JAASCI
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JOURNAL OF ADVANCED APPLIED SCIENCES
e-ISSN: 2979-9759
PRENSİP
https://prensip.gen.tr

RESEARCH ARTICLE

Investigation of the Effect of Marble Powder Fineness on the Mechanical and Physical Properties of Cement Mortars

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ARTICLE INFO

Article History
Received: 28.06.2025
Accepted: 27.11.2025
First Published: 31.12.2025

Keywords
Chloride permeability
Compressive strength
Sustainable construction materials
UPV
Water absorption

ABSTRACT

This research explored how marble powder with two particle size ranges (0–45 µm and 0–75 µm), when used as a partial cement replacement, influences the physical and mechanical behavior of mortars. As a recycled by-product with environmental and economic advantages, marble powder was incorporated at replacement levels of 5–40 %, and specimens were prepared accordingly. The experimental program assessed compressive strength, ultrasonic pulse velocity (UPV), water absorption, and chloride penetration after 28 and 90 days of curing. The results indicated that low replacement levels (5–10 %) improved performance, particularly in compressive strength and UPV. At higher levels (15–20 %), however, increased porosity led to a reduction in all measured properties. The finer marble powder (0–45 µm) enhanced matrix densification, resulting in better strength and permeability outcomes compared to the coarser fraction (0–75 µm), which showed weaker performance at elevated replacement ratios. Overall, the findings suggest that incorporating marble powder in controlled proportions and with appropriate particle size can be a viable approach to producing sustainable mortars with satisfactory mechanical and durability characteristics.

Please cite this paper as follows:

Filazi, A., Uzun, K., & Uzun, C. (2025). Investigation of the effect of marble powder fineness on the mechanical and physical properties of cement mortars. *Journal of Advanced Applied Sciences*, *4*(1-2), 25-36. https://doi.org/10.61326/jaasci.v4i1-2.379

1. Introduction

The construction industry is a sector where the demand for building materials continues to increase due to population growth and urbanization. However, the production of conventional building materials poses serious sustainability challenges, primarily due to high energy consumption and environmental impacts. In particular, cement production leads to significant carbon emissions and depletes natural resources. Therefore, the incorporation of various industrial wastes into construction materials is being increasingly explored to reduce environmental damage and develop economically viable alternatives. In this context, marble powder, a byproduct of marble processing, is considered a promising waste material.

During the cutting, shaping, and polishing of marble blocks in processing facilities, a considerable amount of marble powder waste is generated. A large portion of this waste is directly discharged into the environment, contributing to pollution. Utilizing marble powder waste in the construction sector not only offers environmental benefits but also provides economic advantages by reducing material costs. Marble powder can serve as a partial cement substitute in mortars, offering both environmental benefits and potential improvements in performance. In this study, the influence of particle fineness on the behavior of cement mortars was

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examined. Two types of marble powder (0–45 μm and 0–75 μm) were incorporated at replacement levels ranging from 5 % to 40 %. The investigation focused on compressive strength, flexural strength, water absorption, and bulk dry density. For the mixture that achieved the highest mechanical performance, additional tests—including chloride permeability, ultrasonic pulse velocity (UPV), and microstructural characterization—were carried out to provide deeper insight into the material's properties.

Previous research has explored the incorporation of marble powder into cement-based materials. Findings indicate that substituting a portion of cement with marble powder can improve mechanical performance and support the hydration process (Corinaldesi et al., 2010). Other studies have highlighted its role in lowering permeability and enhancing the durability of concrete structures (Chahour & Safi 2020).

(Mohamadien, 2012) investigated mortars incorporating both marble powder and silica fume as partial cement replacements, reporting that the optimum compressive strength was achieved at a 15 % substitution level. More recently, (Chahour et al., 2024) studied eco-friendly mortars containing marble powder and highlighted that a 30 % replacement provided the most favorable balance of rheological and mechanical properties.

Similarly, research involving the use of marble and brick powders in self-compacting mortars reported improved mechanical properties up to a 20% marble powder replacement level (Boucherit et al., 2020). In studies on high-performance concrete, it was shown that 15% marble powder enhanced resistance to chloride ion penetration and reduced oxygen permeability (Talah et al., 2015).

Experimental investigations have also demonstrated that concrete with marble powder exhibits high durability, particularly in terms of chloride permeability (Talah et al., 2015). Moreover, marble powder has been found to improve mechanical properties and increase resistance to high temperatures (Khan et al., 2021).

Other studies have shown that combining marble powder with granite powder as a partial cement replacement improves durability while reducing carbon emissions (Nega et al., 2023). Overall, the positive effects of marble powder on the strength and durability of cement mortars and concrete have been widely documented in the literature, particularly when used at optimal replacement levels (Amin et al., 2024).

However, there is a limited number of studies examining the influence of marble powder fineness on mechanical and physical performance. Thus, this research aims to provide a comprehensive assessment of the behavior of cement mortars incorporating marble powders of varying fineness.

The findings of this research highlight the potential of marble powder as a supplementary material in cement-based composites, offering a pathway toward more sustainable practices in construction. Utilizing marble waste not only mitigates environmental impacts but also contributes to the production of cost-effective and durable building materials.

2. Materials and Methods

2.1. Materials

2.1.1. Binder material: Portland cement (PC)

The primary binder used in this study was CEM I 42.5 R Portland cement, supplied by Baştaş Başkent Cement Industry and Trade Inc (TS EN 197-1, 2002). This cement type is equivalent to ASTM Type I and is known for its rapid hardening behavior, which provides high early-age strength. As a nearly pure Portland cement with minimal additives, CEM I 42.5 R is commonly employed in precast elements, structural applications, repair mortars, and engineering works requiring fast strength gain.

