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Research Article

Experimental Investigation on the Utilization of Marble and Scoria Powder as Partial Replacement of Cement in Concrete Production

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This paper explores how marble and scoria powder can be used as partial substitutes for ordinary Portland cement in creating C-25 concrete. Both materials contain over 50% of the major oxides found in cement, with marble high in CaO and scoria high in SiO_2. Experimental investigations were conducted to study the chemical, physical, mechanical, and fresh properties of concrete containing marble and scoria powder. For the investigation, 13 different mixes, including the control mix, were used with a constant water–cement ratio of 0.5 and a slump range of 25–50 mm for concrete with a compressive strength (CS) of 25 MPa. Marble-to-scoria ratio of 2 : 1, 1 : 1, and 1 : 2 was used, and then the combined fraction of both marble waste and scoria in concrete was increased from 0% to 20% in 5% range. Including the control test specimens, a total of 117 (150 × 150 × 150 mm) concrete cubes for CS test, 39 (100 × 100 × 500 mm) concrete beam specimens for flexural strength test, 39 (100 × 200 mm) cylinder specimens for splitting tensile strength (STS) test and, 39 (100 × 100 × 100 mm) cube specimens for water absorption test were cast and tested at 3, 7, 28, and 56 days. The test results indicate that marble and volcanic scoria powders with marble-to-scoria ratio of 1 : 1 could replace cement up to 15% without compromising the CS and up to 10% without compromising the flexural and STS; also, the water absorption decreases up to 10% replacement; however, the workability of the fresh mix decreases as the combined replacement level of marble and scoria increases. Generally, a 10% replacement with marble-to-scoria ratio of 1 : 1 produces concrete with higher compressive, flexural, tensile strength, and water absorption manifestations when compared to conventional concrete.

1. Introduction

1.1. Background. As the construction industry is becoming the main focus of a nation's economy, it is seen that the demand for construction materials is increasing. Because of its versatility, economy, and widespread availability of ingredients, concrete is the most widely used construction material in the world [1]. Though it looks unachievable now, the global cement consumption volume was expected to reach 4.42 billion tons in 2021, growing at a compound annual growth rate (CAGR) of 2.96% for the duration spanning 2018–2021 [2]. However, the faster the growth of the market results, the faster the depletion of natural fossil fuels, which in turn affects the environment and/or the inhabitants in it.

Concrete is the most extensively used construction material in the world because of the economics and widespread availability of ingredients, its versatility, adaptability, and durability [3]. Concrete consists of two components: aggregates and paste. The paste, comprised of Portland cement and water, binds the aggregates (usually sand and gravel or crushed stone) into a rocklike mass as the paste hardens because of the chemical reaction of the cement and water. Supplementary cementitious materials and chemical admixtures may also be included in the paste. Aggregates, both fine and coarse, take about 65%–75% by the volume of concrete and are important ingredients in concrete production [4]. Among concrete ingredients, cement is the most expensive and environmentally unfriendly element. The production of

Portland cement required for concrete construction makes the cement industry a hub for CO_2 emissions [5]. The production of 1 ton of Portland cement produces nearly 1 ton of CO_2 and demands high energy [5].

Sustainable development of construction materials involves recycling wastes to compensate for the future scarcity of natural resources and conservation of the environment [6]. Besides its environmental effect, the production of cement is too costly. Nowadays, several researchers have been undertaken to replace cement with new materials, such as industrial wastes, agricultural byproducts, and materials, which are abundant widely in nature. These materials are mainly pozzolanic materials (viz. volcanic scoria (VS), fly ash, rice husk ash, and sugarcane bag ash) and other calcareous materials like animal bone powder, marble powder, and corncob ash. So, we can wisely use these and other materials to replace the scarce and costly cement and create an eco-friendly production industry as well [7–18].

The East Africa cement market reached a volume of 14.4 million tons in 2017, and it is further projected to reach a volume of 22.2 million tons by 2023, at a CAGR of 7.5% during 2018–2023. Because of the booming construction activities in the region, the cement industry experienced sustained growth. However, the market growth has declined since 2015 due to increased power tariffs, currency devaluations, and high-interest rates, which retards construction activities in the region. In addition, imports from Asian countries lead to an oversupply of cement in the region, which further impedes market growth. Looking forward, the International Market Analysis Research and Consulting Group expects the East Africa cement market to exhibit stable growth during 2020–2025 [1].

Nowadays, the development of infrastructures and private-sector constructions in Ethiopia have raised the demand for construction materials. Due to this, there is a huge imbalance between the demand and the supply of construction materials. In 2010, the total cement demand has been 4.19 million tons, and out of this, the supply was 3.5 million tons, indicating that there had been a 0.69-million-tons shortage [19]. On the other hand, VS and marble are highly abundant in different parts of Ethiopia [6].

The significance of this study is it potentially offers an alternative way to create concrete by reducing the cost of cement and the environmental impact of its production by exploring the use of waste materials such as marble and scoria powder as partial substitutes for ordinary Portland cement (OPC), by reducing the amount of waste materials produced and their negative impact on the environment. The main objective of the study is to investigate the engineering properties (workability, compressive strength (CS), flexural strength, split tensile strength, ultra-pulse velocity test, and water absorption test) of concrete containing marble waste and VS powder in concrete having a CS of 25 MPa.

The motivation and intention of this paper is to investigate the extent to which marble dust powder and VS can be employed as partial replacements for cement in concrete production. Previous studies have not explored this area, despite the abundant availability of these waste materials in Ethiopia and their potential to improve the sustainability of the construction industry.

Moreover, no research has ever been conducted on the combined use of marble dust powder and VS as cement replacements. This is surprising given that the chemical composition of the combined powder is even better suited for concrete production than that of cement. Therefore, this study aims to fill this research gap by examining the potential of these materials to be used together as partial replacements for cement in concrete mixes.

1.2. Marble Waste Powder. Marble is a recrystallized hard, compact, fine to very fine-grained metamorphosed rock capable of taking polish for shining. The chemical composition of marble mainly includes calcite, dolomite, or serpentine minerals, and the rest varies from site to site. Quartz, muscovite, tremolite, actinolite, micro line, chert, talc, garnet, osterite, and biotite are the major mineral impurities, whereas SiO_2, limonite, Fe_2O_3, Mn, and FeS_2 are the major chemical impurities associated with marble [20].

