SSRG International Journal of Civil Engineering
ISSN: 2348-8352/ https://doi.org/10.14445/23488352/IJCE-V12I4P114

Volume 12 Issue 4, 134-147, April 2025

Review Article

Utilization of Waste Marble Powder in Concrete: A Review of Mechanical Properties, Environmental Impact, and Future Directions

Mithlesh Kumar Jha[1], Lal Bahadur Roy[2]

[1,2]*Department of Civil Engineering, NIT Patna, Bihar, India.*

[1]*Corresponding Author : mithleshKumar_jha@ymail.com*

Received: 10 February 2025 Revised: 12 March 2025 Accepted: 14 April 2025 Published: 30 April 2025

Abstract - *The construction industry is one of the key contributors to environmental issues, with cement production requiring large amounts of electricity and fuel, liberating huge quantities of heat, causing noise pollution and generating pollutants. Sand extraction from rivers and ocean beds also disturbs aquatic animals and microorganisms. A worldwide annoyance, marble dust is a Waste that is the non-biodegradable product produced while marble is being mined and processed. To reduce environmental damage, researchers have studied the use of powdered marble as a material that can be reused in the construction sector. The study found that Concrete's compressive strength rose when marble dust was added, and production costs were reduced based on the percentage of marble dust used to replace cement. The characteristics of concrete and mortar were unaffected when 10% of the cement was replaced by marble powder. It was more beneficial when mixed with fly ash as a binder instead of simply substituting regular Portland cement. The performance of waste marble powder in replacing fine and coarse aggregates according to characteristics such as the geological origin of coarse aggregate and the particle size distribution of the fine aggregate being substituted.*

Keywords - *Waste marble powder, Mechanical strength, Permeability, Workability, SEM.*

1. Introduction

Global warming and environmental destruction have become critical challenges, largely driven by industrial activities that release significant amounts of greenhouse gases. As a result, society is increasingly shifting from mass-production systems to zero-emission approaches, prioritizing waste management and resource conservation. The construction industry plays a vital role in this transformation. In India, managing waste is a complex issue, further compounded by rapid industrialization and urban growth [1, 2]. Using substitute cementitious materials could reduce the amount of cement produced and its emissions. Using alternate cementitious materials, cement manufacturers use far less energy, require less money and time, and have less environmental risk [3]. The usefulness of the dust form of marble and optical fibre against the detrimental effects of freeze-thaw cycles on cement mortars was experimentally studied [4]. The increasing global demand for cement made researchers consider using alternative cementitious materials, such as industrial by-products, to reduce production costs and lessen environmental impacts, thereby improving cement manufacturing efficiency [5]. Nearly 50% of the world's marble production is concentrated in four countries: Spain, China, Italy, and India, with India accounting for about 10% of the total output [6]. The study looks into how WMP affects the mechanical characteristics of concrete. In ratios 0, 25, 50, and 100%, marble dust was used to replace sand in four different concrete compositions. At various curing ages, the samples' compressive strength was assessed. The results show that marble dust addition enhanced compressive strength. A by-product of marble production, marble dust can lower resource consumption and environmental pollution [7]. Using MD in normal-strength concretes as a substitute for fine aggregate could help prevent environmental pollution and reduce natural resource consumption in regions with excessive marble production [7, 8].

Concrete, made from a mixture of cement, aggregates and water, is a highly versatile material widely used in construction due to its strength and ability to create large, durable structures. Considering the scarcity of natural resources, researcher's look into alternative construction materials has been gaining momentum. A study investigated the use of Bethamcherla Marble Stone in varying proportions of concrete mixes - 0%, 25%, 50%, 75%, and 100%. This flaggy limestone was combined with Galvanized Steel Fibres to enhance the concrete's performance [9, 10]. The study evaluated the feasibility of fibre-reinforced concrete by substituting natural aggregates with Bethamcherla Marble Stone. The workability of the mixes was tested using slump tests, compaction factor tests, and Vee-Bee tests for each proportion [9, 11]. Corinaldesi et al. investigated the chance of involving marble ooze instead of concrete and sand while making cement mortars and cement concrete. It was noticed that marble sludge could change the thixotropic characteristics of concrete pastes, making it simpler for the glue to go through contracted regions [12].

Disposing marble dust (MD), a waste product generated by masonry industries, contributes to environmental issues. Despite some benefits, researchers have recommended replacing cement or aggregates in mortar and concrete with MD. A new technique has been introduced to use inert waste or fillers as a substitute for paste. When applied to mortar mixes, this method demonstrated that adding WMP as an alternative to paste improved water resistance and carbonation, minimized shrinkage strain rate, and reduced cement consumption by as much as 33% [13]. Kirti Vardhan et al. looked into the possibility of replacing cement with MD. The study shows that, without compromising the mixture's technical uniqueness, up to 10% marble powder is additionally used in place of cement [14]. Buyuksagis et al. examined the availability of WMP as a substitute material in various ratios for dolomite, which is the raw material used in insulating board glue mortars. Economic research was also conducted on using WMP in conjunction with dolomite, and it was shown to be favourable regarding price calculations and compliance with EN standards [15]. Researchers in the construction sector are exploring the WMP application in cement concrete, a non-biodegradable waste produced in large quantities. The study examines the impact of marble debris on concrete's durability, freshness, and mechanical properties. This implies that mixing fly ash and marble debris before utilizing it as a binder is more beneficial than substituting OPC. Waste from marble can be utilized in larger quantities to replace coarse and fine aggregate with satisfactory results; the performance is determined by replacing the fine aggregate and the geological source of the coarse aggregate's particle size distribution. The findings demonstrate that discarded marble can effectively replace cement, additives, and coarse/fine aggregate to produce concrete with greater strength [16].

Table 1. Physical properties of marble

Authors	MWP utilized as	Formation procedure	Sp. gravity	W.A	Particle Size	Sp. surface
Corinaldesi et al. (2010) [12]	Cement	Marble derived from processing facilities	2.55		7–50μm	1500
Ergün et al. (2011) [17]	Cement	Marble derived from processing facilities	2.68			5960
Soliman et al. (2013)	Cement	Marble derived from processing facilities	2.63	0.97		350
Southararajan and Sivakumar (2013) [18]	Cement	Marble derived from processing facilities	2.74		< 90 μm	1500
Vaidevi et al. (2013) [19]	Cement	Marble derived from processing facilities	2.3		< 0.25 mm	
Aruntaş et al. (2010) [20]	Cement	Marble derived from processing facilities	2.60			3097
Deepankar Ashis (2017) [21]	Cement	4.25mm-75μ	2.65	1	< 90μ sieve	1500
Imbrose B.Muhit (2014) [22]	Cement	Crushing Plant	2.65	-	Passing through 200N sieve	2529
Messaoudene et al. (2022) [23]	Cement	-	2.7	0.5		
Ertug Aydeni (2019) [24]	Cement	Passing through 50μ	2.49			335
L.G li (2018) [13]	Cement	Polishing, cutting and shaping of marble from a stonework factory	2.70	0.16	Passing through 150μ sieve and retained on 90μ sieve.	--
Manish et al. (2022) [25]	Cement	Obtained from the nearby marketplace.	2.7	0.60	< 90μ sieve	-
Ch. Kavya (2022) [26]	Cement	Marble derived from processing facilities	2.68	0.60	90μ sieve to 150μ sieve.	-
Mushraf Majeed (2021) [27]	Cement	From sawing and cleaning of marble slurry construction site	2.60		< 90μ sieve	
Filali and Nasser (2024) [28]	Cement		2.71	1.48		3320
Md. Ajmal khan (2024) [29]	Cement	From a nearby construction site	2.46	1.1		-

Fig. 1 (A) Marble dust, (B) Marble from construction site, and (C) Grinded marble waste powder.