Its early strength development is largely associated with the high proportion of tricalcium silicate (C_3S), while dicalcium silicate (C_2S) supports strength growth at later ages. The Blaine fineness was determined as 3351 cm²/g and the specific gravity as 3.17 g/cm³, values that indicate high reactivity and accelerated hydration. The relatively low amounts of tricalcium aluminate (C_3A) and tetracalcium aluminoferrite (C_4AF) also contribute to improved sulfate resistance.

Overall, the physical and chemical characteristics of the cement were decisive in shaping the mechanical performance, durability, and microstructural features of the mortars produced. A concise summary of these properties is provided in Table 1, serving as a baseline for evaluating the influence of marble powder replacement on compressive strength, water absorption, ultrasonic pulse velocity (UPV), and chloride ion permeability.

Table 1. Physical and chemical properties of CEM I 42.5 R cement.

Chemical Properties (%)	**Content (%)**
SiO_2	20.85
Al_2O_3	5.25
Fe_2O_3	3.40
CaO	62.50
MgO	2.05
Na_2O	0.42
K_2O	0.78
SO_3	3.15
Physical Properties	
Specific Gravity (g/cm^3)	3.12
Blaine Fineness (cm²/g)	3425
Loss on Ignition (%)	2.36

2.1.2. CEN standard sand

For the experimental program, CEN standard sand supplied by Limak Trakya Cement Factory was employed in accordance with TS EN 196-1. The sand, with a particle size range of 0.08–2 mm, consists mainly of high-purity quartz (SiO_2), which ensures chemical stability and mechanical robustness. Its specific gravity is about 2.65 g/cm³, and the low water absorption capacity helps maintain consistent water-to-cement ratios in the mortar mixtures.

Using standardized sand reduces variability associated with aggregates, allowing the influence of marble powder replacement on mortar performance to be evaluated more reliably. The particle size distribution and essential physical properties of the sand are summarized in Table 2.

Table 2. Particle size distribution of reference sand.

Square Mesh Opening (mm)	Cumulative Retained (%)
2.00	0
1.60	7 ± 5
1.00	33 ± 5
0.50	67 ± 5
0.16	87 ± 5
0.08	99 ± 1

2.1.3. Marble powder

In this research, marble powder derived from processed waste marble was incorporated as a supplementary material. Owing to its high calcium carbonate ($CaCO_3$) content, typically between 90–95 %, the powder mainly functions as a filler within the cement matrix, enhancing compactness and reducing permeability.

Two particle size ranges were considered (0–45 μm and 0–75 μm). The material has a specific gravity of about 2.7 g/cm³ and Blaine fineness values in the range of 2800–3500 cm²/g. Minor constituents such as SiO_2, Al_2O_3, and Fe_2O_3 are also present in its composition.

Although the pozzolanic activity of marble powder is relatively low, its micro-filler effect contributes to the hydration process and matrix densification. In this study, it was introduced as a partial cement replacement at levels between 5 % and 40 % to assess its impact on mechanical and physical properties, including compressive and flexural strength, water absorption, and dimensional stability. For the most effective replacement ratio, microstructural examinations were additionally performed. A summary of the powder's properties is provided in Table 3.

Table 3. Physical and chemical properties of marble powder.

Chemical Properties (%)	Marble Powder
CaO	52.5
CO_2	42.5
SiO_2	1.98
Al_2O_3	1.1
Fe_2O_3	0.3
MgO	0.3
Others	0.4
Physical Properties	
Blaine inceliği (cm²/g)	2925
Specific Gravity (g/cm³)	2.65

2.2. Particle Size Classification

In this study, a particle size separation process was applied to enhance the physical and mechanical performance of the marble powder used in the experiments. Particle size is known to significantly affect the microstructure of cement mortars, hydration reactions, and overall mechanical properties. Therefore, utilizing marble powder at different fineness levels is a critical step in optimizing material performance and achieving properties suitable for various applications.

The marble powder was classified into two distinct particle size ranges—0–45 μm and 0–75 μm—through sieve analysis. This classification was intended to improve the homogeneity of the marble powder distribution within the cement matrix and to enhance the filler effect in micropores. Fine particles are expected to positively influence hydration and contribute to improved mechanical strength and water impermeability due to their micro-filling capability.

Replacement levels of marble powder were set between 5% and 40% by weight of cement, and mortar specimens were prepared accordingly. The comprehensive evaluation of the mechanical and physical performance of different replacement ratios and particle sizes enabled the determination of the optimal substitution level.

The mechanical strength of the modified mortars was assessed through flexural and compressive strength tests in accordance with TS EN 196-1 standards. These tests facilitated detailed comparisons of early-age and long-term strength performance for each marble powder content and particle size. Additionally, the effects of marble powder incorporation on water absorption, volumetric stability, and microstructural characteristics of the mortars were investigated.

2.2.1. Molding procedure

Mortar mixtures were placed into standard prism molds in two layers, each layer compacted with 60 controlled vibrations in accordance with TS EN 196-1 to ensure adequate compaction and minimize the influence of reduced workability

at higher replacement levels. Excess mortar was leveled with a steel trowel to obtain a smooth surface. The prepared specimens were then stored at 20 ± 2 °C and 95% relative humidity for 24 hours prior to demolding.