Previous local and international researchers investigated the potential replacement of cement using marble powder; they concluded that the replacement of cement with marble up to 10% slightly decreases the CS, and the others agree that the CS of concrete increases up to 10% replacement. Regarding split tensile strength & flexural strength, the replacement level can be increased up to 10%–15% without compromising the strength [21–25]. The dust and wastes in the marble industry constitute approximately 30% of the processed marbles, and these byproducts can be used in various industrial areas at a much cheaper cost [26], whereas marble waste produces a significant negative effect on air, water, vegetation, animals and human health, and living conditions [6].

A review based on the strength of concrete containing marble waste states that it is necessary to prioritize recycling applications to contribute to the marble industry, ecology, and economy. It is also stated that, currently, the waste marble is used extensively in concrete instead of aggregate and cement. The review indicates that the use of waste marble in concrete at certain rates was viable to replace the coarse/fine aggregate and cement [27].

Şahan Arel [21] reviewed in-depth the recyclability of waste marble in concrete production. Based on the review, it was observed that $CaCO_3$ and SiO_2 are present in the chemical structure of marble. Also, marble powder that was replaced in cement in excess of 20% was determined to have adverse effects on the CS and workability of concrete [28].

As per Akinwumi [29], a 10% replacement of cement using waste marble powder improves the CS of concrete by 2.34%, the splitting tensile strength (STS) by 11.34%, whereas a 15% replacement increases the flexural strength by 19.73% as compared with the control mix [28, 30]. Vardhan et al. [31] studied the effect of the partial replacement of cement by marble dust on concrete production and concluded as the replacement level goes from 0% to 20%, the slump value decreases by 16%, and the CS also decreased by 39% [29].

1.3. Scoria Powder. VS can be defined as a vesicular course to fine aggregate having more or less spherical bubbles. It is a

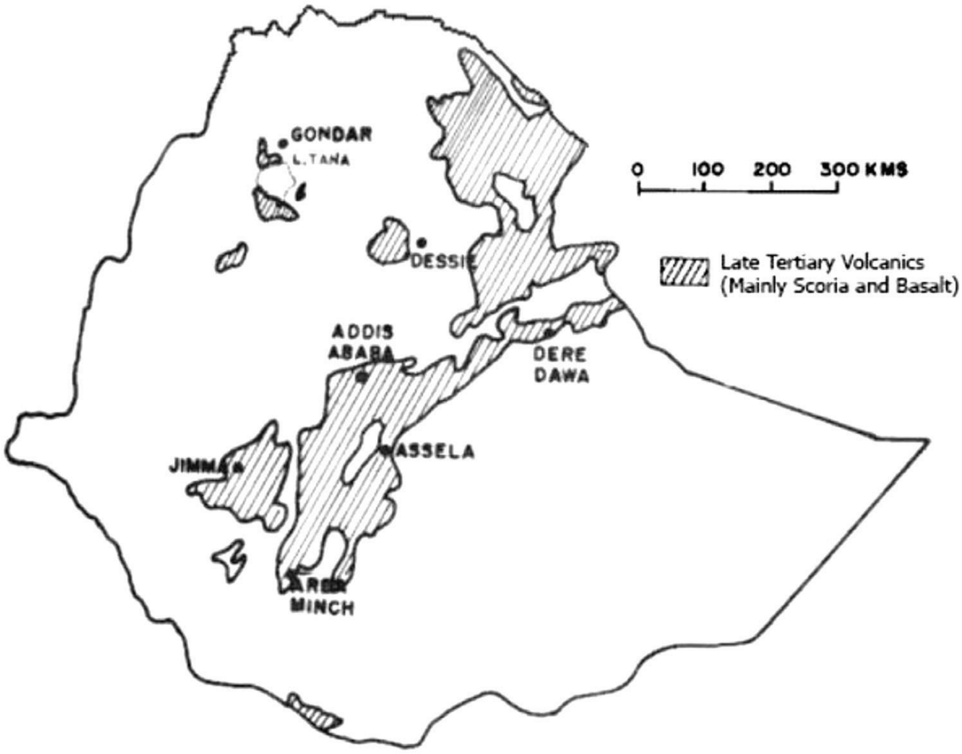

Figure 1: Scoria distribution in Ethiopia [29].

volcanic cinder having a rough surface and highly porous nature, with its pores chiefly in the form of vesicles [4]. Scoria varies in color with common colors like black, red, gray, or brown, whereas the black color is mostly due to its high iron content, and the red color indicates intensive oxidation of iron in the scoria, and this may be due to rainfall during the eruption [31].

Previous studies revealed that VS from different sources around the world exhibits high pozzolanic behavior and can replace cement up to a certain level based on the desired properties of the final output. Pozzolanic materials are siliceous or siliceous–aluminous material that has little or no cementitious value but, in finely divided form and in the presence of water, it will chemically react with calcium hydroxide at room temperature to form compounds possessing cementitious properties [32]. Ethiopia is the 4th leading producer of pumice and scoria aggregate in the world, following Italy, Chile, and Ecuador [33]. Scoria is abundantly found, especially in the Main Ethiopian Rift Valley (as shown in Figure 1) [34].

Al-Swaidani and Aliyan [35] investigated the effects of adding scoria as cement replacement on durability-related properties by varying the replacement level from 10% to 35%. The test results reveal that the resistance to chloride penetration of concrete improves substantially with the increase of replacement level, and the concretes containing scoria-based-blended cement exhibited corrosion initiation periods several times longer than the control mix. Further, an increase in scoria addition improves the acid resistance of mortar, especially in the early days of exposure, whereas after a long period of continuous exposure, all specimens show the same behavior against the acid attack [36].

Al-Swaidani [37] studied the production of more durable and sustainable concretes using VS as cement replacements. Compressive and tensile strength development of mortars and concretes containing VS with replacement levels ranging from 10% to 35% was investigated. Water permeability, chloride penetrability, and porosity of concretes cured for 2, 7, 28, 90, and 180 days were also examined. Results revealed that VS could be suitable for making blended cement. The strength of mortar/concrete containing VS was lower than that of plain cement mortar/concrete at all ages. However, at 90 days of curing, the strengths of VS-based mortars/concrete were comparable to those of plain cement. In addition, water permeability, chloride penetrability, and porosity of scoria-based concretes were much lower than those of plain concrete [38].

