

Evaluating Marble Dust As A Replacement Material In Cement Concrete: A Comparative Study

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Abstract

Marble has historically been one of the most extensively used construction materials, and its processing generates a significant amount of waste in the form of marble dust. This by-product, if not managed properly, poses serious environmental concerns such as increased soil alkalinity, adverse effects on vegetation, and potential health hazards for humans. Nearly one-fourth of the marble block is lost as fine powder during cutting and polishing operations, highlighting the need for sustainable utilization of this waste.

One promising approach is to incorporate marble dust into concrete, either as filler or as a partial replacement for fine aggregates. This not only minimizes waste disposal issues but also promotes cost-effective and environmentally friendly construction practices. The present study investigates the effect of substituting fine aggregate with marble dust in M25 grade concrete at replacement levels of 0%, 4%, 8%, 12%, and 16%. Properties of both fresh and hardened concrete, including slump values, compressive strength, water absorption, and specific gravity, were evaluated.

The results demonstrated that compressive strength decreased progressively with increasing marble dust content; however, up to 4% replacement was found feasible without notable loss of strength. Additionally, water absorption reduced at higher replacement levels, though workability declined with increasing dust percentages.

The findings suggest that marble dust, a readily available by-product, can be effectively used as a partial replacement for fine aggregates in concrete. This provides a dual benefit of resource efficiency and waste reduction, aligning with sustainable construction practices.

Keywords: Marble Dust, M25 Concrete, Compressive Strength, Workability, Waste Utilization

1. INTRODUCTION

1.1 Background

Concrete is the most widely used construction material in the world, consisting primarily of cement, fine aggregates, coarse aggregates, and water. With the rapid expansion of the construction industry, the demand for these natural resources has increased substantially. Simultaneously, industrial by-products and wastes have emerged as potential alternatives for partial substitution in concrete, offering both economic and environmental benefits.

1.2 Marble Industry and Waste Generation

Marble has been extensively used as a building and decorative material since ancient times. However, the processing of marble blocks into slabs and tiles produces large quantities of waste in the form of marble dust and slurry. Studies estimate that nearly 20–25% of the original marble volume is lost as fine powder during cutting and polishing operations. Improper disposal of this waste not only leads to soil contamination and increased alkalinity but also affects plant growth and creates environmental hazards.

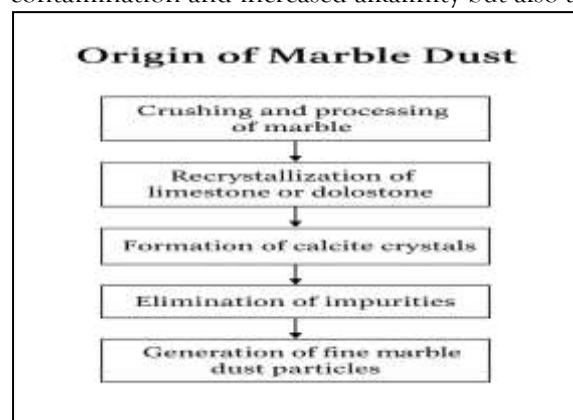


Fig. 1 Origin of Marble Dust

1.3 Potential of Marble Dust in Concrete

Marble dust, due to its fine particle size and chemical composition rich in calcium carbonate, can be effectively utilized in concrete production. It can function as a filler material, improving particle packing, or as a partial replacement for fine aggregates. Incorporating marble dust in concrete mix design has been found to influence properties such as workability, compressive strength, water absorption, and durability.