2.2.2. Curing process

After demolding, specimens were submerged in water tanks at constant temperature for specified durations (7, 28, and 90 days). This ensured complete hydration and consistent curing before testing.

2.2.3. Mechanical strength tests

Flexural strength was determined using the three-point bending method in accordance with TS EN 196-1 standards. The fractured halves obtained from the flexural test were subsequently subjected to compressive strength testing at a loading rate of 2400 ± 200 N/s. For each condition, six specimens were tested, and the average values were calculated. Any result deviating more than ±10% from the mean was excluded from the dataset. In addition, standard deviation values for compressive strength, flexural strength, and UPV at each curing age (7, 28, and 90 days) were calculated and incorporated into the revised figures and tables to provide a clearer representation of variability and ensure statistical reliability.

2.3. Water Absorption and Bulk Density

Water absorption and bulk density tests were conducted in accordance with ASTM C642 using 50×50×50 mm cube specimens (ASTM C642, 2013). Water absorption was calculated as the difference between the saturated surface dry (SSD) mass and the oven-dried mass of the specimens. Bulk density was determined using the Archimedes principle by evaluating the immersed and saturated masses. These parameters are critical indicators of the porosity and compactness of the material. It should be noted that Table 8 presents bulk dry density values (≈2.05–2.09 g/cm³), which include the effect of pore volume, whereas Table 9 reports apparent density values (≈2.23–2.26 g/cm³) obtained by Archimedes' principle, excluding open porosity. The discrepancy between the two ranges is explained by the difference in measurement principles. The results showed that the use of finer marble powder led to a reduction in porosity, while longer curing durations contributed to an improvement in bulk density.

2.4. Ultrasonic Pulse Velocity (UPV)

Ultrasonic Pulse Velocity (UPV) testing was applied to evaluate the uniformity and internal soundness of the mortar specimens. In this technique, an ultrasonic wave is passed through the sample, and its velocity (km/s) is determined from the travel time relative to specimen length. The obtained values were compared with a standard classification (Table 4) to assess how marble powder content and particle size influence the microstructural quality of the mortars.

Table 4. Concrete quality classification based on ultrasonic pulse velocity values.

Velocity (km/s)	Concrete Quality
≥ 4.5	Very Good
3.5 - 4.5	Good
3.0 - 3.5	Medium
2.0 - 3.0	Poor
≤ 2.0	Very Poor

3. Results and Discussion

3.1. Mechanical Properties of Marble Powder-Substituted Cement Mortars

In this part of the study, the mechanical behavior of cement mortars containing marble powder was investigated with respect to particle size distribution. Two fractions of marble powder (0–45 μm and 0–75 μm) were incorporated at different replacement levels. Compressive and flexural strength tests were conducted after 7, 28, and 90 days of curing. The results allowed a detailed assessment of how particle fineness influences strength development over time.

3.1.1. Materials and mix proportions

In the experimental program, mortars were prepared using CEM I 42.5 R Portland cement, waste marble powder, standardized quartz sand, and potable water. Marble powder was incorporated as a partial cement substitute at replacement levels ranging from 0 % (control) to 40 % by mass. Figure 1 presents the mix designs with varying substitution ratios. This methodology enabled a systematic evaluation of how particle size and dosage of marble powder influence the mechanical properties of cement mortars.

Figure 1. The mortar specimens produced with different marble powder substitution ratios.

The mortar specimens were cast into molds and initially cured for 24 hours under controlled conditions of 20 ± 2 °C and 95 % relative humidity. This preliminary curing step was intended to minimize early-age cracking and maintain balanced hydration. Afterward, the samples were immersed in water tanks and stored until the designated curing ages of 7, 28, and 90 days. This procedure provided adequate hydration, enabling reliable evaluation of the mechanical and physical property development over time.

To clearly identify the influence of marble powder substitution, the water-to-binder ratio (w/b) was fixed at 0.50 for all mixtures. By keeping this ratio constant, regardless of the replacement level, uniformity in workability, rheological behavior, and hydration conditions was ensured. Thus, the observed variations in performance can be attributed solely to the marble powder content. The detailed mix proportions for each substitution level are summarized in Table 6.

Table 6. Mix design ratios of cement mortars.

Sample Code	Marble Powder (g)	Cement (g)	Aggregate (g)	Water (g)
MT0	0	450	1350	225
MT5	22.5	427.5	1350	225
MT10	45	405	1350	225
MT20	90	360	1350	225
MT25	112.5	337.5	1350	225
MT30	135	315	1350	225
MT40	180	270	1350	225

3.1.2. Compressive and flexural strength analysis of cement mortars containing marble powder

Figure 2 presents the compressive strength results of cement mortars containing 0–75 µm marble powder after 7, 28, and 90 days of curing. The data demonstrate how marble powder influences strength development at both early and later ages. The finer particles contribute to matrix densification by filling microvoids, which in turn improves strength. At specific substitution levels, the inclusion of marble powder enhances mechanical performance while simultaneously promoting sustainability through the reuse of industrial waste.