Tchamdjou [39] assessed the use of VS as cement replacement and fine aggregate by sand substitution in mortar for masonry. Natural pozzolans powder with different fineness and from different colors was taken, and cement was replaced by 25% and 45% by mass, and mortars containing VS as sand substitution of 25%, 50%, 75%, and 100% by mass were made. Flow value, fresh and dry density, dynamic modulus, and mechanical strengths of mortars at 28, 56, and 90 days were evaluated, and average dry densities of OPC/NPs mortars and VS mortars mixtures were ranged from 2,043 to 2,112 kg/m^3 and 1,381 to 1,945 kg/m^3, respectively. Also,

Figure 2: Material collection and preparation.

Table 1: Major chemical compounds in marble and volcanic scoria powder.

Parameters	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	LOI
Marble powder (%)	49.4	7.84	<0.01	<0.01	<0.01	40.23
Volcanic scoria powder (%)	7.76	54.36	16.27	11.02	5.44	1.78

Table 2: Fine aggregates test result.

Tests performed	Test result	Test method	Allowable limit	Standard
Fineness modulus	2.7	ASTM C136	2.3–3.1	ASTM C33
Unit weight	1,783 kg/m^3	ASTM C29	1,200–1,760	ASTM C33
Specific gravity	2.69	ASTM C128	2.3–2.9	ASTM C128
Absorption	3.95%	ASTM C128	0.2%–2%	ASTM C128
Moisture content	3.42%	ASTM C566	0%–10%	ASTM C33
Silt content	2.8%	ASTM C-117	≤5%	ASTM C33

OPC/NPs mortars and VS mortars mixtures developed around 11.9–28.3 and 9–19.4 MPa CS, respectively [40].

The presence of marble waste powder and scoria in concrete improves the strength by increasing condensed C-S-H gels due to the presence of CaO and SiO_2 and also acts as microfills, which reducing portlandite crystals, porosity, and permeability [38, 41, 42].

Previous researchers conducted a variety of pure studies on marble waste and scoria as substitutions for cement, coarse aggregate, and fine aggregate; however, to the author's knowledge, no research was ever conducted by combining both marble waste and scoria for cement replacement. This study will determine the extent to which waste marble and scoria powders can be substituted in cement and the effect it has on the strength, workability, and water absorption properties of concrete.

2. Materials and Experimental Methods

2.1. Materials

2.1.1. Cement. An OPC with a grade of 42.5R and manufactured by the Dangote Cement Factory was used. The grading and physical properties are in conformity with the requirements necessitated by standard specifications of ASTM C150, and potable tap water was employed for all mixes.

2.1.2. VS and Marble Powder. VS and marble powder were extracted and collected from a quarry and factory near Bahir Dar, Ethiopia, respectively, in which the raw materials for the marble were transported from Mamkush, Ethiopia, which is located 350 km away from the factory. To remove impurities and coarser particles, the powders particle size was reduced to the required level of finesse using a milling machine and sieved with a 75 mm sieve. Figure 2 shows the marble and scoria waste extraction and preparation.

The chemical requirements of ASTM C618 limit the sum of oxides $SiO_2 + Al_2O_3 + Fe_2O_3$ to 70%. The result of the chemical analysis of marble powder and VS is presented in Table 1; as indicated, the major compounds for marble powder are CaO and SiO_2 with a major loss on ignition, which is much higher than the permissible limit specified by the same standard, since the summation of the marble compounds less than the limit, marble powder is not considered pozzolanic rather as cementitious material, whereas the major compounds of VS are CaO, SiO_2, Al_2O_3, Fe_2O_3, and MgO and considered pozzolanic material, the sum of the oxides greater than 81%. As a result, the combined effect of volcanic powder and marble powder can be considered as both pozzolanic and cementitious material.

2.1.3. Fine Aggregate. Locally available, well-graded river sand free from deleterious materials used as a fine aggregate. Tests were carried out to assess different properties of the fine aggregate as per ASTM standards, and test results are presented in Table 2 and Figure 3.

2.1.4. Coarse Aggregates. Well-graded crushed basaltic stone coarse aggregate was used and washed to make it free from

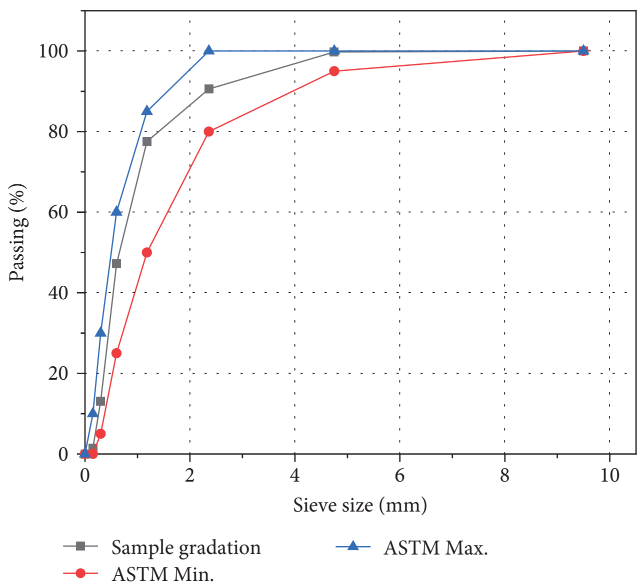

Figure 3: Gradation test result for sand.

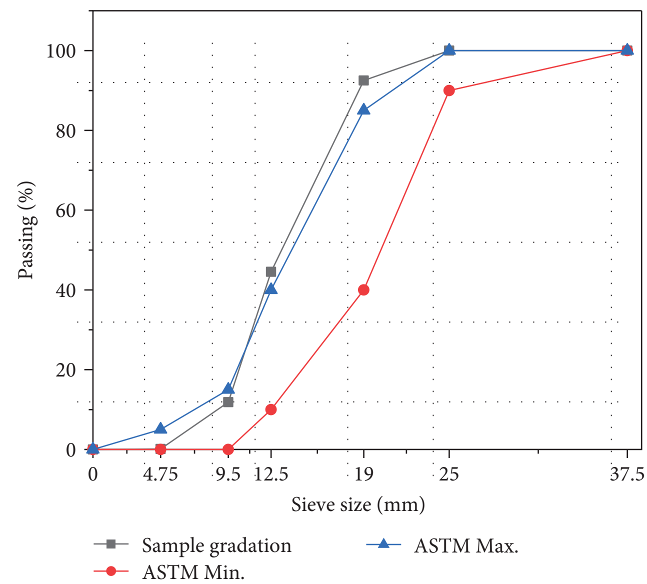

Figure 4: Gradation test result for coarse aggregate.

