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UTILIZING RECYCLED MARBLE POWDER DUST TO PART OF THE CEMENT IN CONCRETE

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ABSTRACT

This research investigates the mechanical properties of environmentally friendly concrete utilizing waste marble powder (WMP) as a partial substitute for cement. Both non-destructive and destructive testing methods were employed to assess the concrete's qualities. The aim is to reduce the negative effects of marble powder waste on the environment and reduce the excessive extraction of natural resources. Concrete mixtures with varying levels of WMP substitution (ranging from 0% to 20%) were developed and evaluated for splitting tensile strength, compressive strength, and flexural strength. Durability properties were assessed using the Schmidt Hammer, and ultrasonic pulse velocity tests. Findings showed that concrete containing 10% WMP could be safely used in cement production. However, adding WMP reduced workability by up to 32.07% compared to the control mixture due to its high-water absorption. Significant improvements in compressive strength were observed, particularly on day 7, with increases of up to 25.34% for 10% WMP substitution. Nonetheless, after reaching a 10% replacement level, compressive strength gradually decreased over time. This decline suggests an optimal substitution level of 10% WMP for practical and efficient use. Furthermore, correlation analysis between compressive strength measurements obtained by different methods confirmed the reliability of the results obtained by the Universal Testing Machine (UTM).

Keywords: marble powder, cement replacement, workability, strength, Schmidt hammer, ultrasonic velocity.

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1. INTRODUCTION

Concrete, a widely utilized composite material, is a pivotal structural component in the evolution of global infrastructure. It ranks second only to water in terms of usage, boasting a worldwide production of around 5.3 billion cubic meters annually (Ullah *et al.*, 2022). It consists of three primary elements: water, aggregate, and cement. Cement, the primary ingredient in concrete, in its powdered state, acts as a binding agent when combined with water and aggregate. Cost-effective, adaptable, durable, and malleable into various shapes and finishes, concrete is typically plain. It demonstrates high compressive strength but low tensile strength, very limited ductility, and weak crack resistance (Rai, 2017). As a result, ensuring durability has progressively emerged as a notable concern within the construction sector (Aggarwal *et al.*, 2014). The manufacture of concrete reportedly accounts for 8% of the carbon dioxide emissions worldwide, with Portland cement being a primary contributor (Anwar *et al.*, 2015; Jang, 2016). The extraction of all concrete's raw materials, directly or indirectly sourced from the Earth's crust, has heightened the global depletion of these resources. Consequently, significant environmental and economic concerns have arisen due to the widespread utilization of concrete (Sankh, 2014; Rashad, 2013). This necessitates an entire or partial cement replacement with an ecologically friendly substance. In this scenario, we anticipate two objectives: the first strives to diminish the CO2 emissions generated by cement manufacturing, while the second seeks to mitigate environmental effects by utilizing residual industrial materials as a fine/coarse aggregate or as an alternate for cement.

Researchers have suggested several waste products from industry and agriculture materials in the last century like husks of rice ash, fly ash, sewage sludge ash, bagasse ash, Polyvinyl Chloride waste powder (PWP), and textile sludge ash (TSA) capable of partially substituting concrete ingredients. This approach notably preserves natural resources, mitigating their depletion, while also enhancing the economy and sustainability of concrete production (Arulmoly, 2021).

In their 2019 research, Jalil *et al.* incorporated steel slag, an industrial byproduct as a substitute for some cement in conventional concrete. Their findings highlighted the superior mechanical properties achieved with finely ground slag powder in contrast to the control specimens. Khan *et al.* (2020) replaced a part of the sand in regular concrete with recycled rubber tire particles. Their study indicated that a minimal 5% dosage of finely and coarsely textured rubber particles, uniformly dispersed, enhanced compressive strength and bolstered adhesion with the adjacent cement paste. In their study, Munir (2016) partially substituted rice husk ash for cement in concrete. According to their findings, reducing the alkali-silica reaction in the material can be achieved by adding 10 to 40 percent rice husk ash to cement. Abubakr (2019) partially substituted recycled ceramic powder for cement in standard concrete specimens. Based on their research, flexural strength, density, and workability are all improved when there is a 10-20% fine ceramic powder content.

It's been proven that waste marble powder (WMP) has potential instead of cement or as fine/coarse aggregate when making concrete. Marble, a metamorphic stone with finely divided crystals consisting of calcite grains, forms from the dolomitic and limestone rocks' low-level transformation. This carbonate rock can contain up to 99% calcium carbonate (CaCO3) along with varying traces of MgO, SiO2, Al2O3, Fe2O3, and Na2O.

A substantial quantity of waste is generated by the marble production industry (Aruntas *et al*., 2010)). This waste, which makes up about half of the minerals extracted, is produced continuously from the start of the mining process until the finished product. The marble blocks are delivered to a point of sale or workshops close to the quarry. Marble block-cutting machines first split the block into slabs that are easier to handle. If required, a second manual cut is made with a saw. Other procedures include polishing, flame-firing, brushing-hammering, and finishing. Throughout the marble cutting process, a significant volume of water is used as a coolant, reaching 1.5 m^3 per square meter of the sawn slab (Ruiz-Sánchez *et al*., 2019). Following its discharge, this water is recycled within the wastewater infrastructure, where suspended solids, or sludge, are recovered. These sludge materials and the ready marble grains makeup the waste generated using these procedures, which have been displayed to have almost the same makeup as the initial rock and to be free of harmful substances (Ruiz-Sánchez *et al*., 2019). As a result of incorporating residual marble dust as an additive, the resulting dried sludge product becomes highly refined, with 90% of its particles measuring below 200 μm. Marble dust finds extensive application across various fields and uses as both a raw material and strengthening agent, including in ceramics (Aruntas, 2010)), brick production (Saboya, 2007), and the creation of building materials (Sarkar, 2006)). The classification of these waste materials, whether as marble dust or coarse marble waste, dictates their application (Akbulut, 2007).

Using waste as concrete aggregates have been extensively studied, highlighting its durability (Andre *et al*., 2014; Binici *et al.,* 2007-2008), technical viability (Silva, 2017 and Rahal., 2007), and physico-chemical effects (Hebhoub, 2011). On the other hand, cement can be substituted with waste dust. Making use of residual marble in the concrete and ceramic industries for producing mortar, concrete, and cement has captured the attention of several researchers.