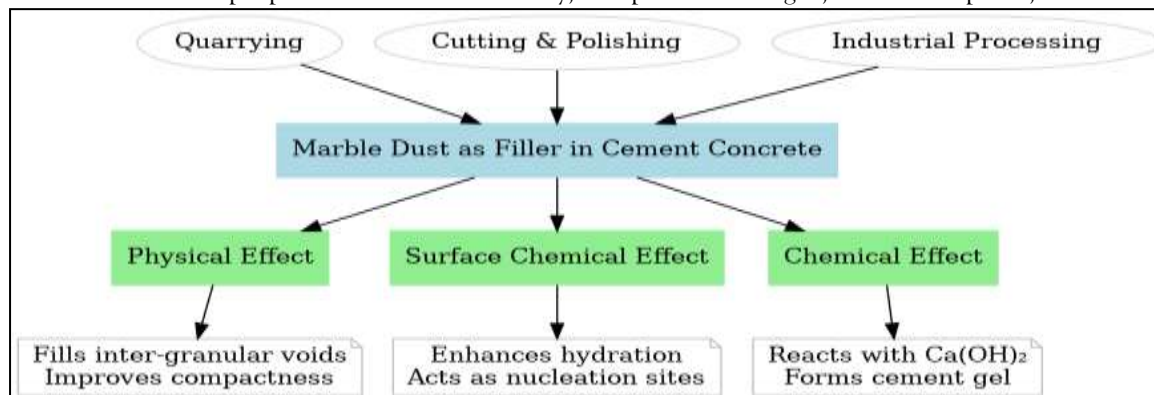


Fig. 2 Marble Dusts as Filler in Cement Concrete

1.4 Problem Statement

The construction industry is facing a dual challenge: the depletion of natural fine aggregate sources and the escalating cost of raw materials. This situation has created significant pressure on sustainable construction practices. At the same time, marble processing industries generate large quantities of waste in the form of dust, which is often discarded indiscriminately. Such disposal practices contribute to land degradation, reduction in soil fertility, dust pollution, and pose risks to both ecological balance and human health.

Given these concerns, there is a pressing need to identify innovative ways to manage marble waste while addressing the scarcity of natural aggregates. A potential solution lies in evaluating the suitability of marble dust as a partial replacement for fine aggregates in cement concrete. However, this raises a critical question: Can marble dust be effectively incorporated into concrete mixes to maintain or enhance mechanical performance and durability, while simultaneously offering environmental and economic benefits.

1.5 Objectives

1. To study the mechanical properties of concrete i.e compressive strength, split tensile strength, and flexural strength.
2. To protect the environment from pollution
3. To find out the optimum replacement percentage of marble dust with hooked end steel fibres.
4. To develop eco- friendly buildings

1.6 Scope of the Study

The scope includes:

- Mix design of conventional and marble dust concrete.
- Experimental testing for fresh and hardened properties (slump test, compressive strength, water absorption, and specific gravity).
- Comparative analysis of results with control concrete.

Long-term durability aspects such as shrinkage, creep, and chemical resistance are beyond the scope of this study.

1.7 Significance of the Study

Utilizing marble dust as a replacement material addresses two key issues: reducing the environmental impact of marble waste disposal and conserving natural resources used in construction. Furthermore, it aligns with sustainable construction practices by promoting resource efficiency, cost-effectiveness, and eco-friendly alternatives.

1.8 Need for the Study

The construction sector faces two major challenges:

1. **Scarcity of natural resources** – The depletion of river sand and increasing costs of construction materials necessitate the exploration of alternative resources.
2. **Environmental concerns** – The improper disposal of marble dust contributes to land, water, and air pollution, making it essential to find environmentally friendly ways of reusing this waste.

By incorporating marble dust into concrete, it is possible to achieve:

- Eco-friendly disposal of marble waste.
- Reduction in the use of natural aggregates.
- Cost-effective and sustainable concrete production.

2. RESEARCH METHODOLOGY

2.1 Materials Used

2.1.1 Cement

Ordinary Portland Cement (OPC) of Ambuja brand, conforming to IS 269:1976 and IS 4031:1968, was used in this study. The cement employed was OPC of 43 grades. Cement is a fine, grey powder obtained by grinding Portland cement clinker (more than 90%), a small quantity of calcium sulphate (to regulate setting time), and up to 5% minor constituents. When mixed with water and aggregates, cement forms a binding paste that hardens over time, holding the concrete mass together.

Cement primarily consists of two raw materials: calcareous (containing calcium carbonates or lime) and argillaceous (containing silica, alumina, and oxides of iron). OPC is the most widely used type of cement due to its easy availability, cost-effectiveness, versatility, and adaptability to different construction purposes. It also requires minimal maintenance during service life. The Ambuja OPC-43 grade cement used in this work was fresh, of standard quality, and free from lumps.



Fig. 2.1 Cement

Table 2.1 The various tests results conducted on cement

S. No.	Characteristics	Values obtained	Standard value
1.	Normal consistency	30 %	25% - 33%
2.	Initial setting time (minutes)	55 min.	Not less than 30
3.	Final setting time (minutes)	280 min.	Not more than 600
4.	Specific gravity	3.150	3 to 3.250

2.1.2 Fine Aggregate

Natural sand, which is economical and readily available, was used as fine aggregate in this study. The sand particles were predominantly cubical or rounded in shape with a smooth surface texture, which contributed to improved workability of the concrete mix. The sand was sourced from a stone crushing plant, and the particles were observed to have a brownish color and smooth texture.