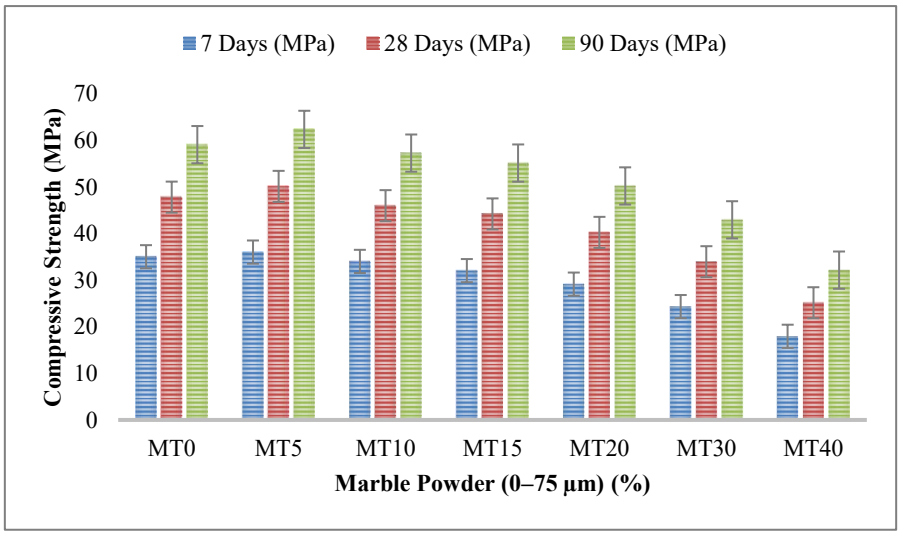

Figure 2. Compressive strength of mortars with 0–75 µm marble powder at various replacement levels.

Figure 2 illustrates the progression of compressive strength in cement mortars produced with partial substitution of cement by marble powder with a particle size of 0–75 µm. The figure compares different replacement levels across curing ages of 7, 28, and 90 days, thereby providing a comprehensive view of both early-age and long-term strength development. The inclusion of fine marble particles contributes to matrix densification by filling microvoids, which enhances the compactness and mechanical integrity of the mortars. At certain substitution ratios, this effect leads to noticeable improvements in compressive strength, demonstrating that marble powder can serve not only as a sustainable alternative to conventional cement but also as a performance-enhancing additive. The results emphasize the dual benefit of utilizing industrial waste materials: reducing environmental impact while maintaining or

even improving the engineering properties of cement-based composites.

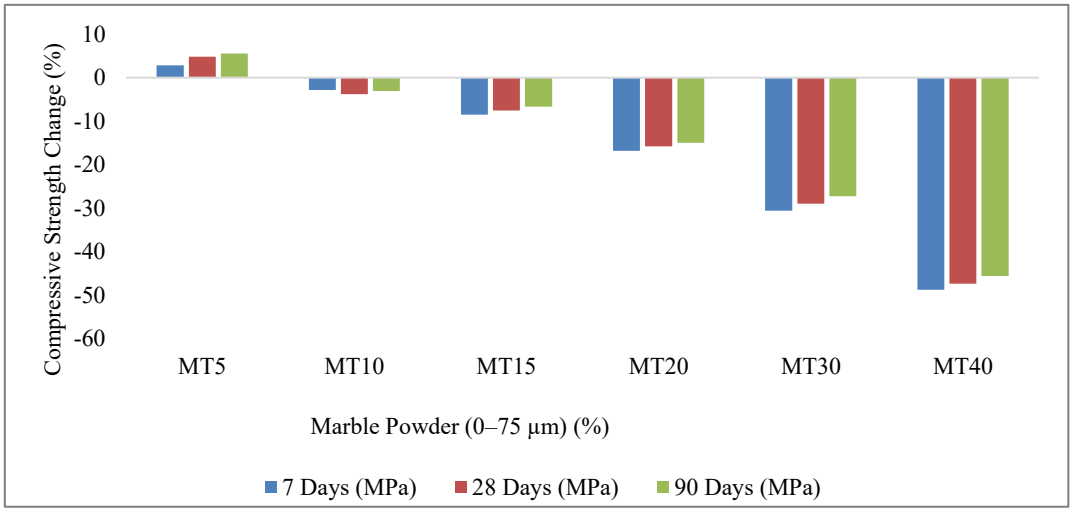

Figure 3. Strength variation of mortars with 0–75 micron marble powder replacement.

Figure 3 illustrates how the substitution of cement with 0–75 µm marble powder influences the compressive strength of mortars across different replacement levels. A 5 % addition of marble powder improved strength both at early curing (7 days) and at later ages (90 days), which can be attributed to the filler effect of fine particles that reduce internal voids and densify the matrix. This demonstrates that finely ground marble powder enhances compactness and contributes positively to mechanical performance. At 10 % replacement, a minor reduction in strength was recorded, though the values remained comparable to the control mix and within acceptable engineering standards. Higher substitution levels, particularly 15 % and above, caused a noticeable decline in strength, with 30 % and 40 % replacements showing significant losses by 90 days. The reduction is linked to increased porosity and weaker binder cohesion. Overall, the findings suggest that around 5 % marble powder substitution provides the most favorable balance, improving mortar strength while maintaining structural reliability.