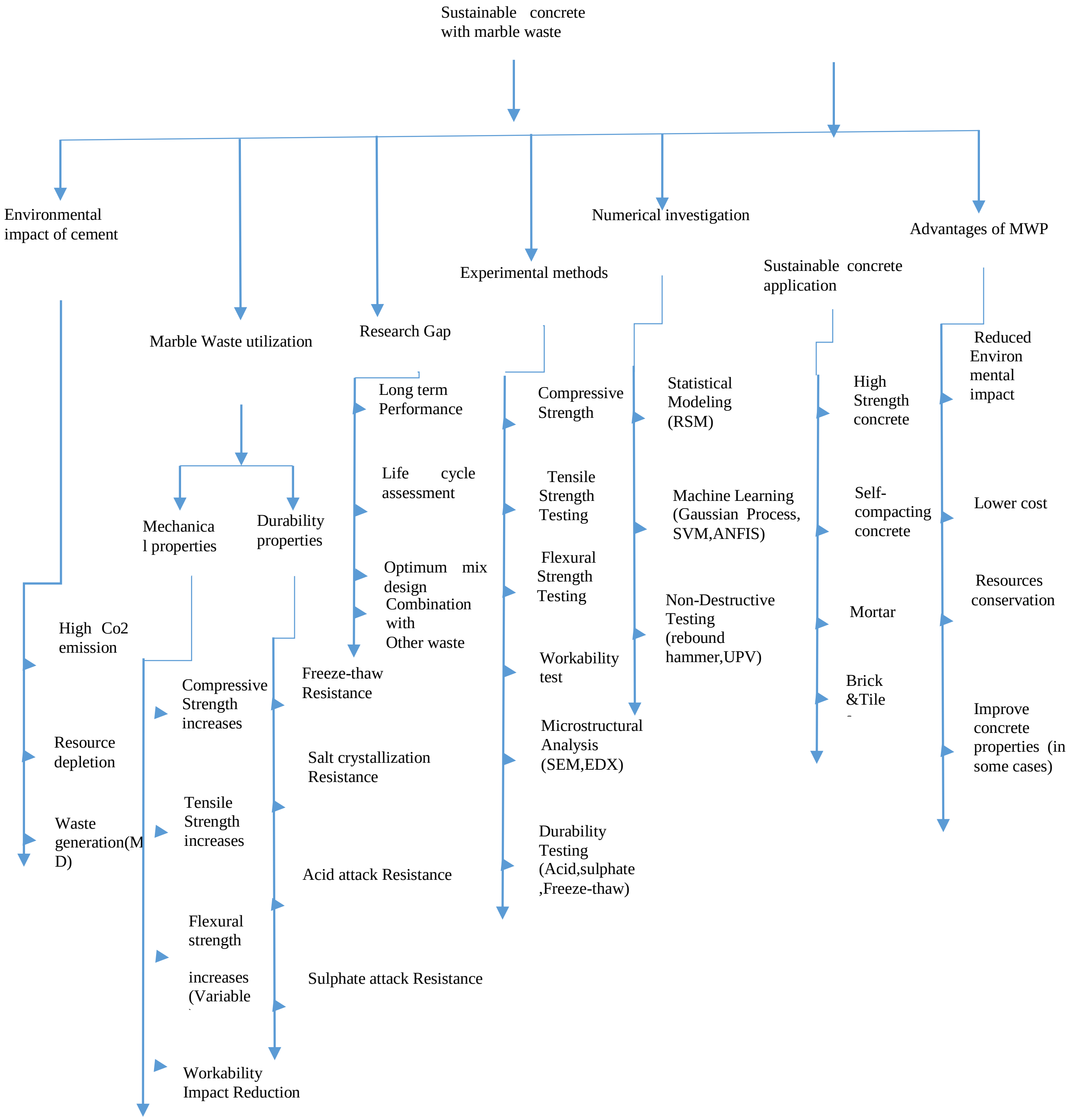

Fig. 2 Roadmap of review paper

Table 2. Chemical composition of WMP

Authors	SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	Na_2O	K_2O	SO_3	LOI
Ranjan et al. (2013) [30]	-	51.29	0.70	0.33	0.36	0.19	0.25	0.20	44.60
Aliadbo et al. (2014) [31]	1.12	83.12	0.73	0.05	0.52	1.12	0.09	0.56	2.50
Messaoudene et al. (2022) [23]	0.13	57.67	0.11	0.04	0.17	0.05	-	-	-
Vardhan et al. (2019) [32]	5.77	41.64	0.56	0.821	5.65	0.07	0.73	0.11	-
Vardan (2015) [14]	6.01	40.73	0.6	0.8	15.21	0.06	0.05	0.09	-
E.Bacarji (2013) [33]	58.67	6.13	11.26	7.59	2,96	2.74	2.90	0.04	5.99
Ashis et al. (2017) [34]	8.83	61.83	0.67	0.65	14.36	0.60	0.07	0.33	-
Ceren Ince (2020) [35]	23.4	65.4	4.32	2.83	1.73	0.79	1.04	0.43	2
Filali and Nasser (2024) [28]	20.90	60.06	3.905.85	3.9	1.85		2.14	2.35	21.84
Khan and Dhanoa (2024) [29]	28.35	40.75	0.43	9.7	16.25	-	-	--	-
Alham o Hussain (2024) [36]	22.5	42	1.8	0.4	1.75	1.5	1.2	3.2	-
Syed Afzal Basha (2024) [37]	2.13	59.48	3.46	3.21	2.62	-	2.21	-	25.79

1.1. Problems with Cement Concrete

Cement concrete, while widely used in construction, has some notable issues. It tends to crack over time due to shrinkage and thermal expansion. The material can suffer from reduced durability when exposed to harsh weather, chemical attacks, or corrosion of embedded steel. Additionally, achieving the right mix for workability and proper setting can be challenging. Moreover, the production of cement concrete significantly contributes to CO_2 emissions, posing environmental concerns. To ensure the best performance, it's crucial to follow proper mix designs, construction techniques, and maintenance practices.

1.2. Gap in Literature

The review of WMP use in concrete identifies several important research gaps that must be filled for improved comprehension and use. Among these gaps are:

- *Life Cycle Assessment (LCA) and Long-Term Performance*: Research on the long-term performance of concrete that incorporates WMP is lacking. There is a substantial lack of knowledge about the long-term effects of WMP on concrete under different environmental conditions because the majority of research has focused on short-term mechanical properties.
- *Optimal Mix Design*: Although the usage of WMP in concrete has been studied in some detail, little is known about the ideal mix design for various scenarios and uses. This entails figuring out whether using residual marble powder to make concrete is economically feasible and performing cost-benefit evaluations.
- *Combination with Other Waste Materials*: More investigation is needed to explore the synergistic effects of combining WMP with other waste materials, which includes Nano silica, rice husk ash, Granite, scoria powder, ECC, limestone, etc. This could lead to improved performance and sustainability in concrete applications, but current literature lacks comprehensive studies on these combinations.
- *Microstructural Analysis:* There is a deficiency in research that examines the microstructural changes by XRD, ITZ, SEM, etc., in concrete when WMP is used as a partial replacement for cement or aggregates. Understanding these changes is crucial for predicting the material's long-term behaviour and durability.
- *Economic Viability*: Not much research has been done on the financial implications of employing WMP in concrete manufacturing. More investigation is needed to evaluate the financial effects and any savings related to employing waste materials in buildings.
- *Environmental Impact*: More thorough life cycle assessments are required to measure the ecological benefits and potential disadvantages of mixing marble waste into concrete, even though some studies highlight the environmental advantages of employing WMP.