In research conducted by Binici (2007), stone and marble dust were substituted for sand in the same experiment to ascertain the cement's compressive strength. Changes were made to the mixture at the 5%, 10%, and 15% levels. It appears from the results that concrete with fine aggregates of marble dust (MD) and limestone dust (LD) works well and resists abrasion just like conventional concrete. Concrete composed of recycled granite and marble aggregates was tested for freshness and durability by Binici (2008) in an additional study. The combination of aggregates, cement, and additives is better joined in specimens that contain both marble and granite. Hameed (2009) replaced natural sand in concrete mixes with a mixture of marble sludge and quarry dust. This resulted in concrete mixes that were stronger, more resistant to sulfates, and had lower permeability than mixes that used natural sand. The effects of incorporating recycled marble dust as a component of mixed concrete were studied by Aruntas (2010). They assessed the influence of adding recycled marble dust to cement at different weight ratios of 2.5%, 5%, 7.5%, and 10% on the mechanical, physical, and chemical characteristics. The findings suggested that mortars containing 10% recycled marble dust could be safely used in cement production. Corinaldesi (2010) looked into the potential substitution of marble dust for cement in concrete and mortar, either with or without extra additives. Among the several mortar blends they mechanically evaluated, the concrete using 10% powdered marble in comparison to cement had the highest compressive strength in their investigation. Demirel (2010) discovered that when marble powder content in concrete increases, the concrete's porosity decreases and the ultrasonic pulse velocity (UPV) increases. It's worth noting that proportions of 0%, 25%, 50%, and 100% were used for fine sand, which had passed through a 0.25 mm sieve. In a study, Hebhoub (2011) suggested substituting marble aggregates for coarse and fine aggregates at a level of substitution as high as 75%. Ergun in 2011 explored the use of recycled marble dust and diatomite as partial replacements for cement in concrete blends. Their assessment involved varying the ratio (w/c) of water to cement from 0.50 to 0.63 while evaluating the compressive and flexural strengths. The findings showed that concrete samples containing 5% and 10% diatomite recycled marble dust exhibited the highest values for compressive and flexural strength. Belachia (2011) experimented with different ratios of marble waste to substitute aggregates. Incorporating recycled marble waste into the concrete mix, demonstrated that including 25% marble waste by weight maximized the concrete's compressive strength. Their findings support the viability of replacing recycled marble waste, offering satisfactory outcomes in qualities of workability and strength, compared to the traditional mixture. Marble dust functions as a micro-filler within the concrete mix and exhibits superior performance when replacing sand rather than cement. In a study by Omar (2012), concrete mixes incorporated replacement percentages of limestone waste at 25%, 50%, and 75%. Additionally, they contained marble powder at 5%, 10%, and 15%. The study encompassed tests for modulus of elasticity, permeability, flexural strength, indirect tensile strength, and compressive strength. It has been noted that integrating waste limestone as a fine aggregate improved the workability of freshly mixed concrete. However, there was no change in the concrete's unit weight. As found in the research by Shirley (2012), the incorporation of 10% marble dust into cement increased the compressive strength after 28 days by up to 17%, and by 11.5% for the tensile strength. Shelke (2012) investigated how incorporating marble dust in specific ratios to cement impacted concrete strength. The findings demonstrated that the most favorable compressive strengths at both 7 and 28 days resulted from including 8% recycled marble dust and 8% silica fume in the cement. Bacarji (2013) utilized marble and granite waste (MGR) at 5%, 10%, and 20% levels as substitutes for Portland cement. Within the MGR-incorporated concrete, the most favorable outcomes for mechanical properties, encompassing abrasion resistance, elastic modulus, compressive strength, and concrete rheology, were attained at a 5% replacement rate. As noted by Soliman (2013), there was a maximum increase in compressive strength of 24.56% at 28 days when 5% of the cement was replaced with marble powder in the nominal mix. However, the strength decreased when marble powder was included in the nominal concrete mixture instead of cement. The splitting tensile strength was reduced by 47%, and the compressive strength at 28 days decreased by 26% compared to a 20% replacement. In 2014, F. Gameiro concluded that adding WMP in place of 20% sand enhanced the long-term durability of concrete by improving the capillary absorption of water and resisting carbonation. Another study by Pathan (2014) explored the application of marble powder alternatively to fine particles in mortars and concrete. Their findings highlighted that the optimal strength was achieved by replacing 12.5% of sand with marble powder. In their study, Aliabdo (2014) manufactured concrete by substituting marble dust waste at rates of 5%, 7.5%, 10%, and 15% for both sand and cement separately. Their findings indicated that incorporating 15% marble powder showed no significant alteration in ultrasonic pulse velocity compared to scenarios using cement and sand. Additionally, substituting 10% marble powder for sand led to a 14% enhancement in concrete's compressive strength, while the strength of the mix with a low ratio of water to cement increased by 22%. Kumar (2015) noted a 21.48% enhancement in the compressive strength on day 28 when 10% of cement was substituted with marble powder. Rana (2015) explored the viability of employing marble sludge as a partial Portland cement substitute used in the manufacturing of concrete. They created concrete blends where up to 25% of Portland cement was substituted with marble slurry, evaluating various characteristics including strength, permeability, porosity, morphology, chloride migration resistance, carbonation, and corrosion. According to their findings, a substitution of 10% of Portland cement with marble slurry was viable. The outcomes of the carbonation test, as demonstrated by Malay (2016), indicate that increased marble powder concentrations result in a minor reduction in carbonation depth while simultaneously improving compressive strength. Munir (2018) investigated the effects on the properties of clay bricks made with marble powder instead of some of the clay. They noticed that the porous nature of marble powder made it possible to produce strong bricks that were only slightly weaker. According to Li (2018), the absorption of water is reduced by 46% and the depth of carbonation is reduced by 43% when marble powder slurry is added up to 20%, which enhances the durability of mortar mixtures or concrete. Ashish (2018) concluded in their study that, to maintain suitable concrete compressive strength, the optimum amount of marble powder replacement in cement should not exceed 20%. Concrete exhibits more capillarity when there is more marble dust present. Based on the findings of the study conducted by Ruiz-Sánchez (2019), the addition of 10% marble dust does not affect flexural strength, but it decreases with replacement values greater than 10%. Based on experimental research by Selvasofia (2021), the concrete mixture demonstrated exceptional workability, split tensile strength, and compressive strength up to 10% marble powder (WMP). In the study by M. Belouadah (2021), marble powder was used to partly substitute cement at varying weight replacement levels: 5%, 10%, 15%, 20%, 25%, and 30% by weight, with a 1.5% admixture. With the use of non-destructive assessment techniques like the rebound hammer and ultrasonic pulse velocity, the concrete's compressive strength was established. The values for compressive strength and ultrasonic pulse velocity were relatively low at an early stage of curing. Nonetheless, the velocity of ultrasonic pulses and the compressive strength of every sample rose along with the curing period. In the study of Majeed (2021), with replacement ratios of 0%, 5%, 10%, 15%, and 20%, various mixes of concrete were created. Apart from non-destructive exams such as the velocity of ultrasonic pulses and rebound hammer tests, samples were subjected to destructive tests for their flexural, tensile, and compressive strengths. It was found that adding more cement could increase the strength of the concrete by up to 10%. The compressive strength results were validated by Schmidt rebound numbers. Bourzik (2023) conducted a study involving the preparation of five different concrete mixes, replacing sand at levels of 0%, 5%, 10%, 15%, and 20%. They carried out multiple tests to evaluate density, workability, compressive strength, and ultrasonic pulse velocity. Their research revealed a direct correlation between the increase in waste marble powder proportion and the concrete's compressive strength, peaking at an optimal percentage of 15%.

