA

Sieve size	Mass retained (gm)	Mass cumulative retained (gm)	Mass cumulative retained in %	Mass cumulative passing in %	IS Zone II
4.75 mm	-			100	100
2.36 mm	45	45	4.5	95.5	75-100
1.18 mm	235	280	28.0	72.0	55-90
600 µ	358	638	63.8	36.2	35-59
300 µ	282	920	92.0	8.0	8-30
150 µ	65	985	98.5	1.5	0-10
Pan	12	997	99.8	0	0

3.4Water

The concrete mix was prepared with freshwater whose pH value was found to be 7.0+/- 1. Curing of concrete has also been done with the same pH-valued water.

3.5Environmental conditions

By using WMP in place of OPC in the concrete mix, the concrete reactions to the environment during testing and curing may change dramatically.

3.5.1Temperature

Because of the higher rates of chemical reactions, higher temperatures (above 25°C) may initially speed up the process of hydration. This causes rapid evaporation of water may impede the overall progress of hydration resulting in slow growth of strength. Rapid moisture loss with greater replacement levels of WMP increases the drying shrinkage causing cracking in the concrete [37]. At lower temperatures (below 10°C), the hydration of concrete slows down dramatically resulting in a delay in strength gain and an increased curing period. Low temperatures increase the stiffness of the concrete mix and decrease its flowability, thereby negatively affecting workability.

3.5.2Humidity

Because moisture evaporation is delayed, prolonged high humidity (over 70%) can result in maximal strength growth, full hydration, and reduced drying shrinkage. The increased absorption of water and the leaching of calcium carbonate ($CaCO_3$) could potentially harm the long-term durability over an extended period. Significant increases in drying shrinkage and reduction in strength promote cracking and potential structural damage. Hydration may be hampered at low humidity levels (below 50%)

because of the quick loss of moisture. Overall, the effects of humidity and temperature on concrete containing WMP are complicated and rely on many variables which include curing techniques, mix composition, replacement percentage etc. To guarantee the intended performance and durability of concrete containing WMP, careful evaluation of these aspects and suitable modifications in curing and testing techniques are necessary [10,16, 38].

3.5.3Sulphate attack

Both marble and cement paste are susceptible to reacting with sodium sulfate (Na_2SO_3) [39]. The sulfate (SO_3) concentrations in cement exceeding 1 g/L cause calcium hydroxide $(Ca(OH)_2)$ to transform into gypsum, which is sparingly soluble resulting in a decreased pH value, followed by reduced stiffness and strength. The gypsum is expandable, causing fractures and a decrease in cohesiveness. The sulfates target the tricalcium aluminate (C_3A) molecules that exist as calcium mono-sulphate hydrate $(3CaO.Al_2O_3.CaSo_4.12H_2O)$ at lower concentrations.

3.6Experimental procedure

The flow chart of the experimental work involve in this research work have been presented in *Figure 1*. In this study, concrete mix of M25 grade was prepared by considering the five different percentage 0%, 5%, 10%, 15%, and 20% of WMP by weight.

The WMP was used to partially replace the cement in a concrete mix. All the different five percentages of WMP were passed through the sieves of 90µ, 80µ, 75µ, 63µ, and 53µ. The mix proportion have shown in *Table 7*.

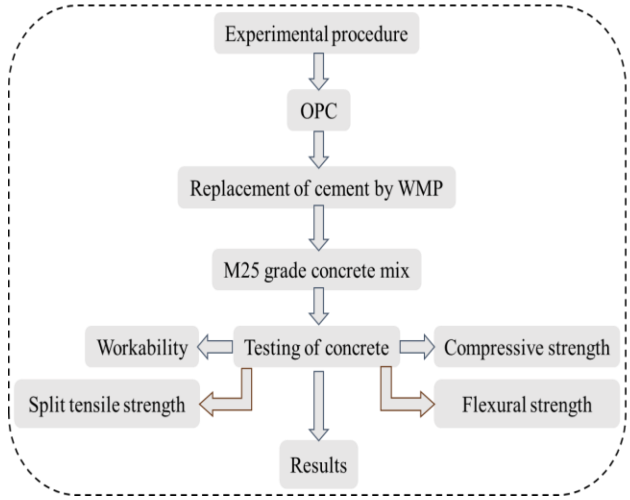

Figure 1 Flow chart of the experimental work

To achieve the desired properties in concrete, an appropriate combination of cement, FA, and CA was used, as presented in *Table 8*.