1.3. Objectives

The purpose of this study is to find out how WMP can be used in cement concrete, considering its effects on performance and the mechanical and durability characteristics. It also looks at the potential of WMP in cement concrete mixes and finds sustainable ways to dispose of it. The feasibility of incorporating marble powder into concrete, as well as its effects on the characteristics of the material and compressive and tensile strengths, are also examined in this study. The application of Pozzolanic activity in concrete and the possibilities of using WMP in concrete are also examined in this study. Determining the performance and longevity of concrete made from waste marble is the ultimate objective.

2. Literature Review

Utilizing WMP and other industrial by-products can support sustainable development. However, waste marble powder has not been examined for concrete that contains sand and cement amalgam. This study aimed to determine whether it is possible to use WMP as a partial replacement. Several concrete mixtures were made; marble powder served only as a filler and had no role in the hydration process. The best substitute was found to be 10% cement amalgam, and 10% sand [21]. An investigation was made considering the importance of partially substituting cement with WMP, which has been carried out periodically. They examined the relative compressive, tensile, and flexural strengths of concrete or mortar when marble powder is used as a fine component by partially reducing cement quantities. A higher WMP ratio results in stronger mortar when a variable percentage of marble powder partially replaces cement [38]. The mining and processing of dimensional stones like marble generates a significant amount of non-biodegradable waste, which has become a global environmental issue. The construction industry, a major consumer of natural resources, has been exploring using marble waste in concrete. Studies have shown that using WMP as a 10% substitution for OPC doesn't affect concrete properties. However, it works better as a binder when mixed with fly ash. Depending on the fine aggregate's particle size distribution and the coarse aggregate's geological origin, marble waste can also substitute for both fine and coarse aggregates; this substitution could range from 50% to 75% [39]. The increasing population and environmental pollution have led to a growing concern about the disposal of industrial waste. This study investigates using concrete waste glass as a binding material and waste marble as a filler material to create high-strength concrete. The results demonstrate that adding waste glass and marble to concrete reduces its workability, but replacing glass waste and WMP improves mechanical performance. Both waste materials in concrete were optimized using the Response Surface Methodology (RSM) statistical technique, which showed improved agreement between statistical and experimental results [40]. Mortar, a crucial masonry product, is essential in reinforced structural construction. This research investigates the compressive and tensile strength of mortar by replacing cement and sand with stone dust. According to the study, the tensile strength increased by up to 13.47%, while the compressive strength increased by 21.33% and 22.76%, respectively. The appropriateness of stone dust as a construction material was checked to minimize demand and ensure solid waste minimization. The optimum dose was selected, and crack analysis was conducted [39]. This study investigates the impact of marble fineness on the rheological behaviour of ordinary concrete at fresh and hardened states. Five types of concrete were made, with CEMI cement partially replaced with marble powder at 5% and 10% rates. The rheological parameters and compressive and flexural strengths were measured. Results showed that the optimal marble powder content is 5% without high grinding, retaining rheological characteristics at fresh and hardened states. A 10% replacement rate and 7000 cm^2/g fineness increase yield stress, but mechanical strengths remain important [41]. Researchers have been investigating the usage of MS in concrete and cement products. MS at 2%, 5.5%, and 7.5% by weight of cement enhanced the mechanical qualities of concrete, reducing surface cracks and raising tensile and compressive strength, according to a study on 120 concrete specimens. The possible advantages of using MS in the manufacturing of concrete are highlighted in this study [42].

2.1. Experimental Investigation

The impact of MDP's lime content on the production of high-strength concrete has been investigated. They discovered that the MDP was examined for the properties of hardened concrete up to 10% by weight of cement. Additionally, it was assessed how various percentage replacements of MDP affected the flexural, splitting tensile, and compressive strengths [43]. The ratio of cement to total aggregate and the proportion of coarse to fine aggregate was found to have a greater impact on improving strength properties. 10% replacement of MDP in cement content resulted in a remarkable 46.80 MPa increase in compressive strength at seven days and better mechanical properties when compared to controlled concrete [44]. Large quantities of marble dust are accessible as waste from buildings. The use of substantial quantities of marble slurry in place of cement in pastes to create lightweight, eco-friendly building materials for sustainable construction was investigated in this lab study. The marble composites' compressive strength ranged from 2.95 MPa to 28.63 MPa, and their dry unit mass varied between 1000 kg/m^3 and 1520 kg/m^3 and their mass loss after being exposed to sulphate solution of concentration in between 9.8% to 16.2%. The findings shows that it was successful to substitute marble powder for up to 60% of the cement component in paste compositions. The composites can be used as building materials for various purposes, including controlled low-strength applications and the production of bricks and tiles. The advantages of employing a lot of marble waste are also covered, considering both economic and environmental factors [24]. The study looks into using WMP in concrete instead of cement. The replacement of WMP at different amounts resulted in decreases in mechanical strength (compressive strength, splitting tensile strength, and flexural strength). Three calculations were proposed to calculate the mechanical resistances of concrete with WMP, with complex calculations based on the concrete mixture's design, sample age, and WMP percentages. The study recommends using 10% WMP for optimal benefits in both mechanical and environmental aspects. The results suggest that WMP replacements can significantly impact concrete properties [10, 45].

Rapid industrialization and urbanization are increasing concrete demand, potentially leading to a shortage of natural resources. Recycling waste, such as WMP from Pakistan's marble factories, can help meet these demands without compromising quality [46]. A study found that WMP can partially substitute fine aggregate in concrete manufacturing, affecting its mechanical properties. The study found that WMP decreased workability and unit weight proportionally with replacement percentage but improved compressive strength and tensile strength. According to the study, up to 40% of the concrete mix should contain WMP [47]. This paper reviews research on incorporating marble waste in concrete production, focusing on its effects on concrete's properties. It explores using marble waste in coarse aggregate, fine aggregate, and cement replacement. The authors note that marble waste can be used up to 75% without significant adverse effects and 50% for fine aggregate. The optimal amount for partial cement replacement is around 10% to 15%. The paper also highlights the environmental benefits of using marble waste, such as reducing CO_2 emissions and reducing reliance on natural resources. It also highlights the importance of considering local materials in concrete mix design.

The study shows that adding residual marble dust to pozzolanic concrete improves its durability and long-term mechanical qualities. With only a slight reduction in compressive strength, adding marble dust greatly enhanced salt crystallization and freeze/thaw resistance over the year. This demonstrates the advantages of marble dust for longevity. Additionally, the study discovered that adding silica fume and marble dust to concrete can lower CO_2 emissions, improving the impact on the environment and the economy. Concrete that is more sustainable results from this ecologically friendly waste disposal technique [35]. The process of making cement clinker uses a lot of energy and resources and increases greenhouse gas emissions. A study suggests partially substituting cement with marble dust in various percentages to mitigate environmental issues. 70% of all stone extracted comes from quarrying waste, causing financial losses and environmental issues. After testing concrete samples with varying percentages of marble dust, all physical characteristics, including compressive strength, split tensile strength, and flexural strength, improved with a partial replacement of up to 10%. This approach could help reduce the environmental impact of cement-based materials [35]. Waste materials, such as slag from metal smelting, can be used as aggregates in the construction industry to meet the increasing demand for concrete ingredients. This experimental study focuses on the performance of concrete by replacing cement with WMP and fine aggregate with steel slag. The viability of producing concrete with leftover marble powder is discussed, and the effective percentage of steel slag is determined for maximum strength through workability, compressive strength and tensile strength tests [1, 35, 48].