2. RESEARCH RELEVANCE

Reducing reliance on natural resources and minimizing environmental degradation are the main goals of this study. The principal aim of this research is to examine the mechanical consequences of partially replacing leftover marble powder with cement. The percentage of marble powder added to concrete in place of cement was the primary variable considered in this investigation. One method to help reduce CO2 emissions is to partially replace cement with marble powder. Part of the Cement is changed out with marble powder at rates of 5% and 20%, progressively increasing by 2.5%. The concrete samples produced with these modifications are evaluated for workability, compressive, split tensile, flexural strength, ultrasonic pulse velocity, and Schmidt Rebound Hammer.

3. INVESTIGATING EXPERIMENTALLY

3.1 Materials

With a minimum clinker content of 65%, Portland cement CPJ 45 was selected as the binder for this project to formulate concrete. The remaining materials consisted of additives such as fly ash, pozzolans, and fillers provided by Holcim and complying with the Moroccan specifications NM10.1.004. The concrete was mixed using water for drinking supplied by Oujda's Autonomous Intercommunal Water and Electricity Distributing Agency (RADEEO). This water meets the physical and chemical standards of NM 10.1.353. The choice of cement was based on its widespread use in Morocco's construction industry. It is particularly suitable for large-scale constructions requiring gradual temperature increases, as well as reinforced concrete. For this project, Oujda region natural crushed sand was used. It was almost devoid of impurities, with a specific gravity of 2.68 g/cm^3, a 1.5% water absorption, and a 2.85 fineness modulus. Its smooth, spherical, cube-shaped construction provides good workability. To manage the water content of the concrete, the sand was dried for an entire day at room temperature. The largest sand's size was 4.75 mm. The NF EN 12620 standard was followed for conducting the sand tests.

In this investigation, two varieties of coarse stone aggregates, G1 and G2, with specific densities of 2.70 and 2.72 g/cm^3 respectively, were used. As stated by the NF P-18-560 standard, Figure 1 shows the particle size analyses of the different materials utilized.

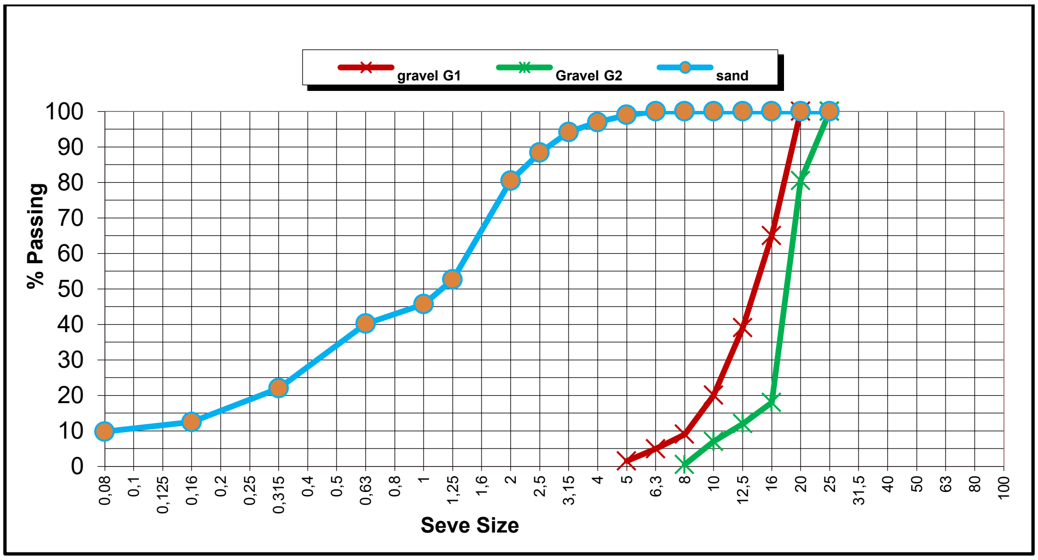

Figure-1. Distribution of sand, gravel G1, and gravel G2 particle sizes.

As an auxiliary material in the process of shaping and cutting, marble companies provided marble dust in the form of wet slurry. It had a Blaine fineness of 1500 m^2/kg and a specific gravity of 2.71 g/cm^3. To get rid of extra water, the trash was first air-dried and then oven-dried. The marble powder exhibits a large specific surface area, which suggests that adding it to mortars and concretes should increase their cohesiveness. The chemistry constitution of marble dust and cement was assessed by the use of X-ray fluorescence (XRF) analysis, according to Table-1. The marble powder X-ray diffraction (XRD) spectrum is displayed in Figure-2. The physical characteristics of marble powder and cement are shown in Table-2. Figure-3 depicts a mixture of marble powder and cement.

Table-1. Chemical constitution of residual marble powder and cement.