Table 3: Coarse aggregates test result.

Tests performed	Test result	Test method	Allowable limit	Standard
Fineness modulus	2.34	ASTM C136	2.3–3.1	ASTM C33
Unit weight	1,650 kg/m^3	ASTM C29	1,200–1,760	ASTM C33
Specific gravity	2.69	ASTM C128	2.3–2.9	ASTM C128
Absorption	1.76%	ASTM C128	0.2%–2%	ASTM C128
Moisture content	0.73%	ASTM C566	0%–10%	ASTM C33

dust and deleterious materials, which meet the requirements of ASTM standards and test results presented in Table 3 and Figure 4.

2.2. Test Methods. The general flow of the research is presented in Figure 5.

2.2.1. Mix Design. Based on the physical properties of aggregates, a mix design was conducted as per ACI 211.1-91. A C-25 concrete grade was chosen as a control mix. A total of 13 (Table 4 shows the reference mix) series of concrete mixes were prepared for a constant water-to-cementitious ratio of 0.52 and a slump range between 75 and 100 mm. A percentage mass of 100% cement, 0% waste marble powder (WMP), and 0% VS was used for the control mix.

2.2.2. Formulation of the Combination Method. In this study, VS and waste marble powders were used to replace part of cement in concrete production at an increasing level as 5%, 10%, 15%, and 20%, and each level of increment was divided into three mixes with marble-to-scoria ratios of 2 : 1, 1 : 1, and 1 : 2 resulting [6] to have a total of 13 different mixes, including the control mix as presented in Table 5.

2.2.3. Test Types and Methods. The harden property of concrete, which includes compressive, flexural, and STS, ultrasonic pulse velocity (UPV) test, and water absorption tests were conducted as per ASTM and BS standards as presented in Table 6, and a total of 156 concrete cubes, 39 concrete cylinders, 39 concrete beams (Table 7) were mix, cast, and tested.

All ingredients of concrete mixes were measured by weight according to their proportions. Based on the proportioning, coarse aggregate, sand, scoria powder, marble waste powder, and cement were dry mixed for 2 min. After dry mixing, the specified quantity of water was then added, and the mixture was subsequently mixed for another 4 min as per ASTM C-192. To test the workability of concrete, a slump test was made by slump cone and fed directly into the cube molds and compacted by vibration for slumps less than 75 mm and by tamping for slumps greater than 75 mm and demolded after 24 hr. of casting and immersed into curing tank.

The test results of concrete were analyzed based on the control mix and concrete having marble waste and scoria powder based on their proportioning. Sigma plot and SPSS were used to perform the basic graphs and a two-way factorial analysis of variance based on the dependent and independent variables. A Shapiro–Wilk test on the histograms, normal *Q*–*Q* plots, and box plots were used to check the normality of the test results, and a 95% confidence interval was used in the entire analysis. Finally, a conclusion was drawn.

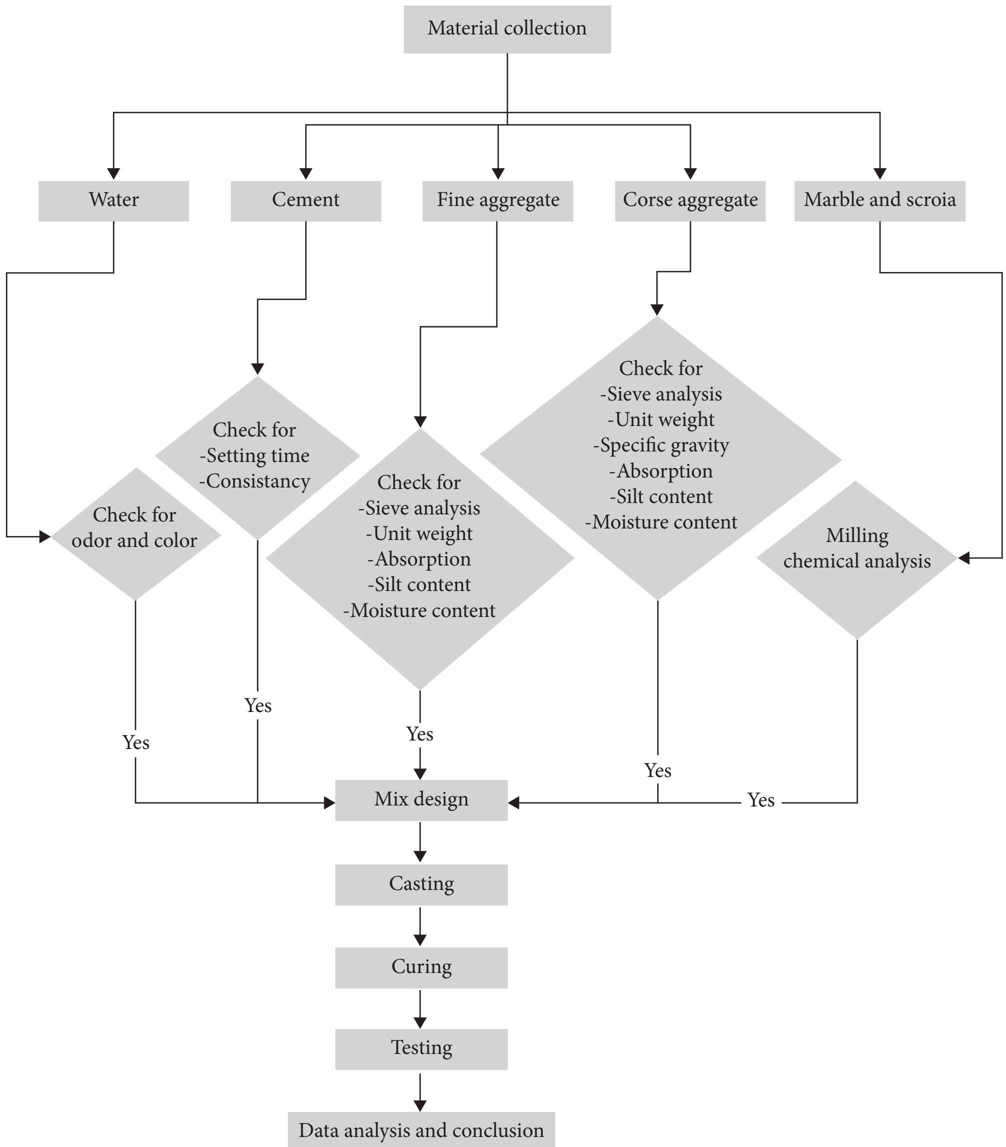

Figure 5: Flow of research process.