This study uses silica fume (SF) and recycled coarse aggregates (RCA) to assess the compressive strength, durability, and other characteristics of self-compacting concrete (SCC). The study examines the impacts of partially substituting RCA for natural coarse aggregate (NCA) and SF for OPC in SCC mixes cured for 28–270 days in the presence of sodium sulphate (Na_2SO_4) solutions and regular tap water. Three different SCC mixes were tested, and the fresh and hardened properties were determined. XRD was used to investigate the change in microstructure due to sulphate attack. According to the study, the CSs of SCC mixes treated to Na_2SO_4 solution decreased by 6.76–25.00%, and fresh properties rose up to an optimal SF level (SF-10%). SF10 and SF10RCA25, the SCC mix including SF, were less affected by the Na_2SO_4 assault [49]. The study evaluates concrete using WMP as a partial replacement for cement due to its high calcium oxide content and potential environmental benefits. The marble business produces WMP as a by-product and has a specific gravity of 2.6, reducing the weight of the finished product. Five concrete mixes were prepared with different substitution stages, and the Samples were assessed using compressive, tensile, and flexural strengths. The study found that WMP inclusion decreases workability due to water absorption, and the strength of concrete can increase by up to 10% [27].

The study examines how the water-binder (w/b) ratio and NS affect the longevity of concrete in a harsh chemical environment. The research involved exposing concrete specimens to varying NS and w/b ratio concentrations. The results indicated that the w/b ratio and NS substantially impacted concrete resistance, with NS inclusion having a more prominent effect than the w/b ratio. To learn more about the endurance of the mix, the study also performed split tensile and flexural tensile strength tests [50]. Marble-cutting slurry waste (MCSW) disposal is a serious health and environmental issue. Although high-strength self-compacting concrete (HSSCC) is utilized extensively, it uses more cement, which raises CO_2 emissions significantly. The goal of this project is to use FA, SF, and MCSW to create a cost-effective and environmentally friendly HSSCC. A total of sixteen HSSCC mixes were prepared, with one mix being a control mix. The impact of MCSW and FA on HSSCC's fresh properties was assessed using SEM and FTIR techniques.

The study found that incorporating MCSW and FA improved HSSCC's mechanical performance and microstructure. Performance was improved by combining 10% MCSW and 15% FA with 5% SF [51]. The study investigates the use of fly ash (FA) and silica fume (SF) as waste supplementary cementing materials (SCMs). To increase the self-compacting high-performance concrete's compressive strength (SCHPC), the study employed SCHPC in six distinct SCHPC mixes, partially substituting ASTM C618 class F, FA, and SF Portland cement. 40% PC, 50% FA, and 10% SF combined, according to the data, was 5% higher than the control specimen's maximum compressive strength, measuring 87.06 MPa at 28 days of curing age. The goal of the project was to identify a cost-effective and environmentally friendly use for FA produced by Malaysia's four coal-fired power plants [52]. Because acid rain combines CO_2, SOx, and NOx with rainwater, it deteriorates concrete structures close to thermal power plants. Calcium hydroxide is attacked by sulphuric acid to form calcium sulphate, which can leak out and degrade the Interfacial Transition Zone (ITZ). To improve permeability, water-retaining structures like dams and weirs can be impermeable using binary cementitious blends with SF. Because of its finer particle size, SF, a by-product of the silicon industry, enhances the microstructure of concrete. A water permeability test showed an 87% reduction in permeability coefficient when 10% SF was added to cement [50]. The study investigates how waste materials, like FA and WMP, can be used as partial replacements in cementitious fine grout production. The study attempts to improve cement quality while lowering the construction industry's cost and carbon footprint. The study discovered that substituting marble powder increased the compressive strength to 26 MPa, higher than the required minimum of 14 MPa. Replacement material type, quantity, and W/C ratio all affected the mixtures' strength and flow ability; the rheology data provided valuable insights into grout mixes' flow ability and setting behaviour [53, 54].

In summary, it provides a valuable study that reveals that adding leftover marble dust to Pozzolanic concrete improves its durability and long-term mechanical qualities. This method can lower CO_2 emissions and contribute to more sustainable concrete. The study also suggests partially substituting cement with marble dust to reduce environmental impact.

Waste materials like slag from metal smelting can be used as aggregates in the construction industry. The study also evaluates the performance of SCC using SF and RCA. The study also explores the impact of the water-binder ratio and NS on concrete resistance. The study also explores using FA and SF as waste supplementary cementing materials to create cost-effective and environmentally friendly HSSCC.

2.2. Numerical Investigation

Khan et al. (2024) proposed the partial replacement of sand with WMP; for this, they investigated varying the percentages of sand from 10%,20%,30%, and 40% considering fixed w/c ratio of 0.45 and 0.28% superplasticizer and conducting destructive and non-destructive testing. They concluded that non-destructive testing has better-enhanced results [55].

Hussain et al. (2024) made an effort to lower down CO_2 emissions, looking to produce cement mortar from marble and porcelain powders instead of cement. The greatest findings were found when the study looked at the mechanical and microstructural properties of mixes containing M and P. The best compressive and flexural strengths were demonstrated by 13 mixes varying the combinations containing 10% M, 10% P, and 5% M+5% P.

The production of calcium hydroxide and high-density calcium silicate hydrate phases was the main cause of the dense, compact microstructure shown in the SEM examination. According to the study, M and P can be utilized as substitute resources to produce concrete that is both sustainable and high-performing [36].

Zeleke et al. (2023) examined the partial replacement of Portland cement in C-25 concrete with marble and scoria powder. With marble having a high CaO content and scoria having a high SiO_2 content, both materials contain more than 50% of the main oxides present in cement. The chemical, mechanical, physical, and fresh properties of concrete containing marble and scoria particles were investigated experimentally. Results show that cement could be replaced with marble and volcanic scoria powders at a 1:1 ratio up to 15% without compromising CS and 10% without compromising flexural and STS. [56] Harmandeep and Lovneesh (2022) replaced course aggregate with WMP and cement with Limestone waste powder by considering varying percentages. Experimental results show that resistance to compressive load increases at a certain replacement level [57].

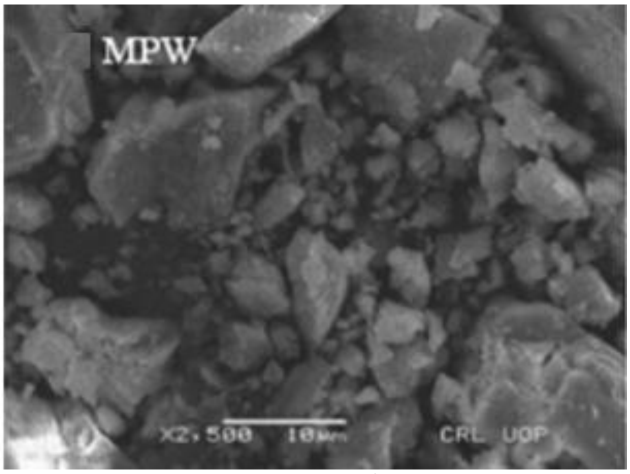

Fig. 3 SEM image of MWP

2.3. Comparative Analysis between Experimental Evaluation and Advanced Modelling Techniques

In scientific research and engineering, two methods are employed: advanced modelling techniques and experimental evaluation. To collect data and validate hypotheses, experimental evaluation entails carrying out actual experiments that yield accurate and dependable real-world data. However, it can be costly and time-consuming, and it might be constrained by real-world issues.

Computational simulations and machine learning models are examples of advanced modelling techniques that employ mathematical and computational methods to analyze complex systems and predict outcomes. Although their accuracy depends on assumptions and the quality of the input data, they are helpful for planning and decision-making.

Models can be used to help design experiments and interpret results, and experimental data can be used to validate models. However, advanced modelling techniques may be more effective for analyzing complex systems and large datasets.