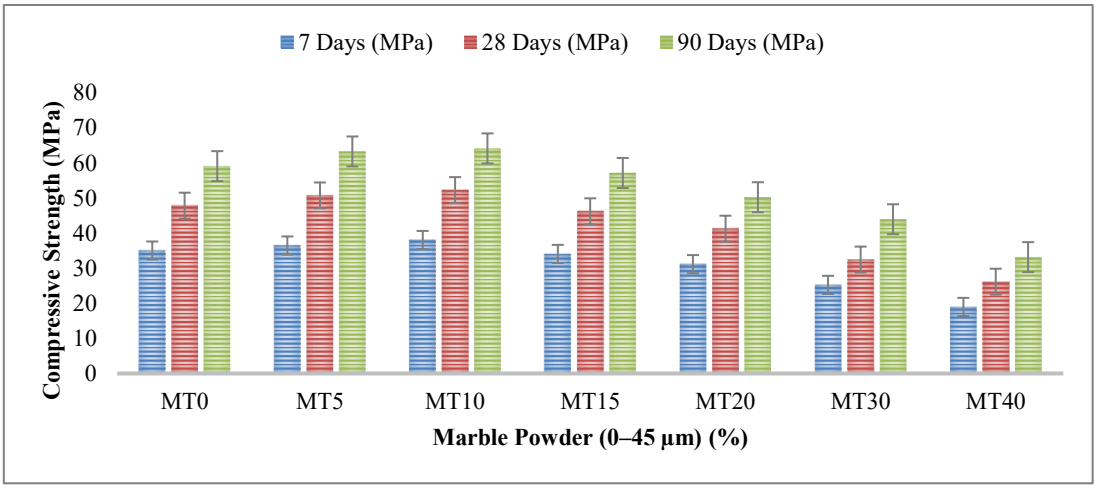

Figure 4. Compressive strength test results of cement mortars incorporating different proportions of 0–45 micron marble powder.

As shown in Figure 4, the compressive strength results for cement mortars incorporating marble powder within the 0–45 µm particle size range reveal that low to moderate replacement levels enhance mechanical performance, whereas higher levels lead to strength reduction.

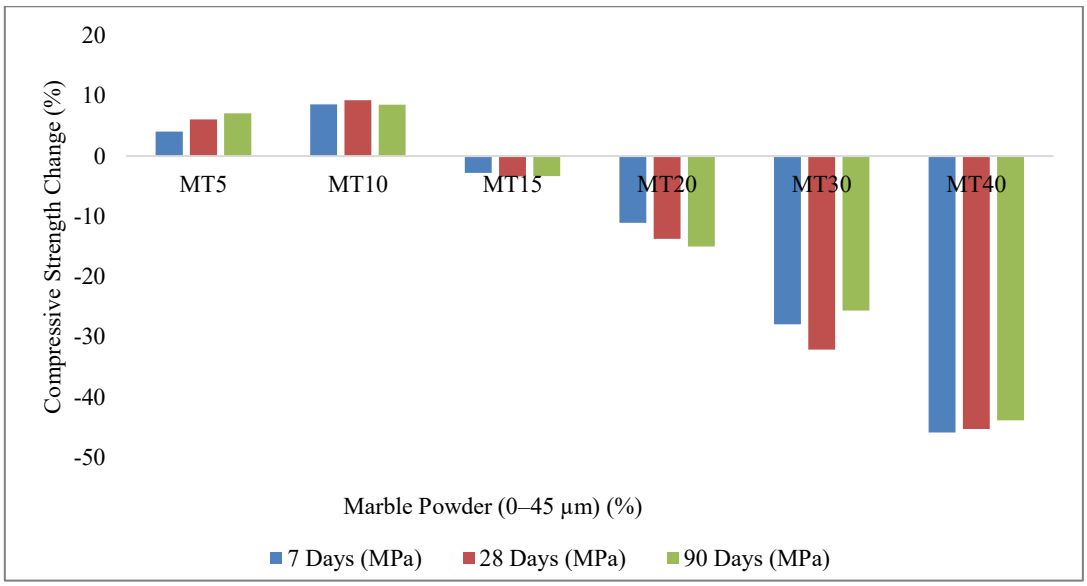

Figure 5. Strength variation of mortars incorporating 0–45 micron marble powder.

As seen in Figure 5, mixtures containing 5% and 10% marble powder consistently exhibited higher compressive strength than the control samples across all curing ages. The MT10 mixture, with 10% marble powder replacement, showed the best performance, reaching a compressive strength of 64.12 MPa at 90 days. This indicates that finely ground marble powder positively contributes to the cement matrix by enhancing the binder phase at optimal replacement levels. However, a decline in compressive strength was observed when the marble powder content reached 15% or higher. While the MT15 mixture's strength values were close to the control, a decreasing trend was apparent at 7 and 28 days. At 20% replacement and above, compressive strength loss became more pronounced, with the MT30 and MT40 mixtures exhibiting significant drops to 43.94 MPa and 33.15 MPa at 90 days, respectively. These results suggest that excessive fine marble powder weakens the binder phase, adversely affecting the mechanical properties. In conclusion, the optimal replacement level for 0–45 µm marble powder is around 10%, which maximizes compressive strength and promotes a denser, more durable cement matrix, whereas replacements above 15% reduce mechanical performance markedly.

3.2. Water Absorption Characteristics of Cement Mortars Containing Marble Powder

The water absorption percentages presented in Table 7 generally correlate well with the compressive strength results.

Table 7. Water absorption (%) of cement mortars containing marble powder.