Table 7 Mix proportions of M25 grade concrete (kg/m^3)

WMP %	Cement	WMP in Kg Passing through sieve (micron)					F.A (kg)	CA (kg)		W/C ratio	Slump (mm)
								CA 10 mm down	CA 20 mm down		
		90	80	75	63	53	-	-	-	-	-
0	404.75	0	0	0	0	0	575.3	521.6	782.4	0.42	60
5	384.52	4	4	4	4	4	575.3	521.6	782.4	0.42	55
10	364.27	8	8	8	8	8	575.3	521.6	782.4	0.42	48
15	344.04	12	12	12	12	12	575.3	521.6	782.4	0.42	40
20	323.80	16.2	16.2	16.2	16.2	16.2	575.3	521.6	782.4	0.42	36

Table 8 Final design mix proportion of materials

Cement	FA	CA	WMP	Water
404.75	575.3	1,304	0	170
1	1.42	3.21.	0	0.42

The target mean strength of the concrete can be calculated by using Equation 1 [40].

$$F_t = F_{ck} + ts \quad (1)$$

Where, F_t =Target mean strength. F_{ck} = Characteristic compressive strength at 28 days = 25 MPa, S= Standard deviation =5, F_t = 25+ (1.65 × 4) = 31.6 MPa.

The CA and FA can be calculated by using Equations 2 and 3.

$$V = \left[W + \left(\frac{C}{S_c}\right) + \left(\frac{F_a}{\rho.S_{Fa}}\right)\right] \times \frac{1}{1000} \quad (2)$$

$$C_a = \left[\frac{1-P}{p}\right] \times F_a \times \left(\frac{S_{ca}}{S_{fa}}\right) \quad (3)$$

Where, V= Absolute volume of fresh concrete or gross volume (m^3) of entrapped air, W= weight of water (Kg/m^3), C= weight of cement of concrete(Kg/m^3), s_c= Specific gravity of cement, P= Ratio of FA to total aggregate by absolute volume, F_a, C_a=total mass of FA and CA, S_{ca}, Specific gravity of CA and FA, respectively.

The casting of concrete has been done in two stages. The first stage involved casting the control sample which consists of CA, FA and OPC [41]. The second stage involves partial replacement of cement by WMP in concrete. Before starting the mixing process, a weighing machine was used to determine the quantity of materials. The concrete mixer speed was maintained at 30 revolution per minute (RPM) to blend ingredients properly. The crushed material is first added to the drum followed by FA. Each ingredient was mixed in dry condition. The quantity of OPC and water was added on time. Blending took place for approximately 2 minutes for each batch. The mixing and casting are shown in *Figure 2*.

Figure 2 Mixing and casting of concrete

The mechanical properties of concrete by adding WMP may change drastically and can be determined by its microstructure [42]. The WMP mainly consists of calcium carbonate $(Ca(CO)_3$ and it acts as a Pozzolanic material that chemically reacts with $Ca(OH)_2$ to form additional CSH gel. This reaction fills voids in the microstructure, densifying the paste and reducing porosity. Binds un-hydrated cement particles, improving cohesion and reducing micro-cracks can potentially lead to stronger hydration bonds due to the presence of additional calcium ions. Concrete has a typical microstructure and it is composed of a varied mixture of FA and CA, held together by a solidified cement paste. This paste is a complex matrix of crystalline calcium silicate hydrate (CSH) gel, $Ca(OH)_2$ crystals, and un-hydrated cement particles that formed after the hydration of cement. The strength, durability and permeability parameters of concrete are significantly influenced by the density and compactness of the paste.