3. Critical Aspect

The majority of research has been carried out experimentally to determine the physical parameters of strength, such as compressive, tensile, and flexural. Also, durability characteristics are analyzed, considering the workability of its behaviour in acidic and alkaline conditions. Moreover, various other aspects, such as machine learning techniques and numerical analysis, were made to predict the above-mentioned characteristics of fresh and hardened concrete. Nasim et al. (2024) this paper made investigated the use of granite and MWP As a substitute for concrete ingredients. Experiments reveal that 25% MWP substitution gives a better strength parameter [58]. Basha et al. (2023) Researchers used locally accessible marble powders Bethamcherla and Kadapa to create high-strength concrete. They tested compressive strength, elastic modulus, chloride resistance, and freeze-thaw durability. Microstructural analysis revealed that HSC with 10% and 15% KMP and BMP content showed higher values, indicating the potential of these marble powders as an alternative cement [37].

Tiwari et al. (2023) researcher made various levels of replacement of cement with WMP and aggregate by metal scrap and came to the conclusion that only 10% of MWP and 0.75 metal scrap replacements hold good mechanical properties. To better analyze the microstructural properties, the researcher used methodologies like SEM and EDX [59].Chadha et al. (2023) emphasize environmentally friendly building materials, and the study explores the application of treated recycled coarse aggregates (RCA) to enhance concrete's qualities. Marble dust is used in place of sand in the study's two treatments, Polyvinyl Alcohol (PVA) and Sodium Silicate + Fly Ash (SS + FA). The strength of RAC is equal to or greater than that of control concrete, according to the results, with PVA-treated aggregates exhibiting a 20.06% increase. Additionally, RCA exhibits greater rebound hammer strength and water absorption [60].

Hashmi et al. (2022) carried out experimental work to find out various inherent strength and durability properties of cement concrete. Moreover, statistical models were also performed, such as RSM, to design the experiment and optimize the doses of marble waste utilization. Further, it was determined that experimental and statical model data differ by 5%, which is much within the limits [61]. Thakur et al. (2022) the main motive of this research paper is to find out the flexural strength of concrete made by replacement of MWP by machine learning tools such as Gaussian Process, SVM, and ANFIS on a data sheet of 202 observations [62]. SCC is a high-performance concrete class that can stretch and consolidate in formwork, eliminating vibration during concrete placement. It can be replaced with limestone residue (LP) and FA without extra processing.

Mechanical properties were examined using three replacement percentages of cement at varying age intervals: 0%, 5%, 10%, and 15%. This approach enhances homogeneity and reduces vibration during concrete placement [63]. The study explores the use of WMP in cement-based materials by NS. WMP can enhance workability but reduce compressive strength, especially when the replacement ratio exceeds 10%. Researchers used NS to offset these effects. They designed 16 mortar mixes with varying levels of WMP and NS. The results showed that WMP improved fluidity but decreased compressive strength. However, NS improved the mechanical properties of cement-WMP systems. The optimal combination was 10% WMP and 3% NS. The study demonstrates how Nano-Scale additives like NS can overcome the limitations of industrial waste materials like WMP in cement-based applications, providing a promising pathway for sustainable WMP utilization in the construction industry [64]. In order to lessen the adverse ecological effects of Engineered Cementitious Composite (ECC), the study investigates the use of WMP as a partial substitute for cement. Four ECC mixes were tested: three test mixes with 10%, 15%, and 20% MWP cement replacement and a control mix without MWP. According to the findings, the compressive strength of ECC decreased by up to 49% as the MWP concentration increased. However, the tensile strain increased with MWP content, indicating improved strain-hardening behaviour. The study suggests that modified ECC samples with 10% and 15% MWP can be a more environmentally friendly alternative to normal ECC without compromising performance. The increased use of MWP makes ECC more economical, as it is a freely available waste material. The study concludes that optimizing MWP content can lead to an ECC that is both environmentally friendly and structurally sound [55]. An agro-waste product with minimal nutritional value, rice husk (RH) can be utilized as an additional cementitious ingredient in the building sector.

The collection of RH from various Khyber Pakhtunkhwa (KPK) regions, the characteristics of RH generated by various high-temperature combustion techniques, and their impact on the mechanical behaviour of cement are all covered in this study. The chemical makeup and quantity of crystalline silica in RHA were assessed using EDX and XRD assays. The findings demonstrated a clear correlation between source variation and silica content. At 800°C (method A) and primarily at 1000°C (method B), a partial conversion of crystalline silica to amorphous silica was observed. When used as a partial substitute for cement, RHA via methods A and B reduced the alkali silica reaction while increasing consistency and setting time linearly. RHA increased the flexural and compressive strength by up to 15% at older ages using methods A and B; however, procedure B showed a slight increase in strength by up to 5% [65].

This study investigates the utilization of leftover marble as a sustainable raw material to make red-firing wall tiles, which can replace up to 15% of natural calcareous material. The waste was tested for technical properties, water absorption, and flexural strength using XRD and SEM. The results showed that marble waste is highly compatible with high-quality tile production, meeting ISO 13006 normative requirements, contributing to recycling and valuing the ornamental rock and ceramic industries [66]. Alternative concrete materials, such as powdered granite and marble, have been investigated by researchers. While some studies used locally available marble powders, others discovered that a 25% MWP substitution can improve strength parameters. Nevertheless, only 0.75 percent of metal scrap replacement and 10% of MWP had good mechanical qualities. The properties of concrete were improved by using recycled coarse aggregates. With 10% and 15% MWP, ECC may offer an eco-friendly substitute without sacrificing functionality. Another sustainable raw material investigated for red-firing wall tiles was rice husk

Table 3. Summaries of various methods and parameters analyses

Material / Methodology	Prominent parameters	References
Replacement of cement by MWP and superplasticizer in Mix design.	Destructive and non-destructive tests on cubes and cylinders, UPV,	[29]
Replace cement with industrial waste such as marble powder and porcelain powder.	Mechanical and microstructural characteristics (SEM, Thermal Analysis)of mixtures	[36]
Limestone waste powder and marble-based coarse aggregate were used in concrete.	Water binder ratio, Compressive, tensile flexural strength, UPV, Rebound hammer	[57]
Statistical modelling using RSM to optimize the MWA and SD dosages and finally validate the experimental results.	Compaction factor workability test, Durability Test: Acid Attack Resistance	[61]
Cubes, beams, cylinders, and cubes with embedded roadways are cast and subjected to physical tests after replacing sand.	Water binder ratio, Compressive, tensile flexural strength,	[58]
Flexural strength of concrete that includes waste marble powder using machine learning methods.	Mechanical strength and Machine learning include SVM, Gaussian processes, and ANFIS.	[62]
High-strength concrete with varying replacement levels of MWP.	Mechanical strength, durability properties and microstructural analysis.	[37]
Replacement of cement and sand by MWP and Waste metal scrap.	SEM, EDX.	[59]
Evaluating recycled aggregate and proposing innovative strategies.	MD, PVA treatment, sodium silicate (SS) + fly ash (FA) treatment, RCA.	[60]

Fig. 4 Mechanical strength testing and crack patterns of specimens

The study looks into using residual materials from marble quarrying to make sustainable SCC. It was discovered that adding sand to marble waste can improve its flexural and compressive strengths. Nevertheless, the quantity of steel fibres affected the specimens' ability to withstand impacts more than the quantity of recycled parts. The number of hits required for surface fractures and the ultimate strength of fibre-containing specimens were both greatly impacted by fibre bridging. Additionally, there was no discernible pattern in the water absorption, suggesting that SCC with recycled marble aggregate functioned successfully [69]. The study examines how leftover marble aggregates might be used to make concrete, emphasizing the rising need for aggregates as a result of industrial expansion and the environmental problems caused by waste from marble manufacture. The study illustrates how leftover marble can be used to replace natural particles in concrete. According to the results, residual marble aggregates can be used to make concrete with similar or even better mechanical qualities than natural aggregates, especially when replacement rates reach 75%. With a sustainable solution to the depletion of natural aggregates and the management of marble waste, this discovery has important ramifications for the building sector. It adds to the financial and environmental advantages of producing concrete. The study emphasizes the significance of taking waste into account [70, 71]

4. Results and Discussion

Marble dust can significantly increase the compressive strength of concrete by filling voids within the concrete matrix, making it denser and more resilient. This waste product, often considered a waste product in the marble industry, can be used in concrete production to reduce costs and reduce energy consumption [72]. By replacing 10% to 15% of cement with marble dust, manufacturers can reduce their carbon footprint and minimize environmental pollution. This optimal replacement level balances structural integrity with mechanical properties and durability, making concrete suitable for various construction applications.