Numune	7 Days (%)	28 Days (%)	90 Days (%)
MT0	8.71	8.45	8.15
0-75 MT5	9.05	8.85	8.81
0-45 MT5	8.95	8.85	8.42
0-75 MT10	9.21	8.98	8.76
0-45 MT10	9.06	8.75	8.62
0-75 MT15	9.34	9.06	8.81
0-45 MT15	9.13	9.05	8.65
0-75 MT20	9.42	9.16	9.05
0-45 MT20	9.19	8.98	8.47

Table 7 shows that water absorption is directly related to the pore structure of the cement mortar, with higher absorption rates expected in samples exhibiting increased porosity and lower compressive strength. The control sample (MT0), containing no marble powder, exhibited the lowest water absorption due to its denser matrix and consequently lower porosity. Although a slight increase in water absorption was observed in samples with 5% marble powder replacement, their compressive strength improved, indicating good integration of low-level marble powder into the cement matrix without significantly increasing pore formation (Yamanel et al., 2019). At 10% replacement, the sample with 0–75 µm particle size

showed higher water absorption compared to the control, whereas the 0–45 μm sample exhibited somewhat lower absorption. This suggests that finer marble powder particles integrate better into the cement matrix, moderately reducing porosity. Similarly, previous studies reported that 10% replacement led to increased compressive strength accompanied by a slight rise in water absorption, with both parameters remaining within acceptable engineering limits (Bùi et al., 2022).

Conversely, samples with 15% and 20% marble powder replacement demonstrated a notable increase in water absorption, especially those containing 0–75 μm particles. This indicates that higher marble powder content adversely affects the binder phase, increasing pore volume and thus water absorption. When considered alongside compressive strength data showing significant strength reduction at these higher replacement levels, the findings are mutually supportive (Majeed et al., 2021; Mohamadien, 2012).

While samples with low marble powder content maintained water absorption rates close to the control, increased porosity at higher replacement levels led to marked increases in water absorption. These observations emphasize the need to maintain marble powder content at optimum levels, as excessive replacement results in decreased mechanical performance and increased water absorption.

3.3. Bulk Dry Density Characteristics of Marble Powder-Replaced Cement Mortars

When examining the bulk dry density values presented in Table 8, the control sample (MT0) exhibits a stable density ranging between 2.085 and 2.090 g/cm³, indicating a homogeneous and compact structure of the plain cement mortar.

Table 8. Bulk dry density values of cement mortars containing marble powder.

Numune	7 Days (%)	28 Days (%)	90 Days (%)
MT0	2.085	2.085	2.090
0-75 MT5	2.075	2.075	2.090
0-45 MT5	2.085	2.085	2.090
0-75 MT10	2.065	2.085	2.090
0-45 MT10	2.080	2.080	2.090
0-75 MT15	2.055	2.085	2.085
0-45 MT15	2.070	2.085	2.085
0-75 MT20	2.050	2.080	2.085
0-45 MT20	2.070	2.080	2.085

In samples with marble powder replacement, density values at low replacement levels (5% and 10%) remain close to the control sample; however, a decrease is observed in the 7-day density values as the replacement ratio increases. Notably, samples containing marble powder with a particle size of 0–75 μm generally show lower 7-day density values. At 15% and 20% replacement levels, the 7-day densities are measured as 2.055 g/cm³ and 2.050 g/cm³, respectively, suggesting that beyond a certain threshold, the integration of fine marble powder into the cement matrix weakens, leading to increased porosity.

Similar findings were reported by Yamanel et al., who observed decreases in density and early-age strength for samples with 15% and 20% marble powder content; however, these differences diminished after longer curing periods of 90 days (Yamanel et al., 2019). Likewise, Singh et al. documented that marble powder additions up to 15% positively influenced long-term physical strength and density, whereas higher ratios caused degradation in matrix integrity (Singh et al., 2019). Furthermore, density values increased for all samples after 28 and 90 days of curing, with differences between samples reducing over time. This trend reflects ongoing cement hydration, which decreases porosity and enhances internal material compactness.

In summary, low replacement ratios of marble powder do not significantly affect density, while 15% and 20% replacement ratios cause some reduction in early-age density. Nevertheless, the diminishing differences at extended curing times indicate improved integration of marble powder within the matrix over time. These findings suggest that marble powder-incorporated cement mortars can form compact and durable structures in the long term, although high replacement levels may adversely affect early-age density.

3.4. Effect of Marble Powder Addition on the Dry Density of Cement Mortars After Curing

This section evaluates the bulk dry density of cement mortars with marble powder (0–45 μm and 0–75 μm) at replacement levels of 5–20% after curing. Bulk dry density reflects pore volume and compactness, directly influencing strength. Longer curing increases density due to continued hydration. Table 8 shows bulk dry density values (≈2.05–2.09

g/cm³), including pore effects, while Table 9 presents apparent density values (≈2.23–2.26 g/cm³) measured by Archimedes' principle, excluding open porosity. The difference arises from the measurement methods. Results are summarized in Table 9.

Table 9. Bulk dry density of cement mortars containing marble powder after curing.

Numune	7 Days (%)	28 Days (%)	90 Days (%)
MT0	2.26	2.26	2.26
0-45 MT5	2.26	2.26	2.26
0-75MT5	2.26	2.26	2.26
0-45 MT10	2.25	2.25	2.25
0-75MT10	2.26	2.25	2.25
0-45 MT15	2.25	2.25	2.25
0-75MT15	2.26	2.25	2.25
0-45 MT20	2.23	2.24	2.25
0-75MT20	2.24	2.24	2.25

As shown in Table 9, the bulk dry density values after 7, 28, and 90 days of curing are very similar across all mixes. For replacement ratios of 5–20 %, densities ranged between 2.23 and 2.26 g/cm³, with no significant variation during curing. The control sample (MT0) and mixes containing 0–45 µm and 0–75 µm marble powder reached nearly identical values at the end of the curing period. These results indicate that marble powder addition does not notably affect density, and all mixes maintain comparable levels after curing.