Table 4: Reference concrete mix proportions.

Mix	Per	Cement (kg)	Water (L)	Coarse aggregate (kg)	Sand (kg)	Scoria (kg)	Marble (kg)
Mix 1	m^3	394	194.5	1,032.5	798.5	0	0
	Trial	14.4	7.1	37.7	29.2	0	0

3. Results and Discussions

3.1. Workability of Fresh Concrete. For a constant water-to-cementitious ratio of 0.52, the slump values of the fresh mix decrease as the replacement level increases. Previous researchers in this area came up with ambiguous findings. Some say, increasing the replacement levels of pozzolans increase the slump [42, 43, 44], and some others state that increasing the level of pozzolans reduces the slump [29, 43, 45, 46].

The findings of this study in terms of the slump of the fresh mix are in agreement with the last four researchers listed above that as replacement level increases, workability decreases. This indicates that waste marble powder and VS require more water than the cement due to the higher surface area and porous structure of the materials, respectively. Figure 6 shows the slump values for different marble-to-scoria combinations and various levels of replacement. The Figure 6 depicts that a marble-to-scoria ratio of 1 : 2 experiences high workability than the other mixes. Figure 7 illustrates the slump test in progress.

3.2. Ultrasonic Pulse Velocity Test (UPV). The average pulse velocity is presented based on the marble-to-scoria combinations and various replacement levels. The cubes prepared for

Table 5: Proportioning and test specimens.

Mix ID	Cement (%)	WMP (%)	VS (%)
M_1	100	0	0
M_2	95	1.67	3.33
M_3	95	2.5	2.5
M_4	95	3.33	1.67
M_5	90	3.33	6.67
M_6	90	5	5
M_7	90	6.67	3.33
M_8	85	5	10
M_9	85	7.5	7.5
M_{10}	85	10	5
M_{11}	80	6.67	13.33
M_{12}	80	10	10
M_{13}	80	13.33	6.67

Table 6: Tests and test methods.

Test name	Test method
Slump test	ASTM C 143M-08
Compressive strength test	BS 1881-116
Splitting tensile strength test	ASTM C 496M-04
Flexural strength test	ASTM C 293-08
Ultrasonic pulse velocity (UPV) test	ASTM C 597-02
Water absorption test	ASTM C 642-06

Table 7: Test types and specimen description.

Specimen type	Size (cm)	Replication	Curing ages (days)	Types of tests
Cube	15 × 15 × 15	117	7, 28, 90	(1) Compressive strength (2) Ultrasonic pulse velocity for 28th day samples
Cube	10 × 10 × 10	39	28	Water absorption
Cylinder	10 × 20	39	28	Splitting tensile strength
Beam	10 × 10 × 50	39	28	Flexural strength

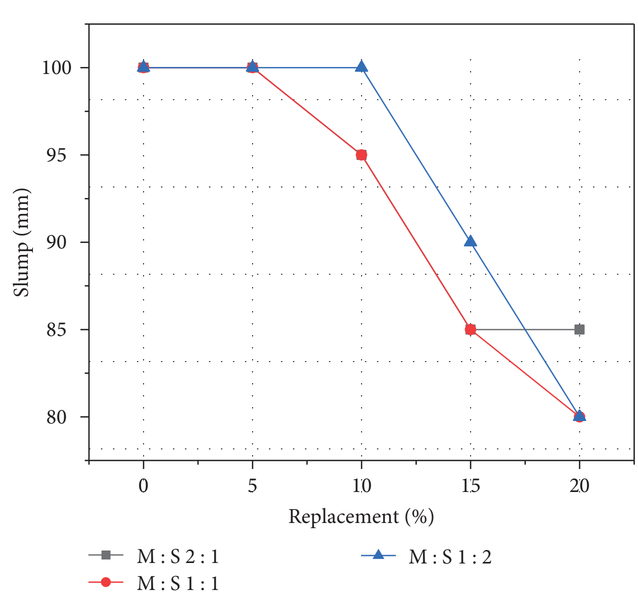

Figure 6: Workability of fresh concrete.

Figure 7: Slump test.

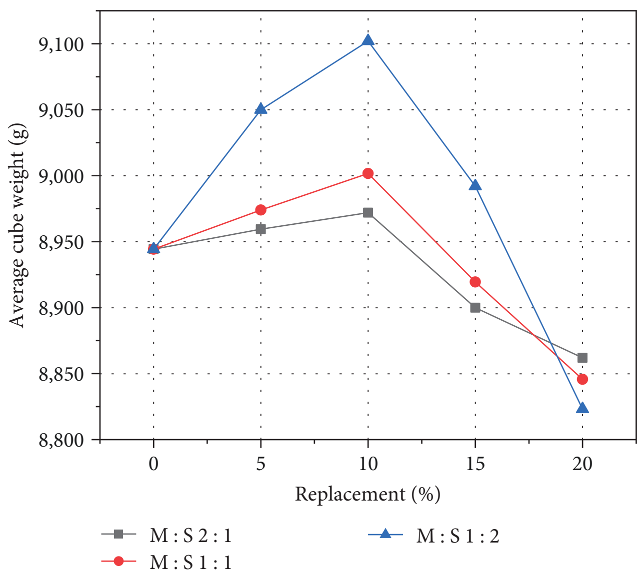

Figure 8: Average cube weight (28th day).