Constituent (%)	Cement (%) by mass	Waste marble powder (%) by mass
CaO	60.06	47.71
SiO2	20.90	6.69
Fe2O3	3.90	0.82
AL2O3	5.85	2.16
MgO	1.85	1.52
K2O	2.14	0.25
TiO2	0.32	0.06
SO3	2.35	0.44
LOI	21.84	39.83

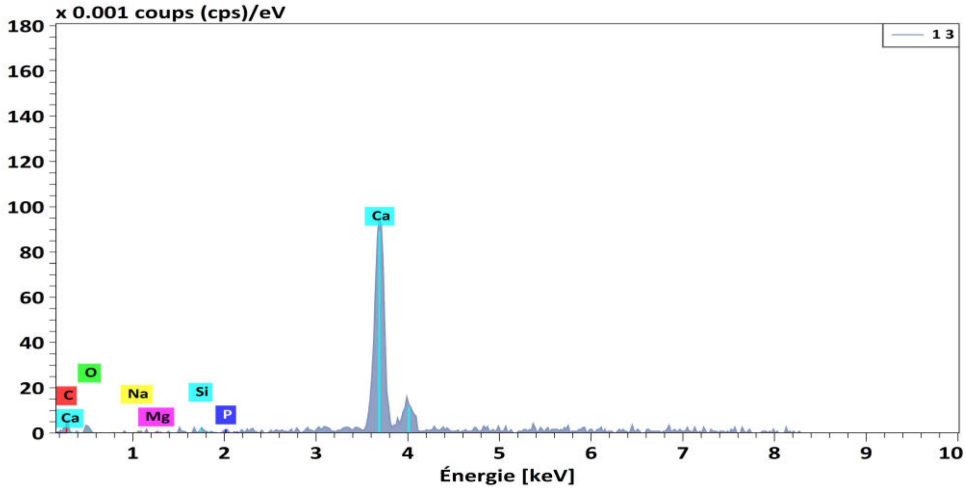

Figure-2. X-ray diffraction spectrum of marble powder.

Table-2. Physical characteristics of Cement, WMP, sand, coarse aggregate G1 and G2.

Property	Cement	WMP	sand	G1	G2
Specific gravity	3,15	2,71	2,68	2.70	2.72
Consistency (%)	29				
Initial setting time (min)	180				
Final setting time (min)	210				
Finesse Blaine (cm^2/gm)	3100	3320			

To evaluate the impact of substituting waste marble powder for a part of the cement on concrete performance, the water-to-binder ratio remained constant at 0.5 for every test specimen. Different percentages of Waste Marble Powder (WMP) were employed instead of cement in the cement concrete. The mixture ratios of concrete are listed in Table-3, with varying percentages of WMP. In the absence of marble powder, CMD-0 is the control paste. CMD-i represents the concrete with i% marble powder by weight of cement. The Dreux-Gorisse model was applied to carry out the concrete design.

Table-3. Mixture proportions with w/c=0, 5.

Mix identification	WMP (%)	Water (L/m3)	Cement (Kg/ m3)	FA (Kg/m3)	G1(Kg/ m3)	G2 (Kg/m3)	WMP (Kg/m3)
CMD-0	0	175	350	763	327	833	0,0
CMD-5	5	175	332,5	763	327	833	17,5
CMD-7,5	7,5	175	323,5	763	327	833	26,25
CMD-10	10	175	315	763	327	833	35
CMD-12,5	12,5	175	306,25	763	327	833	43,75
CMD -15	15	175	297,5	763	327	833	52,5
CMD-17,5	17,5	175	288,75	763	327	833	61,25
CMD-20	20	175	280	763	327	833	70

FA = Fine aggregate, G1= Coarse aggregate of type 1, and G2= Coarse aggregate of type 2.

3.2 Test Parameters

The study's experimental program took place at two locations: the testing building materials laboratory within the Oujda Faculty of Science and the LABNORVIDA testing laboratory in Oujda. Concrete mixes were meticulously prepared using a 125-liter capacity pan mixer. First, the mixer was filled with coarse aggregates, followed by the addition of fine aggregates. A small amount of water, taken from the total calculated quantity, was also added. The blend of cement and marble dust was subsequently added before incorporating the remaining water. The mixer was left running until a homogeneous mixture was achieved.

3.2.1 Workability

The effect of partially substituting marble powder for cement on the regularity of freshly mixed concrete mixes was studied using the slump cone test in compliance with NF EN 12350-2. The slump cone had a standard size, measuring 300 mm in height, 200 mm in bottom diameter, and 100 mm in top diameter. Workability was assessed by conducting slump tests on all the mixtures and measuring the slump values for various concrete blends. Marble powder was used at rates of 0%, 5%, 7.5%, 10%, 12.5%, 15%, 17.5%, and 20% in place of some of the cement.

3.2.2 Compressive split tensile and flexural strength

Compressive strength is crucial for assessing the structural capacity of concrete in buildings. To determine the concrete's compressive strength, 150 mm by 150 mm by 150 mm concrete cubes are cast. According to NF EN 12390-3, compressive strength is measured at curing ages of day7, day 14, and day 28. The samples were cured under 100% relative humidity and a constant ambient temperature of 27 ± 2°C with water. The compressive strength denoted as
R_c, is calculated using Eq. (1).

$$R_c = \frac{Maximum\ load\ at\ failure}{cross\ sectional\ area\ of\ specimen} \quad (1)$$

Cylinders, measuring 300 mm in height and 150 mm in diameter, are created to gauge the concrete's split tensile strength. Following the guidelines of NF EN 12390-6, the tensile strength is assessed at curing ages of day 7, day 14, and day 28. The tensile strength R_t is given by Eq. (2)

$$R_t = \frac{2\times\ Maximum\ load\ at\ failure}{\pi\times\ diameter\ of\ specimen\ \times height\ of\ spacimen} \quad (2)$$

To assess the concrete's flexural strength of, concrete prisms of 500 mm by 100 mm by 100 mm were cast. As per NF EN 12390-5, flexural strength is determined after day 7, day 14, and day 28 of the treatment. Flexural tensile strength is given by Eq. (3)

$$R_f = \frac{3\times Maximum\ load\ at\ failure\times length}{2\times width\ of\ specimen\times heigth\ of\ spacimen^2} \quad (3)$$

Figure-3. Compressive universal testing machine.