WMP enhances strength and durability in concrete by reducing porosity and resistance to water penetration and chemical attack. However, improper mixing can cause weak interfaces. Factors like particle size, chemical makeup, replacement ratio, and mix design affect WMP's effects. Optimal replacement percentages range from 10% to 20% [43]. Understanding WMP interaction is crucial for optimizing construction and enhancing concrete's mechanical properties.

4. Results and discussion

The *Table 7* outlines concrete mixtures with varying percentages of WMP. It compares the amounts of cement (kg), WMP (kg), FA (kg), CA (kg), water-cement ratio (W/C ratio), and slump (mm). Each row represents different WMP percentages (0%, 5%, 10%, 15%, and 20%) and shows how these changes affect the quantities of other materials and the slump value. As the WMP percentage increases, the amount of cement decreases. The W/C ratio remains constant at 0.42 across all mixes. The slump value, which indicates the workability of concrete, decreases with the increase in WMP. This makes sense as replacing cement with WMP would reduce the binding properties, impacting the workability and mix proportions.

4.1 Workability

Workability for typical concrete is medium. *Figure 3* shows the slump cone test. A low slump value produces a stiff mix and hence workability decreases as the replacement level of WMP increases from 0%

to 20 %. The workability of concrete can be greatly affected by low slump levels as shown in *Figure 4*. A slump test was used to examine the workability of all mixtures [44]. *Table 7* displays the amount of water used to achieve the required workability. This resulted from the extremely harsh mixtures created by using WMP in the production of concrete, as well as the fact that the slump values did not accurately reflect the true workability. To maximize the benefits of marble's thixotropic properties while avoiding the associated increase in water consumption, a low slump value was sought. Therefore, the utilization of marble waste has significantly increased, although it has led to a decrease in performance criteria in terms of workability.

Figure 3 Slump cone test

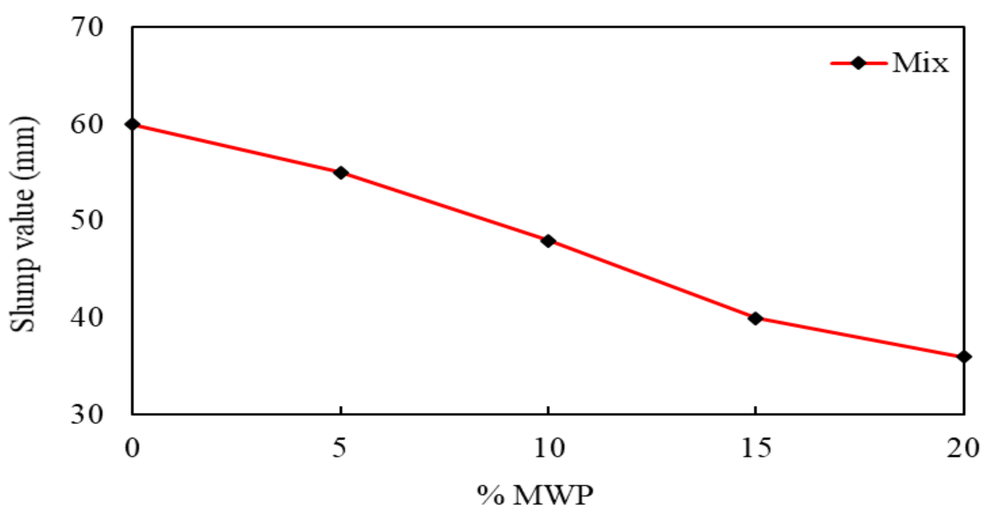

Figure 4 Slump value

4.2 Compressive strength

Compressive strength tests were conducted using a digital compression testing machine (DCTM) (*Figure 5)* with a capacity of 2000 KN, as described in. *Figure 6* shows the fractured cube and cylinder sample. *Figure 7* shows the fractured rectangular beam specimen. Compressive strength for cured concrete cubes of M25 grade for 7 days and 28 days were investigated. The outcomes are presented in *Table 9*, illustrating the substitution of WMP (%) in concrete. A 7-day test was done to see how the concrete's original strength was affected by the early strength gain of conventional concrete concerning concrete produced by WMP replacement. Also, 28-day tests were conducted for final changes in compressive strength of the controlled and modified mix of cement concrete by WMP.