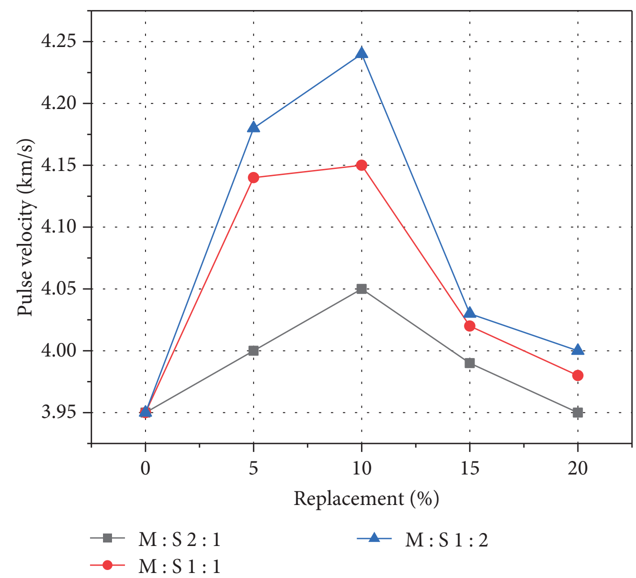

Figure 9: Pulse velocity variation for different marble to scoria ratio (28th day).

the 28th day CS were tested for pulse velocity propagation using the ultrasonic pulse analyzer PULSONIC (58-E4900). According to the pulse velocity, the concrete quality can be classified as excellent, good, medium, and doubtful, which is stated in B.S., 1881, 1993.

As the pulse velocities are between 3.5 and 4.5 km/s regardless of the marble-to-scoria ratios and the replacement level, all mixes are classified to be of "*Good*" quality. The time taken by the pulse to travel through the concrete or any medium depends on the density of the medium. The denser the material, the higher the pulse velocity will be recorded, and the reverse is true. Hence, to check how the UPV test results agree with the density of the concrete, the average cube weight and the pulse velocity for the 28th-day cube specimens and test in progress are presented in Figures 8–10, respectively.

3.3. Compressive Strength (CS). To determine the CS, cube specimens having 150 × 150 × 150 mm were prepared as per BS-1881-116 standard and tested for 7, 28, and 91 days. Figure 7 shows the average CS for all mixes. The variation between consecutive mixes may seem erratic, and that is because of the different marble-to-scoria ratios (M : S) used alternatively.

The mixes were categorized systematically based on the M : S. For instance, M_2, M_3, and M_4 represent the second, third and, fourth mix prepared next to the control mix by substituting 5% of the cement used in M_1 with VS and marble powders using an M : S of 2 : 1, 1 : 1, and, 1 : 2; respectively. As shown in Figure 11, the maximum CS was achieved at Mix 6, 10% combined level of marble and scoria 1 : 1 M : S ratio. For a clear understanding of the effect of control variables (viz. level of replacement and curing period), the CS test results are synthesized into different M : S as discussed briefly in Sections 3.3.1–3.3.3.

3.3.1. CS (M : S of 2 : 1). As the combined level of marble and scoria ratio becomes 2 : 1 (Figure 12), the CS increases as the curing age increases. However, at 7 and 28 days of curing, the CS decreases consistently as the level of replacement increases. At 5% and 10% combined marble and scoria replacement, the 91st-day CS is higher when compared to the control mix.

As the marble content is higher than scoria, the amount of silica might not be quite enough to react with the available portlandite ($Ca(OH)_2$). In addition to that, a previous study revealed that pozzolanas can combine an amount of $Ca(OH)_2$, which may be as much as about 50% of its weight [26]. As the combination is marble-dominated, it is in agreement with the previous study [45].

3.3.2. CS (M : S of 1 : 1). In 1 : 1 marble-to-scoria ratio combination (Figure 13), the CS increases slightly up to 10% replacement for all curing ages. At 10% replacement and 28 days of curing, a 2.75% increase in CS is observed, as shown in Figure 9.

As scoria content increases, the reactive silica in the scoria powder would get the chance to react with the available portlandite (CH) and produce the additional C-S-H gel. That might be the reason for the increase in CS up to 10% replacement in which previous researches show similar findings in terms of CS [47, 48].

3.3.3. CS (M : S of 1 : 2). As shown in Figure 14, on the 7th and 28th day, CS decreases as the replacement level increases, the same trend with the CS (M : S of 2 : 1). As the combined level of marble and scoria ratio becomes 1 : 2 the scoria content is dominant over the marble content. Based on previous studies, using scoria as cement replacement does not modify the CS at early ages. But at longer curing ages, the CS will become equal and even higher as compared with the control mix [47].

A VS-dominated combination, results from previous researches on using VS powder for partial replacement of

Figure 10: UPV calibration and specimen testing.

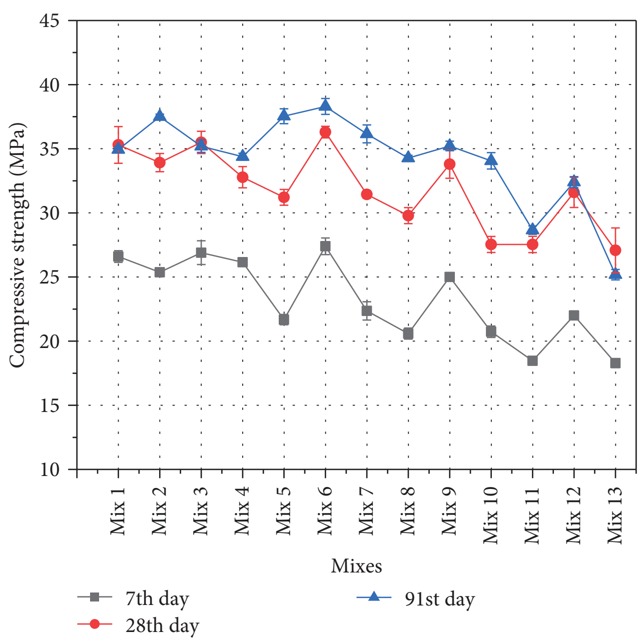

Figure 11: Compressive strength test result.