3.2.3 Ultrasonic pulse velocity

Concrete quality can be evaluated in situ using a non-destructive technique called ultrasonic pulse velocity testing. The NF EN 12504-4 standard procedure for ultrasonic testing is followed. The test was conducted using a voltage of 500 V and a frequency of 54 kHz. The gadget is shown in Figure-4. An ultrasonic pulse sending and receiving processor unit is part of the gadget, and it also measures the interval between the two processes. The sound energy is transferred via two probes on the apparatus. The pulse flow rate is determined by the time interval between these two acts: the probe that is sent into the concrete emits sound energy, and the probe that is received receives this energy. The pulse flow rate in this study is determined via opposite surfaces, as Figure-5 illustrates. Concrete cube specimens are subjected to ultrasonic pulse velocity tests after 28 days.

Figure-4. Sonic inspection device.

Figure-5. Direct transparency measurements.

3.2.4 Schmidt rebound hammer

By measuring the rebound of a spring-driven hammer that strikes the concrete surface, the Schmidt Rebound Hammer is an instrument used to determine the concrete's compressive strength. This non-destructive control technique yields a concrete strength estimate compliant with NF EN 12504-2. The rebound hammer readings are correlated to concrete compressive strength using conversion charts provided by the manufacturer. These charts are based on extensive testing and correlations between rebound values and actual concrete compressive strength.

Figure-6. Scmidt Rebound Hammer.

4. RESULTS AND CONVERSATIONAL ANALYSIS

4.1 Marble Powder's Impact on the Concrete's Workability

The percentages of workability were 5% and 20%, progressively rising by 2.5%, for both blends of concrete mixtures and the control mixture using marble powder combined with cement. Table-4 displays the replacement levels of mixtures and their corresponding slump values. It was observed that when marble powder is used in place of cement, the slump decreases, as illustrated in Figure-7. The increased specific surface area of marble compared to CPJ cement increases internal friction, and the higher water absorption property demonstrated by WMP can be attributed to this. It can be noted that CMD-5, when compared with CMD-0, had 5.66% less workability. The workability values for CMD-7.5, CMD-10, CMD-12.5, CMD-15, CMD-17.5, and CMD-20% decreased by 7.54%, 13.20%, 16.98%, 20.75%, 26.41%, and 32.07% respectively.

Table-4. Slumps values.

Mix designation	Slump(mm)
CMD-0	53
CMD-5	50
CMD-7.5	49
CMD-10	46
CMD-12.5	44
CMD-15	42
CMD-17.5	39
CMD-20	36

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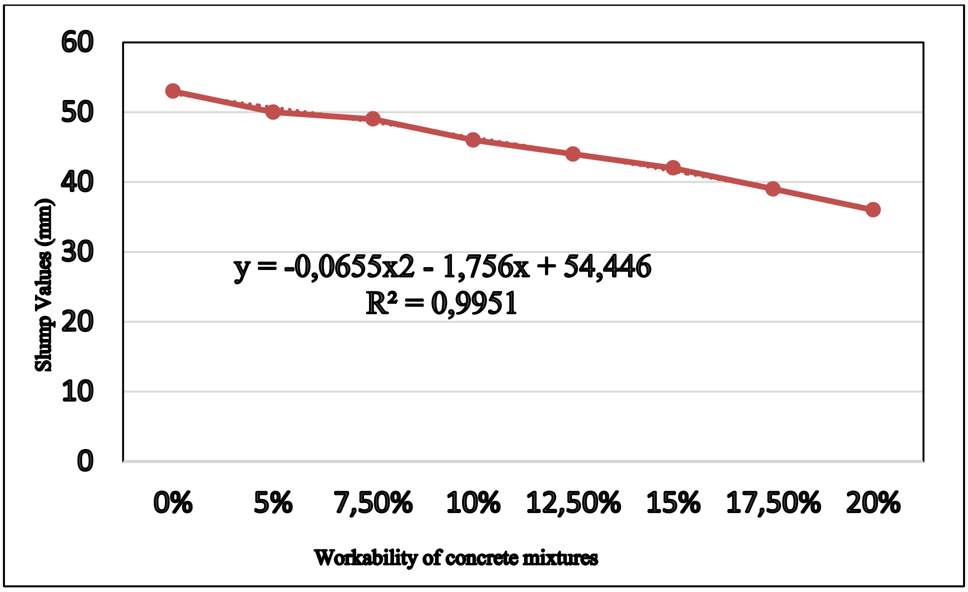

Figure-7. Workability of concrete mixtures.

4.2 Marble Powder's Impact on the Compressive Strength

Tests of compressive strength were conducted on concrete samples. During the process, the specimens underwent water curing. Before analysing each concrete specimen on days 7, 14, and 28, samples were given a full day to dry. Three specimens were used to obtain the average result. Utilizing the universal testing machine (UTM), both tensile strength and compressive strength results were acquired. Table-5 displays the compressive strength values for each test specimen. The specimens' compressive strengths are displayed in Figure-8, after partial cement substitution by 0%, 5%, 7.5%, 10%, 12.5%, 15%, 17.5%, and 20% of WMP. After reaching a 10% replacement level, the concrete's compressive strength gradually decreased at the ages under study. At day 7, improvements of 10%, 15.46%, and 25.34% were observed in the compressive strength of samples in which 5%, 7.5%, and 10% of WMP had been substituted for cement compared to the control mixture. Increases of 12.93%, 18.57%, and 20.73% were noted on day 28, after improvements of 6.46%, 11.77%, and 18.29% on day 14. Conversely, examples with 15%, 17.5%, and 20% of WMP substituted for cement showed a decrease of 8.2%, 11.06%, and 17.4% following the 28th day. The early increase in compressive strength is indicative of the presence of fine WMP particles filling the pores and altering the properties of the transition area enveloping aggregates. Additionally, the particles aid in the creation of alumina hydrates and stimulate the pozzolanic reaction of calcium hydroxide to generate CSH gel. Considering that 10% WMP substitution produced the highest amount of compressive strength, a 10% WMP substitution is a practical and efficient partial substitute for cement.