This study examines the effect of substituting cement with WMP on the compressive strength of concrete, measured at intervals of 7 and 28 days. Without WMP, the baseline strength is 22.1 N/mm² and 32.25 N/mm² respectively. Introducing 5% WMP enhanced the strength by approximately 5.8% at 7 days and 7.4% at 28 days, while 10% WMP lead to even greater improvements of 9.1% and 11.2%. However, at 15% WMP, the initial strength gains diminish, showing a modest 2.3% increase at 7 days but a decline of 6.3% at 28 days. Further increasing WMP to 20% results in significant strength reductions of 6.33% and 8.5% for 7 and 28 days, respectively as shown in *Table 9*. The interaction between the WMP and the cement hydrates, leading to the formation of calcium carbo-aluminates, seems to be a key factor in the initial strength gains. These products provide a denser matrix, enhancing the overall structural integrity of the concrete. Over time, the bond formed by the reaction between WMP and cement becomes stronger, accounting for the observed increase in strength during the curing process. This indicates that while moderate WMP incorporation can enhance concrete strength, excessive amounts are detrimental.

Figure 5 Digital compression testing machine

Figure 6 Fractured cube and cylinder sample

Figure 7 Fractured rectangular beam specimen

Table 9 Compressive strength

Mix	Compressive strength (N/mm²)		% Changes in strength	
	7 days	28 days	7 days	28 days
WMP 0	22.1	32.25	-	-
WMP 5	23.4	34.65	5.8	7.4
WMP 10	24.1	35.85	9.1	11.2
WMP 15	22.6	30.22	2.3	-6.3
WMP 20	20.7	29.5	-6.33	-8.5

4.3 Split tensile strength

This test is evaluated in DCTM having a capacity of 2000 KN, the test is performed at 7 and 28 days, and the cylindrical specimen having a diameter of 150 mm and a height of 300 mm underwent tightness. After 7 and 28 days of adequate curing, the split tensile strength values for M25 grade concrete at various replacement percentages of cement with WMP are presented in *Table 10*. The split tensile strength of cement concrete is calculated using the formula provided in Equation 4.

$$T = \frac{2P}{LD} \quad (4)$$

Where, T=Tensile strength (MPa), P= Maximal force exerted on test samples (N), L= Specimen length (mm), D= Specimen diameter (mm)

Table 10 illustrates the split tensile strength of concrete mixtures incorporating varying percentages of WMP over 7 and 28 days. Initially, with no WMP, the concrete has a tensile strength of 2.85 N/mm² at 7 days, which serves as the baseline. At 5% and 10% WMP, there is a notable enhancement in strength, peaking at 3.40 N/mm² at 7 days and 4.25 N/mm² at 28 days, showing respective increases of up to 19.29%. However, when the WMP content reaches 15%, the results become inconsistent, with a slight decrease at 7 days but a gain at 28 days. At 20% WMP, both 7-day and 28-day strengths significantly decline, indicating the material's diminishing effectiveness at higher concentrations. This data suggests an optimal range for WMP substitution to improve tensile strength without compromising the concrete's overall durability.

Table 10 Split tensile strength

Mix	Split tensile strength (N/mm^2)		% changes in strength	
	7 days	**28 days**	**7 days**	**28 days**
WMP 0	2.85	s	-	-
WMP 5	3.25	4.20	14.03	10.5
WMP 10	3.40	4.25	19.29	7.36
WMP 15	3.20	4.35	12.28	14.47
WMP 20	2.65	3.20	-7.01	-15.78

4.4 Flexural strength

One way to gauge the tensile strength of concrete is through its flexural strength. The capacity of a beam to resist bending-related failure is evaluated by calculating the load for an unreinforced beam. The results of the flexural strength tests for all specimens containing WMP at 7 and 28 days of curing are presented in *Table 11*.