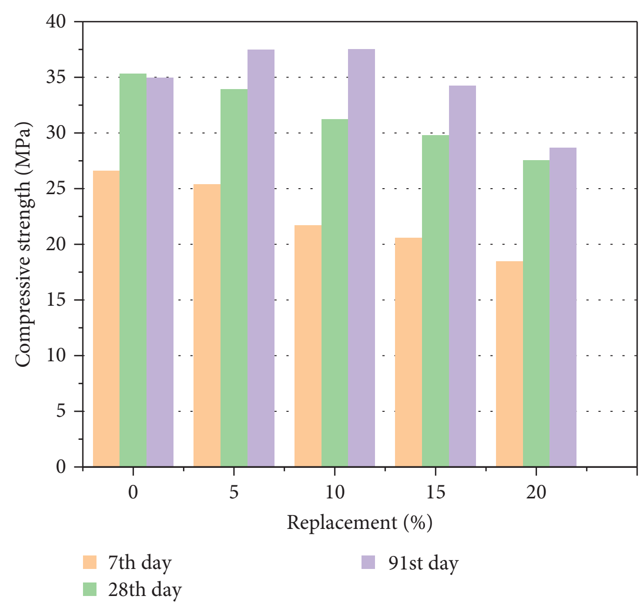

Figure 12: The average compressive strength for a marble to scoria ratio of 2 : 1.

cement in mortar/concrete production indicate that the CS slightly decrease as the replacement level increase [3, 49–51], which agrees with the results presented in Figure 10. Regardless of the marble-to-scoria combination, the 91st-day CS shows an increment of up to 10% replacement. When the combined level of M : S ratio becomes 2 : 1, 1 : 1, and 1 : 2, the CS on the 91st day increased by 7%, 9%, and 4%, respectively, at a 10% replacement level.

3.4. Splitting Tensile Strength (STS). As concrete is very weak in tension due to its brittle nature, it is not expected to resist the direct tension [47]. Therefore, it is essential to know the tensile strength of concrete to determine the load at which the concrete members may crack. Figure 11 shows the average STS test result.

As shown in Figure 15, up to 10% replacement, the STS of concrete is not affected for a marble-to-scoria ratio of 1 : 1, whereas a 20% replacement results in a 5.3% reduction in STS, whereas for M : S of (2 : 1) and (1 : 2) STS were decreasing consistently. Previous researches came with similar findings that the STS of concrete increases up to 15% replacement of cement by marble dust powder [52, 53].

3.5. Flexural Strength of Concrete. Flexural strength (also known as the modulus of rupture (MR)) is also an indirect method of measuring the tensile strength of concrete. As shown in Figures 16 and 17, with the marble-to-scoria ratio of 1 : 1, the MR increases slightly up to 10% replacement, which shows the same trend with the STS and the test, respectively. Since the addition of pozzolana also acts as a

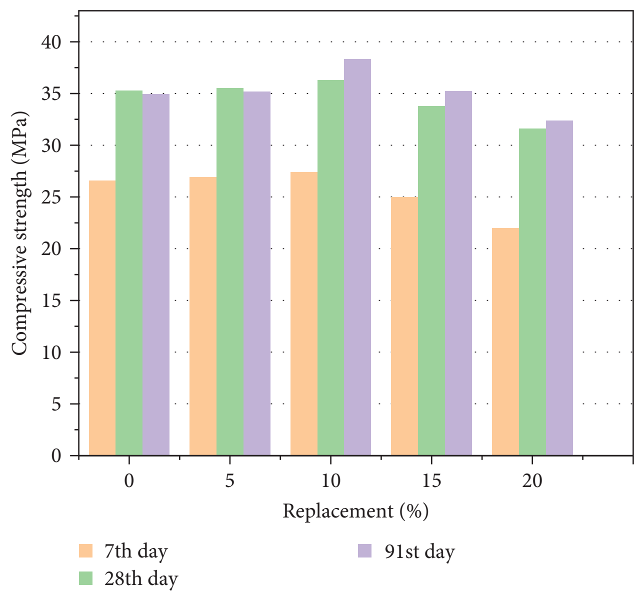

Figure 13: The average compressive strength for a marble to scoria ratio of 1 : 1.

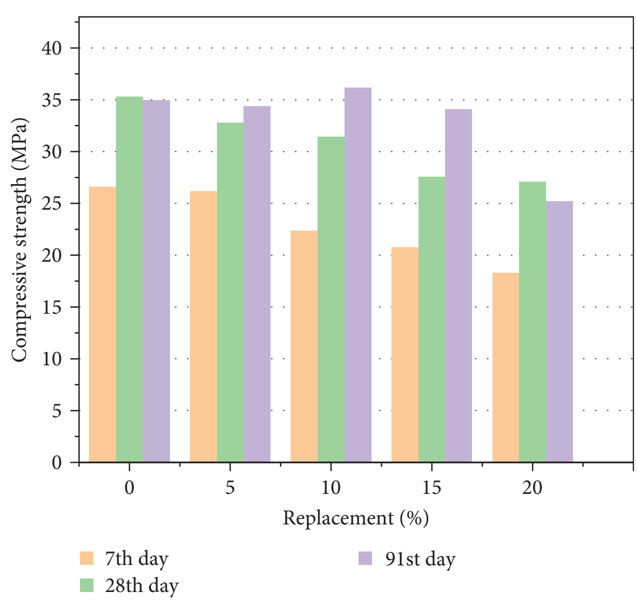

Figure 14: The average compressive strength for a marble to scoria ratio of 1 : 2.

filler, there will be fewer micropores in the hardened concrete as compared with the control mix-up to a certain level of replacement. The result of the UPV test indicates that the pulse velocity slightly increases up to 10% replacement, which is the indication of the enhancement of the concrete quality. Hence, as the flexural strength of concrete is the result of internal frictions between concrete forming materials, the lower the micropores, the higher the internal friction will the concrete experience and the higher its flexural strength will be.

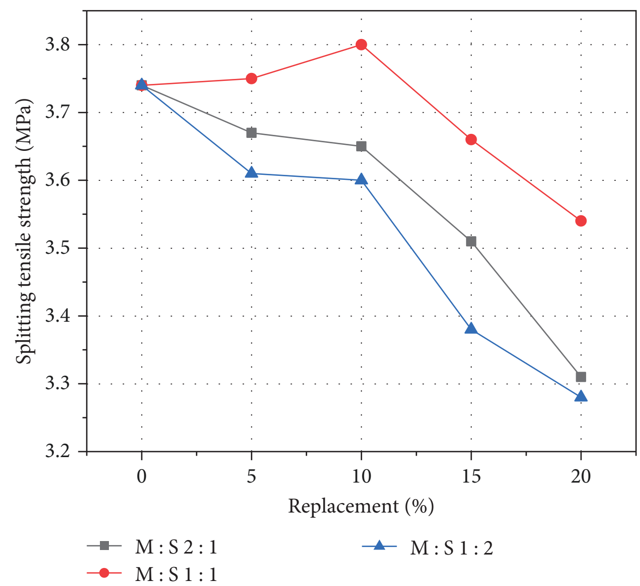

Figure 15: Splitting tensile strength test results.