Table-5. Compressive strength.

the proportion of marble powder substituted for cement	Concrete's Compressive strength		
	Day 7	Day 14	Day 28
0%	17,20	21,32	27,30
5%	18,92	22,70	30,83
7,5%	19,86	23,83	32,37
10%	21,56	25,22	32,96
12,5%	20,69	23,70	30,65
15%	17,25	19,475	25,04
17,5%	16,56	22,51	24,28
20 %	15,52	17,18	22,53

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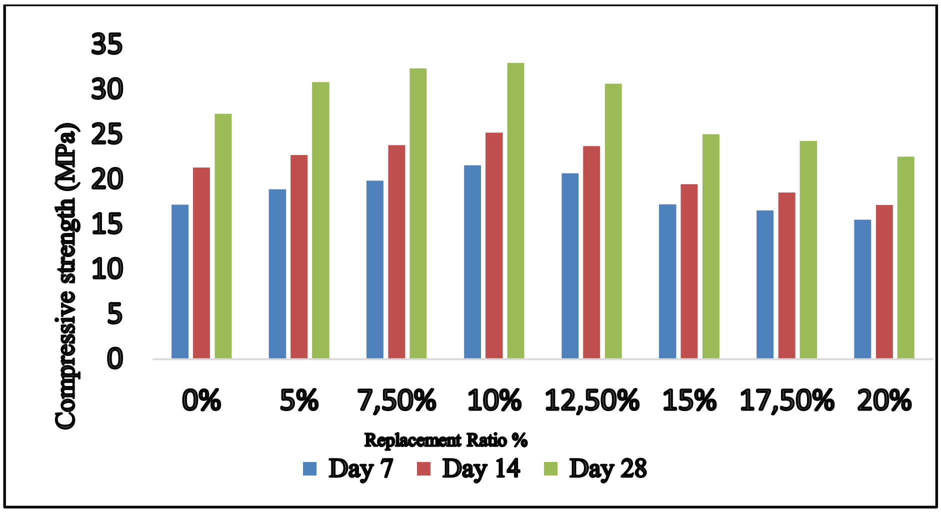

Figure-8. Concrete's compressive strength in the absence and presence of marble powder.

4.3 Marble Powder's Impact on the Split Tensile Strength

The specimens are tested using a universal testing machine (UTM) on days 7, 14, and 28. Table-6 shows the split tensile strength of mixtures in which 0%, 5%, 7.5%, 10%, 12.5%, 15%, 17.5%, and 20% of WMP are substituted for cement. The examined specimens' split tensile strength is impacted by the inclusion of WMP as a substitute for cement, as shown in Figure-9.

It was noted that, compared to the control mix, the splitting tensile strength increased up to a substitution level of 10%. However, at both curing ages, there was a 10.0% decrease in tensile strength upon substitution. Compared with the control mixture, specimens containing 5%, 7.5%, and 10% of WMP as a substitute for cement showed increases in split tensile strength of 11.02%, 14.28%, and 16.73% at day 7, and 1.39%, 3.35%, and 7.54% at day 28, respectively. However, specimens with 20% WMP substituted for cement showed a loss in split tensile strength in contrast to the control mixture, with reductions of 9.76% at day 7, 19.41% at day 14, and 17.47% at day 28.

Table-6. Split tensile strength.

the proportion of marble powder substituted for cement	Concrete's Split Tensile strength		
	Day 7	Day 14	Day 28
0%	2,45	2,54	3,58
5%	2,72	3,4	3,63
7,5%	2,80	3,5	3,7
10%	2,86	3,58	3,85
12,5%	2,74	3,4	3,65
15%	2,58	3,2	3,4
17,5%	2,41	2,95	3,2
20 %	2,25	2,7	3

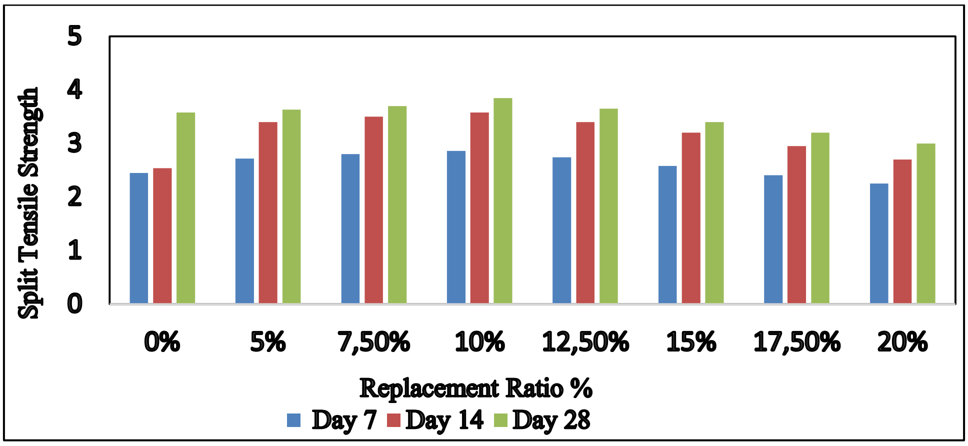

Figure-9. Split tensile strength variation with replacement.

4.4 Marble Powder's Impact on the Flexural Strength

The samples are examined utilizing a universal testing machine (UTM) on day 7, day 14, and day 28. The flexural strength values for the examined concrete specimens with 0%, 5%, 7.5%, 10%, 12.5%, 15%, 17.5%, and 20% of WMP as a substitute for cement are displayed in Table-7. The replacement of WMP for cement at the curing ages had a favorable effect on the specimens' flexural strength, with the maximum flexural strength occurring at 10%, as shown in Figure-10.

Table-7. Flexural strength.

the proportion of marble powder substituted for cement	Concrete's flexural strength		
	Day 7	Day 14	Day 28
0%	2,82	3,49	3,83
5%	2,92	3,67	4,02
7,5%	2,96	3,70	4,07
10%	3,03	3,78	4,21
12,5%	2,84	3,55	3,94
15%	2,64	3,27	3,59
17,5%	2,45	3,01	3,16
20 %	2,39	2,74	2,84