Sieve analysis was carried out to determine the fineness modulus, which was found to be 3.29, falling within the permissible limits specified by IS 383:1970. Fine aggregate is defined as material most of which passes through a 4.75 mm IS sieve, with a lower size limit of approximately 0.07 mm. According to IS standards, fine aggregate is classified into four grading zones (I to IV), with Zone I being coarser and Zone IV being finer.

For the present work, sand conforming to Grading Zone II was used.



Fig. 2.2 Fine Aggregate

Table 2.2 Properties of fine aggregates

S. No.	Characteristics	Value
1.	Type	Crushed
2.	Specific gravity	2.700

Table 2.3 Sieve analysis of fine aggregate

S.No	Sieve Size	Cum. weight retained (%)	Weight passing (%)	Prescribed limit % wt. passing Zone II
1.	10 mm	-	100.0	100
2.	4.75 mm	-	100.0	90 – 100
3.	2.36 mm	7.00	93.0	75 – 100
4.	1.18 mm	33.80	66.20	55 – 90
5.	600 μ	54.40	45.60	35 – 59
6.	300 μ	78.10	21.90	8 – 30
7.	150 μ	76.70	3.30	0 – 10
		$\Sigma C=270.0$		

Fineness Modulus of fine aggregate = $\Sigma C/100 = 270/100 = 2.700$

2.2.3 Coarse Aggregate

The coarse aggregates used in this study were derived from basalt rock, which falls under the category of normal-weight aggregates. These aggregates were locally available and selected in two nominal sizes: 20 mm and 10–12 mm. A proportion of 50:50 was maintained between the two sizes to achieve better gradation and packing density in the concrete mix.

Crushed stone aggregates of 20 mm and 10 mm size were consistently used throughout the experimental program. Prior to use, the aggregates were thoroughly washed to remove dust, dirt, and other impurities, and then dried to attain a surface-dry condition, ensuring reliable test results.



Fig. 3.3 Coarse Aggregate

Table 2.4 The Properties of fresh coarse aggregates are reported

S. No.	Characteristics	20 mm aggregate	10 mm aggregate
1.	Type	Crushed	Crushed
2.	Maximum size	20 mm	10 mm
3.	Specific gravity	2.740	2.740

Table 2.5 Sieve Analysis 20 mm Aggregate

S.No	Sieve Size	Weight Retained (%)	Cumulative weight Retained (%)	Weight Passing (%)	Prescribed limit % wt. passing
1.	40 mm	-	-	100.0	100
2.	20 mm	2.00	2.00	98.0	85 – 100
3.	10 mm	94.40	96.40	3.60	0 – 20
4.	4.75 mm	3.60	100.0	00	0 – 5

Table 3.6 Sieve analysis of 10 mm aggregate

S.No	Sieve Size	Weight Retained (%)	Cumulative weight Retained (%)	Weight Passing (%)	Prescribed limit % wt. passing
1.	12.50 mm	3.50	3.50	96.50	100
2.	10 mm	14.9	18.40	81.60	85 – 100
3.	4.750 mm	66.20	84.6	15.4	0 – 20
4.	2.360 mm	12.50	97.10	2.90	0 – 5

2.1.4 Marble Dust

The marble dust powder used in this study was procured locally. The incorporation of marble dust as a partial replacement material was investigated to study its influence on both the fresh and hardened properties of concrete.

Previous research (Panda et al., 2012) has highlighted the potential of marble dust powder to act as a substitute for conventional cement content or even as a replacement for coarse aggregates in certain concrete mixes. In this experimental program, the feasibility of utilizing marble dust as a partial replacement for fine aggregates was examined, and its effect on workability, compressive strength, and tensile strength was evaluated.

It was observed that replacing natural aggregates with marble dust powder resulted in a reduction in the overall weight of concrete, indicating its potential application in producing lightweight concrete mixtures.

2.1.5 Water

Fresh and clean tap water was used for casting and curing the concrete specimens in this study. The water conformed to the requirements of relevant Indian Standards, being free from harmful substances such as organic matter, silt, oil, sugar, chlorides, and acidic materials that could adversely affect the properties of concrete.

According to IS specifications, the pH value of mixing water should generally lie within the range of 6.5 to 8.0. The water used in this investigation satisfied these criteria, ensuring its suitability for concrete production.