These findings are consistent with numerous studies in the literature. For instance, in research where marble powder was used to replace cement at ratios between 5% and 20%, only limited changes in density were observed, while 28-day compressive strengths remained high (Bùi et al., 2022). Similarly, studies have shown that marble powder used as a partial aggregate replacement up to 15% does not substantially alter the volumetric properties of concrete (Bourzik et al., 2023). Another study reported that the densities of concretes incorporating marble powder replacements did not differ significantly compared to the control mix (Majeed et al., 2021). Furthermore, even when concrete contained 4% marble powder, the density increased only marginally up to 2.82 g/cm³, which still represents a limited rise relative to the control mix (Hundessa et al., 2022).

In conclusion, the stability of bulk dry density values after curing suggests that these samples may not exhibit considerable differences in strength gain post-curing. However, correlating these density findings with mechanical strength tests would provide a more meaningful understanding of the effects of different replacement ratios.

3.5. Ultrasonic Pulse Velocity (UPV) Properties of Cement Mortars Containing Marble Powder

The data presented in Figure 8 illustrate the 28- and 90-day ultrasonic pulse velocity (UPV) values of cement mortars partially replaced with 0–75 micron marble powder.

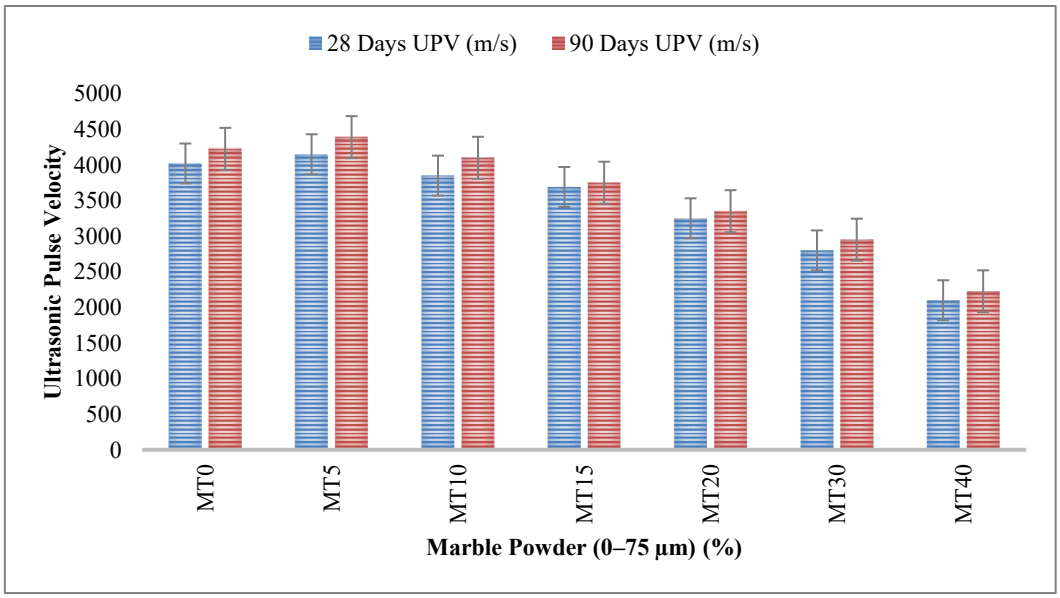

Figure 8. Ultrasonic pulse velocity (UPV) values of cement mortars containing 0–75 µm marble powder at 28 and 90 days of curing.

UPV provides significant insights into the material's internal structure, including porosity, density, and compactness. According to the data, the control sample (MT0) exhibits high UPV values of 4020 m/s at 28 days and 4225 m/s at 90 days, indicating excellent compactness and durability. The sample with 5% marble powder replacement (MT5) shows increased UPV values, reaching 4150 m/s at 28 days and 4390 m/s at 90 days, demonstrating that this replacement ratio enhances the mortar's compactness and strengthens its durability. Similar studies have reported that 5% marble powder replacement fills voids within the matrix, increases compactness, and leads to higher UPV values (Sathe et al., 2024).

However, with a 10% marble powder replacement (MT10), the UPV values decrease to 3850 m/s at 28 days and 4100 m/s at 90 days, indicating that increasing the replacement ratio reduces the density and compactness of the mortar. At higher replacement levels of 15%, 20%, 30%, and 40%, the ultrasonic pulse velocity further declines. These samples exhibit low UPV values of 3690 m/s, 3250 m/s, 2800 m/s, and 2100 m/s at 28 days, respectively, suggesting that higher marble powder content increases the material's porosity, weakening sound transmission and reducing strength. One study also noted that marble powder replacement beyond 10% decreases both density and UPV, thereby weakening the compact structure (Toubal Seghir et al., 2020). Furthermore, Majeed et al. reported that 10% marble powder replacement yielded the highest UPV and strength values, while higher ratios caused declines in both parameters (Majeed et al., 2021).

In conclusion, the ultrasonic pulse velocity data indicate that as the marble powder replacement ratio increases, the mortar's strength and compactness decrease, whereas a 5% replacement ratio produces the most favorable results.