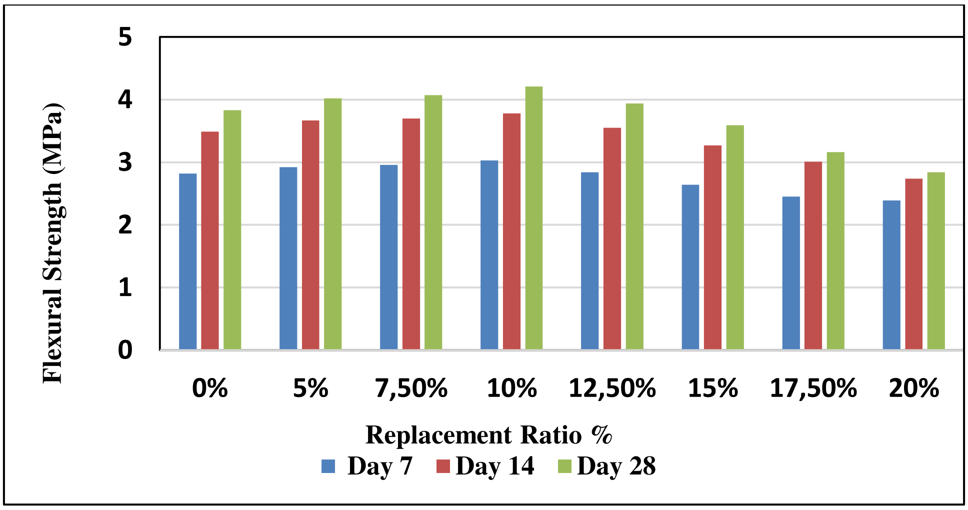

Figure-10. Variation in flexural strength with substitution.

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Compared with the control mixture, specimens containing 5%, 7.5%, and 10% of WMP as a substitute for cement showed increases in flexural strength of 3.54%, 4.96%, and 7.44% at day 7, and 4.96%, 6.26%, and 9.92% at day 28. However, with 20% of WMP as the cement substitute, there was a reduction in flexural strength by 15.24% after day 7, 21.48% after day 14, and 25.84% on day 28 compared to the control mixture.

4.5 Marble Powder's Impact on the Velocity of Ultrasonic Pulses

UPV tests on concrete cube specimens are performed at 28 days. Table-8 and Figure-11 demonstrate the cement paste's UPV results. It is important to observe that, unlike the control concrete CMD-20; all concretes containing marble powder show a normal sound speed. The quality of the concrete is unaffected when marble powder is used in place of cement. The velocity of ultrasonic pulses has increased by 13.05%, 18.05%, and 20.83% for 28 days for concrete mixtures CMD-5, CMD-7.5%, and CMD-10%, respectively, compared with the values of the control mixture CMD-0. It is also noted that there is a decline in the values of UPV at 28 days for the concrete mixture CMD-20 made with partial substitution of cement by 17.5% compared with CMD-0. This might be clarified by the inert addition's impact, which is ultrafine aggregates occupying gaps (Ulubeyli *et al.*, Aliabdo *et al.*, 2014). In conclusion, pulse velocity increases significantly when cement is substituted with waste marble powder up to a 10% substitution rate. But once 12.5% is reached, a decline is shown.

Table-8. Compressive strength and UVP.

the proportion of marble powder substituted for cement Velocity of ultrasonic pulses	UPV (Km/s)	Compressive Strength (MPa)
0%	3,60	27,30
5%	4,07	30,83
7,5%	4,25	32,37
10%	4,35	32,96
12,5%	3,97	30,65
15%	3,65	25,04
17,5%	3,25	24,28
20%	2,97	22,53

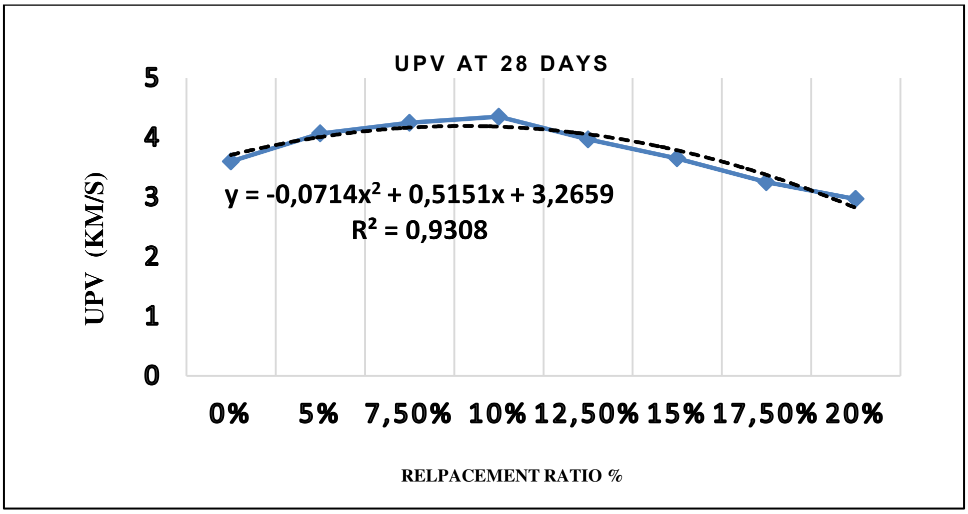

Figure-11. Ultrasonic pulse velocity variation with replacement proportion.

To assess the compressive strength and ultrasonic pulse velocity of concrete incorporating marble powder, experimental findings were compared with empirical data, as depicted in Figure-12.

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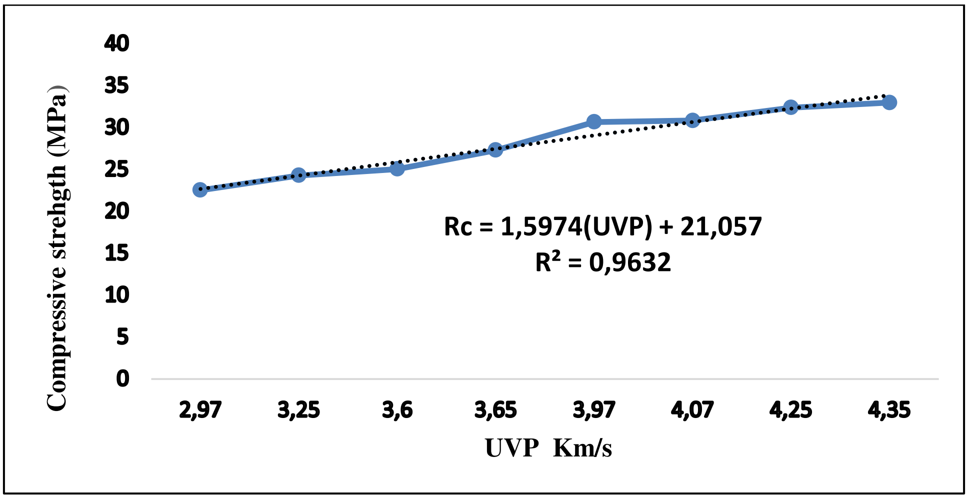

Figure-12. Compressive strength and ultrasonic pulse velocity relationship.