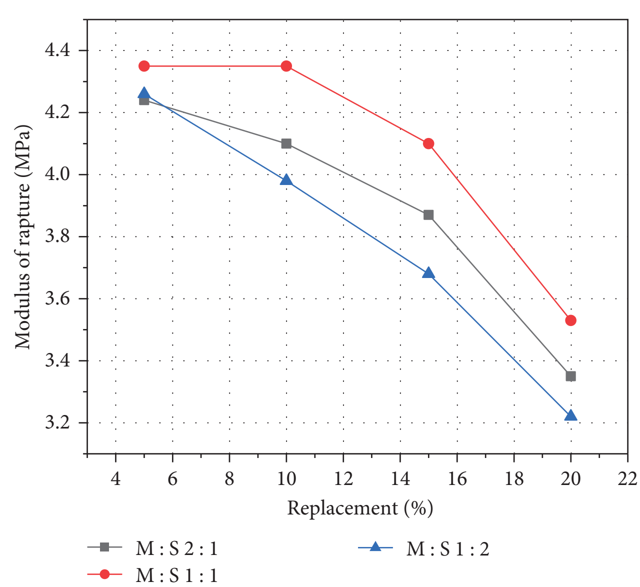

Figure 16: Flexural strength test results.

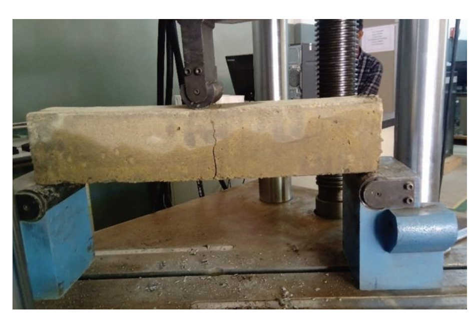

Figure 17: Beam flexural strength.

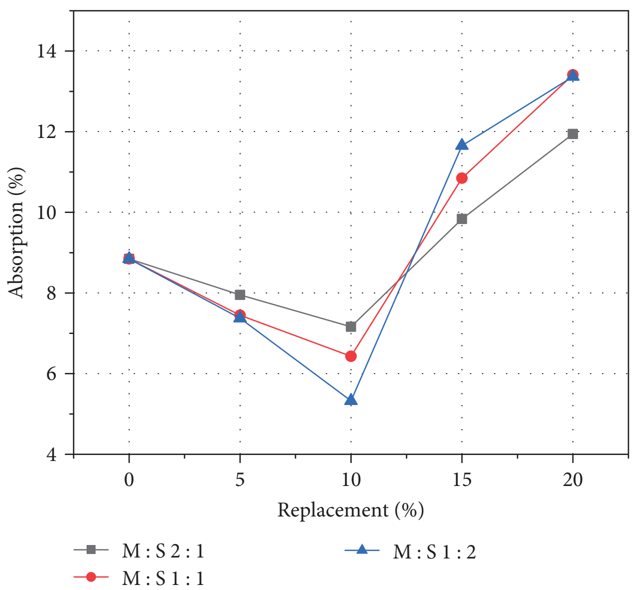

FIGURE 18: Percent absorption test results.

3.6. Water Absorption Test. To determine the percent absorption, cube specimens having a size of 10 × 10 × 10 cm were prepared as per ASTM C 642 standard and cured for 28 days. The average percent absorptions are presented in Figure 18 for different marble and scoria combinations. As the result indicates, regardless of the marble-to-scoria combination, the percent absorption decreases as the replacement level increases up to 10%. Further increase in replacement level, the resulting concrete will have a higher water absorption property. Minimum absorption is observed at a M : S of 1 : 2, and that is because of the high pozzolanic reaction due to high silica content at which any capillary pores that remain after hydration of Portland cement are infilled by the products of pozzolana reaction and calcium hydroxide [31].

4. Conclusions

Based on experimental results, the following conclusions are drawn concerning marble waste and scoria-added concrete:

(1) The chemical composition shows that marble powder has significant CaO, which is a major cement component, whereas the VS considered pozzolans as per ASTM C 618.
(2) Despite the marble-to-scoria ratios used, the workability of the mix decreases as the replacement level increases.
(3) The UPV test result reveals that up to 20% replacement of cement with marble and scoria powders does not affect the concrete strength for all combinations.
(4) A slight increase in the CS is observed up to 10% replacement at a marble-to-scoria ratio of 1 : 1.
(5) The tensile strength of concrete slightly increases up to 10% replacement at a marble-to-scoria ratio of 1 : 1, and beyond 10% replacement reduces the tensile strength.
(6) For all marble and scoria combinations, the concrete water absorption decreases up to 10% replacement, and the lowest absorption percentage is observed at marble-to-scoria combination of 1 : 2.
(7) A 10% cement replacement with a marble-to-scoria ratio of 1 : 1 could produce concrete with optimum compressive, tensile strength, and water absorption of concrete when compared with the conventional mix.

In general, 15% cement replacement with marble and scoria in a 1 : 1 ratio can be used in concrete production where tensile strength and water absorption properties are not critical. However, considering all the aforementioned concrete properties, 10% cement replacement with a marble-to-scoria ratio of 1 : 1 can be used to produce concrete with no significant difference in terms of CS, tensile strength, and water absorption when compared to the control mix.

5. Recommendation

In this study, the following key points are highly recommended to get focus for further study and make the construction industry environmentally friendly:

(i) As the level of replacement increases, the concrete needs more time to gain its full strength. Hence, this work may be extended by incorporating some admixtures, which would help the concrete get early strength.
(ii) Previous studies emphasize that there is a strong dependency between the alite (C_3S) crystal sizes and the 28th-day CS. Hence, it's highly recommended to extend this study by varying the grain sizes of marble and VS powders.

Data Availability

The data used to support the findings of this study have been deposited in the Bahir Dar University Institutional Repository (https://ir.bdu.edu.et/handle/123456789/14673).

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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