5. Methods Adopted

- Microstructural analysis was conducted using SEM and EDX methods [59].
- Machine learning tools like the Gaussian Process and SVM were utilized [61].
- Various concrete and mortar mixes were designed with different WMP, FA and NS levels [73, 74].
- Compressive strength was assessed at various curing ages [75].

5.1. Future Aspect

To learn more about the long-term behaviour and environmental effects of concrete containing WMP, research is required. Life cycle analyses, the best mix design, economic viability, and synergistic impacts with other waste materials should all be included in future research. Much work is needed to analyze other substitute ingredients for cement concrete. Understanding the material's interactions that affect its performance and durability can be gained through microstructural study. This will encourage recycling and sustainability by assisting in identifying the optimal mix design for various applications and environmental circumstances.

6. Conclusion

- The construction industry is a major contributor to environmental issues, with cement production being a significant source of greenhouse gas emissions.
- Marble waste, a non-biodegradable by-product of the marble industry, can be used as a sustainable alternative material in concrete production.
- Marble waste can be used as a partial replacement for cement up to 10% without compromising concrete properties.
- Marble waste works better as a binder when mixed with fly ash.
- Marble waste can replace fine and coarse aggregate between 50% and 75%, depending on the geological origin of the coarse aggregate and the particle size distribution of the fine aggregate being replaced.
- Adding marble waste can enhance compressive strength, particularly when used in conjunction with fly ash.
- Marble waste can improve resistance to salt crystallization and freeze-thaw cycles.

Acknowledgements

I would like to express my gratitude to everyone who helped me finish my work successfully, whether directly or indirectly. The lab facilities used for the research were provided by the Netaji Subhas Institute of Technology, Amhara, Bihta, Patna, which the authors of this paper would like to thank.

References

[1] B. Booma Priya et al., "Experimental Investigation on Concrete Using Marble Waste Powder and Steel Slag," *International Research Journal of Engineering and Technology*, vol. 3, no. 6, pp. 631-635, 2016. [Publisher Link]

[2] Xiao-Yong Wang, "Impact of Climate Change on the Optimization of Mixture Design of Low-CO2 Concrete Containing Fly Ash and Slag," *Sustainability*, vol. 11, no. 12, pp. 1-14, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[3] Aditya Rana et al., "Sustainable Use of Marble Slurry in Concrete," *Journal of Cleaner Production*, vol. 94, pp. 304-311, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[4] Oğuzhan Keleştemur et al., "Statistical Analysis for Freeze–Thaw Resistance of Cement Mortars Containing Marble Dust and Glass Fiber," *Materials & Design*, vol. 60, pp. 548-555, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[5] Mustafa Şahmaran et al., "Frost Resistance and Microstructure of Engineered Cementitious Composites: Influence of Fly Ash and Micro Poly-Vinyl-Alcohol Fiber," *Cement and Concrete Composites*, vol. 34, no. 2, pp. 156-165, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[6] Anshuman Tiwari, Sarbjeet Singh, and Ravindra Nagar, "Feasibility Assessment for Partial Replacement of Fine Aggregate to Attain Cleaner Production Perspective in Concrete: A Review," *Journal of Cleaner Production*, vol. 135, pp. 490-507, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[7] Gurcharan Singh, and S.K. Madan, "Review on the Feasibility of Marble Dust as Replacement of Cement in Concrete," *International Journal of Current Engineering and Technology*, vol. 7, no. 6, pp. 2119-2123, 2017. [Google Scholar] [Publisher Link]

[8] Ronak Malpani et al., "Effect of Marble Sludge Powder and Quarry Rock Dust as Partial Replacement for Fine Aggregates on Properties of Concrete," *International Journal of Innovative Technology and Exploring Engineering*, vol. 4, no. 1, pp. 39-42, 2014. [Google Scholar] [Publisher Link]

[9] C. Naresh et al., "Workability Studies on Fibre Reinforced Concrete Using Bethamcherla Marble Stone as a Replacement of Natural Aggregate," *International Research Journal of Engineering and Technology*, vol. 2, no. 4, pp. 1351-1356, 2015. [Google Scholar] [Publisher Link]

[10] Yasin Onuralp Özkılıç et al., "Optimum Usage of Waste Marble Powder to Reduce Use of Cement toward Eco-Friendly Concrete," *Journal of Materials Research and Technology*, vol. 25, pp. 4799-4819, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[11] V.T. Kirana et al., "Effects of Partial Replacement of Cement with Marble Powder on Properties of Concrete," *International Research Journal of Engineering and Technology*, vol. 5, no. 5, pp. 258-262, 2018. [Google Scholar] [Publisher Link]

[12] Valeria Corinaldesi, Giacomo Moriconi, and Tarun R. Naik, "Characterization of Marble Powder for its Use in Mortar and Concrete," *Construction and Building Materials*, vol. 24, no. 1, pp. 113-117, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[13] L.G. Li et al., "Use of Marble Dust as Paste Replacement for Recycling Waste and Improving Durability and Dimensional Stability of Mortar," *Construction and Building Materials*, vol. 166, pp. 423-432, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[14] Kirti Vardhan et al., "Mechanical Properties and Microstructural Analysis of Cement Mortar Incorporating Marble Powder as Partial Replacement of Cement," *Construction and Building Materials*, vol. 96, pp. 615-621, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[15] Ismail Sedat Buyuksagis, Tayfun Uygunoglu, and Ertunc Tatar, "Investigation on the Usage of Waste Marble Powder in Cement-Based Adhesive Mortar," *Construction and Building Materials*, vol. 154, pp. 734-742, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[16] Salim Barbhuiya, and Bibhuti Bhusan Das, "A Comprehensive Review on the Use of Hemp in Concrete," *Construction and Building Materials*, vol. 341, pp. 1-29, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[17] Gulden Cagin Ulubeyli, and Recep Artir, "Properties of Hardened Concrete Produced by Waste Marble Powder," *Procedia - Social and Behavioral Sciences*, vol. 195, pp. 2181-2190, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[18] V.M. Sounthararajan, and A. Sivakumar, "Effect of the Lime Content in Marble Powder for Producing High Strength Concrete," *ARPN Journal of Engineering and Applied Sciences*, vol. 8, no. 4, pp. 260-264, 2013. [Google Scholar]

[19] C. Vaidevi, "Study on Marble Dust as Partial Replacement of Cement in Concrete," *Indian Journal of Engineering*, vol. 4, no. 9, pp. 14-16, 2013. [Google Scholar] [Publisher Link]

[20] Hüseyin Yılmaz Aruntaş et al., "Utilization of Waste Marble Dust as an Additive in Cement Production," *Materials & Design*, vol. 31, no. 8, pp. 4039-4042, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[21] Deepankar Kumar Ashish et al., "Feasibility of Waste Marble Powder in Concrete as Partial Substitution of Cement and Sand Amalgam for Sustainable Growth," *Journal of Building Engineering*, vol. 15, pp. 236-242, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[22] Imrose B. Muhit, Muhammad T. Raihan, and MD. Nuruzzaman, "Determination of Mortar Strength Using Stone Dust as a Partially Replaced Material for Cement and Sand," *Advances in Concrete Construction*, vol. 2, no. 4, pp. 249-259, 2014. [Google Scholar] [Publisher Link]