A regression analysis was then conducted to establish a formula for calculating compressive strength determined by the UPV test findings. The correlation equation is given by:

Rc = 1, 5974(uvp) +21,057 with R^2 = 0, 9632

Overall, the empirical equation findings exhibited exceptionally high compatibility with the experimental results, as evidenced by the minimal margin of error.

Table-9. Compressive Strength and Rebound Number.

Marble powder substituted for cement	Rebound Number	Compressive Strength MPa
CMD-0	24,8	27,3
CMD-5	26,7	30,83
CMD-7,5	28,3	32,37
CMD-10	29,5	32,96
CMD-12,5	26,5	30,65
CMD-15	20,1	25,04
CMD-17,5	18,2	24,28
CMD-20	17,2	22,53

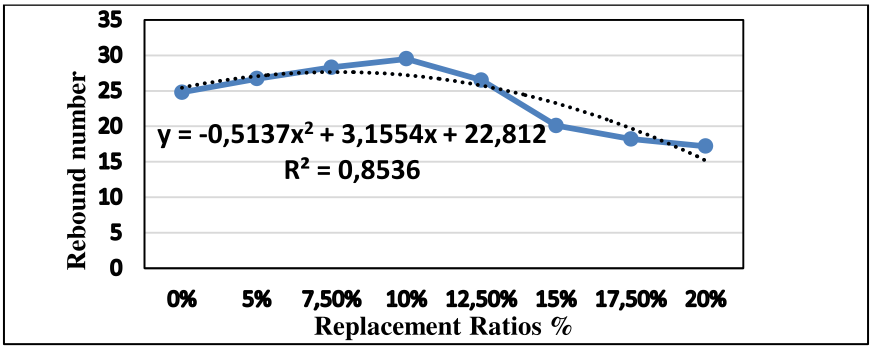

Figure-13. Rebound number variation with replacement proportion.

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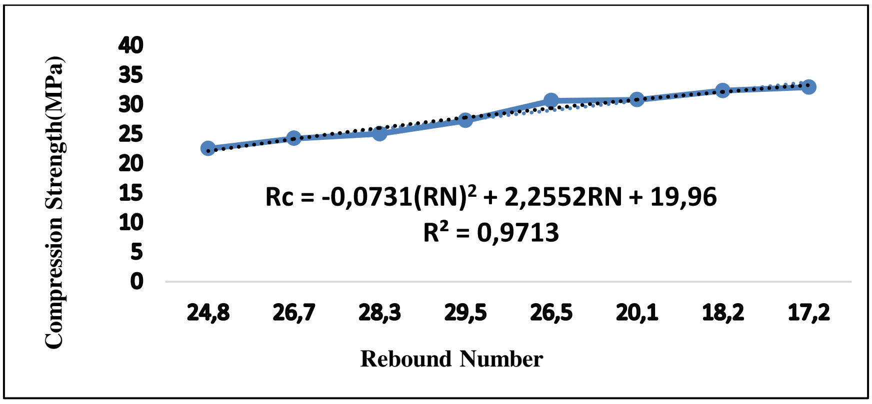

Figure-14. Connectivity between rebound number and compressive strength.

4.6 Rebound Num!ber, UVP, and Compressive Strength Relationships

Examining and assessing the necessary properties would require more than one technique, especially when changes to the concrete's characteristics affect test findings (Neville, 1995). Therefore, by evaluating concrete using both methods simultaneously, errors resulting from relying solely on one method are reduced. The Son Reb method is widely regarded as the non-destructive method most often utilized for evaluating concrete's compressive strength. The principal aim of this paragraph is to set up a correlation between the dependent variable (concrete compressive strength) and the independent variables (rebound number (Rn) and ultrasonic pulse velocity (UPV)), and to compare the results with the strength of samples measured by the universal machine test. A statistical analysis is conducted, and using a combined method, an estimation of the concrete's compressive strength is derived from the following formula:

$$R_C = 4.166 + 3.063\,(UVP) + 0.524(RN)$$

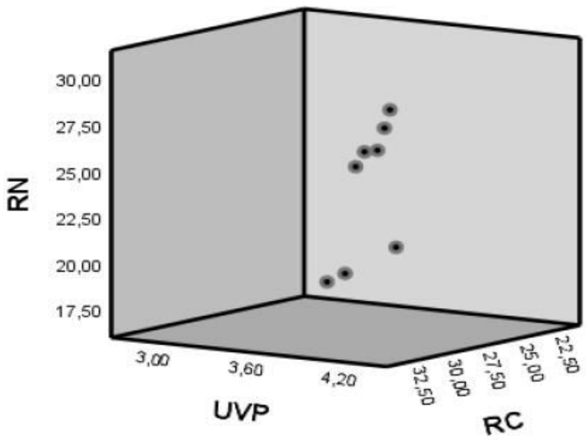

Figure-15. Rebound number RN, compressive strength Rc, and UPV correlation curve.

Given that the R^2 = 0.980 is very near to 1, this linear adjustment models the three variables can be accepted.

5. CONCLUSIONS

a) As a result of the continuous expansion of the construction industry, the availability of natural resources is declining due to the increasing demand for natural aggregates and cement. The principal goal of this research is to assess the feasibility of incorporating waste marble powder into concrete. The results of the tests indicated that: As the proportion of waste marble powder substituted for cement growth, the workability of the entire concrete mix decreases.
b) Up to a maximum of 10% substitution of cement with marble powder a considerable increase in compression, tension, and flexural strength is noted.
c) All mixes containing marble powder, except the CMD-20 mix, show normal ultrasonic pulse velocities, with the CMD-10 mixture exhibiting a peak.
d) It is clear that there is a good approximation of the compression strength obtained from the Universal Testing Machine by comparing the compression strength determined using the Schmidt hammer conversion chart.
e) The rebound number of the Schmidt hammer, ultrasonic pulse velocity, and compressive strength are all highly correlated when using the combined Son Reb method. Here, the rebound number of the Schmidt hammer and the ultrasonic pulse velocity are independent variables.

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