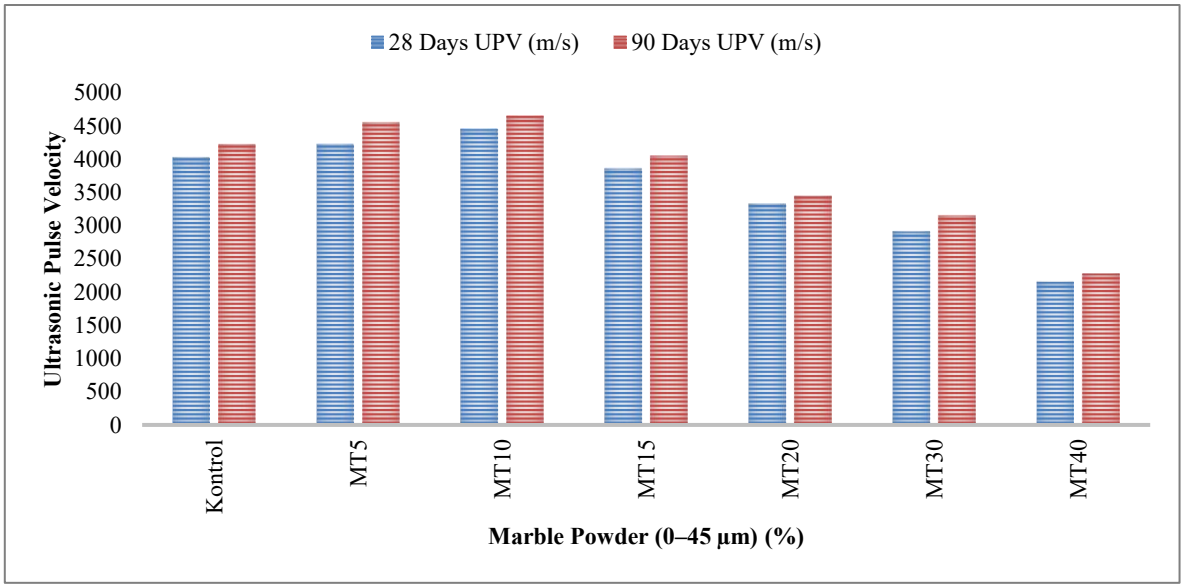

Figure 9. Ultrasonic pulse velocity (UPV) results of cement mortars incorporating 0–45 µm marble powder at 28 and 90 days of curing.

Figure 9 presents the ultrasonic pulse velocity (UPV) values at 28 and 90 days for cement mortars incorporating marble powder with a particle size of 0–45 microns. The data demonstrate how different marble powder replacement ratios affect the compactness and durability of the cement mortar. The control sample (MT0) showed UPV values of 4020 m/s at 28 days and 4225 m/s at 90 days, indicating good compactness and durability. With a 5% marble powder replacement (MT5), UPV values increased to 4220 m/s at 28 days and 4550 m/s at 90 days, indicating that the addition of marble powder enhances the density and durability of the cement mortar. Similar literature findings report that a 5% replacement ratio fills microstructural voids, leading to increases in UPV and compressive strength (Sathe et al., 2024). A 10% marble powder replacement (MT10) further increased UPV values to 4450 m/s at 28 days and 4650 m/s at 90 days, suggesting continued improvement in compactness and strength. Majeed et al. also reported that a 10% replacement ratio increases both the density and UPV of concrete, indicating fewer voids in the microstructure (Majeed et al., 2021).

However, a 15% marble powder replacement (MT15) caused a significant decrease in UPV values, dropping to 3850 m/s at 28 days and 4050 m/s at 90 days, indicating that higher replacement levels begin to weaken mortar compactness and reduce strength. Seghir et al. reported that marble powder replacement exceeding 15% reduces UPV values, associating this with increased porosity (Toubal Seghir et al., 2020). At 20%, 30%, and 40% replacement levels, UPV values further decreased to 3320 m/s, 2910 m/s, and 2150 m/s, respectively. These findings demonstrate that high marble powder content increases internal porosity, slowing sound wave transmission and weakening material strength. Boukhelkhal et al. noted that

replacement levels above 20% significantly reduce UPV and strength due to insufficient binder phase development (Boukhelkhal et al., 2016). In conclusion, marble powder replacement up to 10% in the 0–45 micron range improves UPV values and strength, while higher ratios degrade the microstructure and negatively affect performance.

4. Conclusion

This study evaluated the influence of marble powder incorporation—at two distinct particle size ranges (0–45 µm and 0–75 µm)—on the physical and mechanical performance of cement mortars. Key properties investigated included compressive strength, ultrasonic pulse velocity (UPV), water absorption, and chloride permeability.

For mortars with 0–45 µm marble powder, optimal improvements in compressive strength and UPV were observed at 5% and 10% replacement levels, indicating enhanced matrix densification and reduced internal porosity. Water absorption and chloride permeability remained comparable to the control sample at these levels. However, at 15% and 20%, a marked deterioration in mechanical and durability performance occurred, primarily due to increased porosity and reduced cohesion in the cementitious matrix.

Similarly, mortars containing 0–75 µm marble powder showed strength and UPV gains at 5–10% replacement, but exhibited higher water absorption and permeability compared to the finer powder group. At ≥15%, the coarser particles caused a more significant decline in all measured properties, attributed to their limited packing efficiency and increased void content.

Overall, the finer marble powder (0–45 µm) outperformed the coarser one in terms of strength, compactness, and durability. The results underscore that both particle size and replacement ratio are critical parameters, with the optimal substitution level identified as 10% for 0–45 µm marble powder. This proportion provides a sustainable approach for partial cement replacement, improving performance while reducing environmental impact.

Acknowledgment

This research was supported under the scope of the Scientific and Technological Research Council of Turkey (TÜBİTAK) 2209-A University Students Research Projects Support Program, 2nd term of 2023, with project number 1919B012326839.

Conflict of Interest

The authors declare that they have no conflict of interest.

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