[23] I. Messaoudene et al., "Effect of the Marble Fineness on the Rheological Characteristics of Concrete," *Algerian Journal of Environmental Science and Technology*, vol. 8, no. 3, pp. 2546-2552, 2022. [Google Scholar] [Publisher Link]

[24] Ertug Aydin, and Hasan Şahan Arel, "High-Volume Marble Substitution in Cement-Paste: Towards a Better Sustainability," *Journal of Cleaner Production*, vol. 237, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[25] Manish Kumar, Hirendra Pratap Singh, and Rakesh Sakale, "Utilization of Marble Powder in Making of Cement Concrete and Analysis of Its Strength Characteristics," *International Journal of Trend in Scientific Research and Development*, vol. 6, no. 3, pp. 1673-1679, 2022. [Publisher Link]

[26] Ch. Kavya, and U. Vamsi Mohan, "Properties of SCC with Marble Powder as a Marginal Material," *Materials Today: Proceedings*, vol. 60, no. 3, pp. 2167-2170, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[27] Mushraf Majeed et al., "Evaluation of Concrete with Partial Replacement of Cement by Waste Marble Powder," *Civil Engineering Journal*, vol. 7, no. 1, pp. 59-70, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[28] Filali S, Nasser A. "Investigation of Mechanical Characteristics and Sustainable Practices in Concrete Incorporating Recycled Marble Waste," *ARPN: Journal of Engineering and Applied Sciences*, vol. 19, no. 16, 1038-1049, 2024. [Publisher Link]

[29] Mohammad Ajmal Khan, and Gurpreet Singh Dhanoa, "Innovative and Eco-Friendly Concrete Forming Sustainable and Resilient Structures Using Waste Marble Powder," *International Journal of Innovative Research in Engineering and Management*, vol. 11, no. 3, pp. 112-120, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[30] Ramesh Maluga et al., "Physical, Mechanical and Wear Characterization of Epoxy Composites Reinforced With Granite/Marble Powder," *Materials Today: Proceedings*, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[31] S. Suresh, and J. Revathi, "An Experimental Examination on Mechanical and Durability Properties of Cement Replacing with Marble Powder," *International Journal of Innovative Technology and Exploring Engineering*, vol. 9, no. 2S2, pp. 115-118, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[32] Kirti Vardhan, Rafat Siddique, and Shweta Goyal, "Strength, Permeation and Micro-Structural Characteristics of Concrete Incorporating Waste Marble," *Construction and Building Materials*, vol. 203, pp. 45-55, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[33] E. Bacarji et al., "Sustainability Perspective of Marble and Granite Residues as Concrete Fillers," *Construction and Building Materials*, vol. 45, pp. 1-10, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[34] Deepankar Kumar Ashish, "Concrete Made with Waste Marble Powder and Supplementary Cementitious Material for Sustainable Development," *Journal of Cleaner Production*, vol. 211, pp. 716-729, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[35] Ceren Ince et al., "Utilisation of Waste Marble Dust for Improved Durability and Cost Efficiency of Pozzolanic Concrete," *Journal of Cleaner Production*, vol. 270, pp. 1-62, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[36] Ahlam O. Hussain et al., "Evaluation of the Enhancement of the Mechanical Properties of Cement Mortar Incorporated with Porcelain and Marble Powder," *Engineering, Technology & Applied Science Research*, vol. 14, no. 5, pp. 16116-167124, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[37] Syed Afzal Basha, and Faiz Uddin Ahmed Shaikh, "Suitability of Marble Powders in Production of High Strength Concrete," *Low-carbon Materials and Green Construction*, vol. 1, no. 1, pp. 1-16, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[38] Ashish Mathur, R.C. Chhipa, and Mala Mathur, "Inspection of the Mechanical and Durability Behavior of Concrete Developed Using M-Sand," *International Journal of Advanced Technology and Engineering Exploration*, vol. 10, no. 108, pp. 1537-1551, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[39] Sudarshan D. Kore, A.K. Vyas, and K.I. Syed Ahmed Kabeer, "A Brief Review on Sustainable Utilisation of Marble Waste in Concrete," *International Journal of Sustainable Engineering*, vol. 13, no. 4, pp. 264-279, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[40] Jawad Ahmad et al., "Effects of Waste Glass and Waste Marble on Mechanical and Durability Performance of Concrete," *Scientific Reports*, vol. 11, pp. 1-17, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[41] Chiara F Ferraris, Karthik H Obla, and Russell Hill, "The Influence of Mineral Admixtures on the Rheology of Cement Paste and Concrete," *Cement and Concrete Research*, vol. 31, no. 2, pp. 245-255, 2001. [CrossRef] [Google Scholar] [Publisher Link]

[42] M. Esmailpour, K. Rahmani, and S. Piroti, "Experimental Evaluation of the Effect of Silica Fume on Compressive, Tensile Strength, Abrasion Resistance, Slump and Impact Test and Water Permability Coefficient of Concrete," *Journal of Applied Engineering Sciences*, vol. 8, no. 21, pp. 27-36, 2018. [Google Scholar]

[43] Rishi, and Vanita Aggarwal, "Effect on Partial Replacement of Fine Aggregate and Cement by Waste Marble Powder/ Granules on Flexural and Split Tensile Strength," *IOSR Journal of Mechanical and Civil Engineering*, vol. 11, no. 4, pp. 110-113, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[44] Nadhir Toubal Seghir et al., "The Effect of Curing Conditions on the Properties of Cement-Based Composites Blended with Waste Marble Dust," *Jom*, vol. 71, pp. 1002-1015, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[45] Mahim Mathur, and R.C. Chhipa, "Experimental Study on Durability of Glass Modified Concrete: Resistance to Acid and Sulphate Attack," *International Journal of Advanced Technology and Engineering Exploration*, vol. 10, no. 107, pp. 1353-1367, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[46] Abdullah Anwar et al., "Replacement of Cement by Marble Dust and Ceramic Waste in Concrete for Sustainable Development," *IJISET - International Journal of Innovative Science, Engineering & Technology*, vol. 2, no. 6, pp. 496-503, 2015. [Google Scholar] [Publisher Link]

[47] Abdul Ghani et al., "Experimental Study on the Mechanical Behavior of Concrete Incorporating Fly Ash and Marble Powder Waste," *Scientific Reports*, vol. 14, no. 1, pp. 1-18, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[48] Ali Ergün, "Effects of the Usage of Diatomite and Waste Marble Powder as Partial Replacement of Cement on the Mechanical Properties of Concrete," *Construction and Building Materials*, vol. 25, no. 2, pp. 806-812, 2011. [CrossRef] [Google Scholar] [Publisher Link]