The flexural strength of concrete with various percentages of WMP replacement over 7 and 28 days. At 0% WMP, the baseline strength is 3.5 N/mm² and 5.5 N/mm² at 7 and 28 days, respectively. A 5% WMP replacement shows an increase of 14.3% at 7 days and 10.9% at 28 days, reaching strengths of 3.8 N/mm² and 6.1 N/mm². With 10% WMP, the strength further increases to 4.5 N/mm² and 6.6 N/mm², showing gains of 28.5% and 20.0%. At 15% WMP, the strength increases to 4.1 N/mm² and 6.2 N/mm², reflecting growth rates of 17.2% and 12.7%. However, a 20% WMP replacement sees a decrease in strength to 3.3 N/mm² and 5.1 N/mm², with reductions of 8.6% and 5.5%.

Table 11 Flexural strength

Mix id	Flexural strength (N/mm^2)		% changes in strength	
	7 days	**28 days**	**7 days**	**28 days**
WMP 0	3.5	5.5	-	-
WMP 5	3.8	6.1	14.3	10.9
WMP 10	4.5	6.6	28.5	20.0
WMP 15	4.1	6.2	17.2	12.7
WMP 20	3.3	5.1	-8.6	-5.5

Note on Mix Composition

- **WMP 0** – 0% replacement of cement with WMP.
- **WMP 5 to WMP 20** – 5%, 10%, 15%, and 20% replacement of cement with WMP, respectively. Each replacement level used WMP in equal proportions retained on the following sieve sizes: 90 µm, 80 µm, 75 µm, 63 µm, and 53 µm.

Limitations

One of the major limitations of this study was the challenge of obtaining consistent-quality WMP, as it is typically discarded at various local dumping grounds with varying compositions. Another significant concern is that high-strength concrete mixes often exhibit poor performance in certain properties, particularly workability. This study primarily focused on evaluating the compressive strength of concrete incorporating marble waste, considering a limited set of mix parameters and proportions. Further research is essential to assess the performance of marble-incorporated concrete in regions frequently exposed to acid rain, where durability and chemical resistance become critical factors.

A complete list of abbreviations is listed in *Appendix I*.

5. Conclusion and future work

The use of WMP in concrete improved the strength of the material. The following findings was drawn from the test results study. Concrete’s strength in compression is enhanced by 10% when WMP is used instead of cement, but a decrease in concrete’s compressive strength is seen as greater amounts of WMP are added to the mix. The Concrete's split tensile strength increases by up to 15 percent when WMP replaces cement, and as the amount of WMP grows the split tensile concrete's strength declines. It has been determined that WMP may be utilised as a cement replacement material and that replacing 10% of the cement with WMP yields a good strength result when compared to the standard concrete. As the replacement level rises, workability declines, resulting in higher water usage. MD powder is available free of charge, so we have suggested a simple procedure to minimize construction costs. The impact of partially substituting MP for cement on the workability and mechanical properties of concrete has been examined in this paper. Furthermore, research demonstrates that demonstrates that combining marble waste with fly ash enhances its efficiency in replacing OPC. A study evaluating the performance of this modification suggests that marble waste is particularly effective in sulphate environment. Marble waste can partially replace CA, while limestone aggregate can be entirely replaced, depending on the dry bulk density of the concrete constituents. As we know, experimental lab tests are tedious and time-consuming are tedious and time-consuming, so various numerical methods can be used to predict strength, workability, and durability.

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Conflicts of interest
The authors have no conflicts of interest to declare.

Data availability
None.

Author's contribution statement
Mithlesh Kumar Jha: Draft writing, paper framework concept, revise the paper, conduct the study and result analysis. **Lal Bahadur Roy:** Study conceptualization, supervision during the laboratory test, checking the results and reviewing the paper.

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Appendix I

S. No.	Abbreviation	Description
1	Ca $(OH)_2$	Calcium Hydroxide
2	CSH	Calcium Silicate Hydrate
3	DCTM	Digital Compression Testing Machine
4	FA	Fine Aggregate
5	ICAR	International Center for Aggregate Research
6	MP	Marble Powder
7	MD	Marble Dust
8	OPC	Ordinary Portland Cement
9	P	Porcelain Powder
10	RCBs	Reinforced Concrete Beams
11	RPM	Revolution Per Minutes
12	RSM	Response Surface Method
13	W/B	Water-Binder
14	WMP	Waste Marble Powder