[49] Anjali Singh, P.K. Mehta, and Rakesh Kumar, "Recycled Coarse Aggregate and Silica Fume Used in Sustainable Self-Compacting Concrete," *International Journal of Advanced Technology and Engineering Exploration*, vol. 9, no. 96, pp. 1581-1596, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[50] Satish Kumar Chaudhary, and Ajay Kumar Sinha, "Effect of Silica Fume on Permeability and Microstructure of High Strength Concrete," *Civil Engineering Journal*, vol. 6, no. 9, pp. 1697-1703, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[51] Rakesh Choudhary, Rajesh Gupta, and Ravindra Nagar, "Impact on Fresh, Mechanical, and Microstructural Properties of High Strength Self-Compacting Concrete by Marble Cutting Slurry Waste, Fly Ash, and Silica Fume," *Construction and Building Materials*, vol. 239, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[52] F.A. Mustapha et al., "The Effect of Fly Ash and Silica Fume on Self-Compacting High-Performance Concrete," *Materials Today: Proceedings*, vol. 39, no. 2, pp. 965-969, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[53] Hikmet Sis et al., "Influence of Marble Powder and Fly Ash on Rheological Properties and Strength of Cementitious Grouts," *Journal of Sustainable Construction Materials and Technologies*, vol. 6, no. 1, pp. 12-23, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[54] M. Manjunatha et al., "Life Cycle Assessment (LCA) of Concrete Prepared with Sustainable Cement-Based Materials," *Materials Today: Proceedings*, vol. 47, no. 13, pp. 3637-3644, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[55] Ezaz Ali Khan et al., "Utilization of Waste Marble Powder as Partial Replacement of Cement in Engineered Cementitious Composite," *Cogent Engineering*, vol. 10, no. 1, pp. 1-15, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[56] Tadele Yigrem Zeleke et al., "Experimental Investigation on the Utilization of Marble and Scoria Powder as Partial Replacement of Cement in Concrete Production," *Advances in Civil Engineering*, vol. 2023, no. 1, pp. 1-13, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[57] S. Harmandeep, and S. Lovneesh, "Effect of Limestone Waste Powder and Marble Waste over the Strength Properties of the Conventional Concrete," *IOP Conference Series: Earth and Environmental Science, International Conference on Advance Earth Sciences & Foundation Engineering*, Mohali, India, vol. 1110, no. 1, pp. 1-12, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[58] Mohd Nasim, and Ashish Kumar Rao, "Enhancing Concrete Properties through the Strategic Incorporation of Granite and Marble Dust as Sustainable Alternatives to Natural Sand," *Journal of Physics: Conference Series, International Conference on Materials Innovation and Sustainable Infrastructure*, Bhimavaram, India, vol. 2779, no. 1, pp. 1-10, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[59] Anjani Kumar Tiwari, Prince Yadav, and Samreen Bano, "An Experimental Investigation of Marble Powder as a Partial Replacement of Cement and Waste Metal Scrap as Reinforcing Material on the Mechanical Characteristics of Concrete," *IOP Conference Series: Earth and Environmental Science, International Conference on Creative and Innovative Solutions in Civil Engineering*, Jaipur, India, vol. 1326, no. 1, pp. 1-12, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[60] Vidushi Chadha et al., "Sustainable Concrete Production: Optimizing Recycled Aggregates with Advanced Treatments and Marble Dust as Filler," *Researchsquare*, pp. 1-33, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[61] Syed Roshan Zamir Hashmi et al., "Prediction of Strength Properties of Concrete Containing Waste Marble Aggregate and Stone Dust—Modeling and Optimization Using RSM," *Materials*, vol. 15, no. 22, pp. 1-22, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[62] Nitisha Sharma et al., "Assessing Waste Marble Powder Impact on Concrete Flexural Strength Using Gaussian Process, SVM, and ANFIS," *Processes*, vol. 10, no. 12, pp. 1-24, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[63] S. Anandaraj et al., "An Experimental Study on Fly Ash (FA) and Marble Powder in the Properties of Self-Compacting Concrete (SCC)," *Materials Today: Proceedings*, vol. 52, no. 3, pp. 1771-1774, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[64] Baoguo Ma et al., "Utilization of Waste Marble Powder in Cement-Based Materials by Incorporating Nano Silica," *Construction and Building Materials*, vol. 211, pp. 139-149, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[65] Kaffayatullah Khan et al., "Exploring the Use of Waste Marble Powder in Concrete and Predicting its Strength with Different Advanced Algorithms," *Materials*, vol. 15, no. 12, pp. 1-28, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[66] Ali Khodabakhshian et al., "Durability Performance of Structural Concrete Containing Silica Fume and Marble Industry Waste Powder," *Journal of Cleaner Production*, vol. 170, pp. 42-60, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[67] Rania A. Hamza, Salah El-Haggar, and Safwan Khedr, "Marble and Granite Waste: Characterization and Utilization in Concrete Bricks," *International Journal of Bioscience, Biochemistry and Bioinformatics*, vol. 1, no. 4, pp. 286-291, 2011. [Google Scholar] [Publisher Link]

[68] Abd Elmoaty M. Abd Elmoaty, Alaa M. Morsy, and Abdelrhman B. Harraz, "Effect of Fiber Type and Volume Fraction on Fiber Reinforced Concrete and Engineered Cementitious Composite Mechanical Properties," *Buildings*, vol. 12, no. 12, pp. 1-28, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[69] R. Rodrigues, J. de Brito, and M. Sardinha, "Mechanical Properties of Structural Concrete Containing Very Fine Aggregates from Marble Cutting Sludge," *Construction and Building Materials*, vol. 77, pp. 349-356, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[70] H. Hebhoub et al., "Use of Waste Marble Aggregates in Concrete," *Construction and Building Materials*, vol. 25, no. 3, pp. 1167-1171, 2011. [CrossRef] [Google Scholar] [Publisher Link]

[71] Hanifi Binici et al., "Durability of Concrete Made with Granite and Marble as Recycle Aggregates," *Journal of Materials Processing Technology*, vol. 208, no. 1-3, pp. 299-308, 2008. [CrossRef] [Google Scholar] [Publisher Link]

[72] Sudarshan Dattatraya Kore, and A.K. Vyas, "Cost Effective Design of Sustainable Concrete Using Marble Waste as Coarse Aggregate," *Journal of Materials and Engineering Structures*, vol. 3, no. 4, pp. 167-180, 2016. [Google Scholar] [Publisher Link]

[73] Satish Kumar Chaudhary, Ajay Kumar Sinha, and Praveen Anand, "Synergistic Action of Nano Silica and w/b Ratio on Accelerated Durability Performance of Concrete," *International Journal of Advanced Technology and Engineering Exploration*, vol. 10, no. 105, pp. 1078-1092, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[74] Steve Wilben Macquarie Supit, and Faiz Uddin Ahmed Shaikh, "Durability Properties of High Volume Fly Ash Concrete Containing Nano-Silica," *Materials and Structures*, vol. 48, pp. 2431-2445, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[75] Aamar Danish et al., "Performance Evaluation and Cost Analysis of Prepacked Geopolymers Containing Waste Marble Powder under Different Curing Temperatures for Sustainable Built Environment," *Resources, Conservation and Recycling*, vol. 192, 2023. [CrossRef] [Google Scholar] [Publisher Link]

1	**Abbreviation**	**Full Form**
2	ANFIS	Adaptive Neuro-Fuzzy Inference System
3	ASTM	American Society for Testing and Materials
4	CO_2	Carbon Dioxide
5	ECC	Engineered Cementitious Composite
6	EDX	Energy-Dispersive X-ray Spectroscopy
7	FA	Fly Ash
8	HSSCC	High Strength Self-Compacting Concrete
9	ITZ	Interfacial Transition Zone
10	KPK	Khyber Pakhtunkhwa
11	MD	Marble Dust
12	MCSW	Marble Cutting Slurry Waste
13	NCA	Natural Coarse Aggregate
14	NS	Nano Silica
15	OPC	Ordinary Portland Cement
16	PVA	Polyvinyl Alcohol
17	RCA	Recycled Coarse Aggregates
18	RH	Rice Husk
19	RSM	Response Surface Methodology
20	SCC	Self-Compacting Concrete
21	SCM	Supplementary Cementing Materials
22	SEM	Scanning Electron Microscopy
23	SF	Silica Fume
24	SS	Sodium Silicate
25	SVM	Support Vector Machine
26	STS	Split Tensile Strength
27	UPV	Ultrasonic Pulse Velocity
28	W/B	Water-Binder
29	WMP	Waste Marble Dust
30	WMP	Waste Marble Powder
31	XRD	X-Ray Diffraction