Fig 2.4 Water

2.2 Mix Design

The mix design for concrete was carried out based on the properties of its constituent materials. The target grade of concrete was M35, and the design was prepared in accordance with the guidelines specified in IS: 10262-2009 and IS: 456-2000. A water-cement ratio of 0.5 was adopted, which is the maximum permissible value for M35 grade concrete under moderate exposure conditions.

2.2.1 Methods of Concrete Mix Design

Several approaches are available for designing concrete mixes, including:

- ISI mix design method
- Trial-and-error method
- Road Note No. 4 method
- USBR (U.S. Bureau of Reclamation) method
- Minimum void method
- Maximum density method

2.2.2 Requirements of Concrete Mix Design

The essential requirements to be considered in concrete mix design are as follows:

- a) Limiting the maximum cement content to minimize the risk of shrinkage cracks caused by temperature variations in mass concrete.
- b) Adopting a suitable water-cement ratio and/or cement content to ensure durability under specific site conditions.
- c) Achieving the minimum compressive strength required from structural considerations.
- d) Ensuring adequate workability to allow full compaction using the available equipment.

2.2.3 ISI Mix Design Method

For this study, the M35 grade concrete mix was designed using the ISI method in compliance with standard specifications. This method provided the basis for preparing trial mixes, which were later tested to assess workability and strength characteristics.

2.2.4 Steps Involved in Concrete Mix Design

The process of designing a concrete mix involves the following systematic steps:

- a) Estimation of the target means strength from the specified characteristic strength.
- b) Selection of an appropriate water-cement ratio corresponding to the target means strength, ensuring compliance with durability requirements.
- c) Determination of the water content needed to achieve the desired workability.
- d) Calculation of the cement content using the selected water-cement ratio and water content, followed by verification against the minimum cement requirement for durability.
- e) Selection of the proportion of fine and coarse aggregates based on their physical characteristics
- f) Preparation of trial mix proportions using the calculated values.
- g) Testing of the trial mixes for compressive strength, followed by suitable adjustments until the final mix composition is achieved.

2.2.5 Types of Mixes

Concrete mixes are generally classified into the following categories:

- a) **Nominal Mixes** – Proportions are specified by volume and are typically used for lower grades of concrete.
- b) **Standard Mixes** – Prescribed mixes with defined proportions, suitable for commonly used grades.

c) **Design Mixes** – Proportions are determined based on performance requirements, with adjustments made to suit the specific materials available.

2.2.6 Design Mixes

In design mixes, the performance requirements of the concrete (such as strength and durability) are specified by the designer, while the mix proportions are determined by the concrete producer. Although minimum cement content may be specified, the actual proportioning depends on the unique characteristics of the materials used.

This approach is considered the most rational and economical, as it enables the production of concrete with the desired properties tailored to specific conditions. However, a design mix should not be regarded as a universal guide, since proportions may need adjustment for different material sources or site conditions.

In the present study, the mix design for M35 grade concrete was carried out in accordance with IS: 10262-2009 and IS: 456-2000. A water-cement ratio of 0.5 was adopted, which is the maximum recommended limit for M35 concrete under mild to moderate exposure conditions.

2.2.7 Factors to be considered for Mix Design

Several factors need to be carefully evaluated when designing a concrete mix to ensure both strength and durability. These include:

- Grade designation** – The target grade specifies the characteristic compressive strength requirement of the concrete.
- Type of cement** – Different cements influence the rate of strength development and long-term performance of concrete.
- Maximum nominal size of aggregates** – Larger aggregates can be used within the limits prescribed by IS 456:2000, as they reduce the water demand for a given workability.
- Cement content** – The cement quantity should be controlled to minimize risks of shrinkage, cracking, and creep.
- Workability requirements** – Workability depends on the size and shape of structural elements, the amount and spacing of reinforcement, and the methods of transportation, placing, and compaction adopted.

2.2.8 Mix Design (as per IS 10262:2009)

The concrete mix for this study was designed following the Indian Standard Recommended Guidelines (IS 10262:2009) in combination with IS 456:2000. The design aimed to achieve the target strength for M35 grade concrete, while ensuring durability, workability, and economy.

Step 1 Stipulation for Proportioning

- Grade designation : M – 25
- Type of cement : O.P.C 43 grade conforming to IS 8112
- Maximum nominal size of aggregate : 20 mm
- Minimum cement content : 300 kg
- Maximum water-cement ratio : 0.50
- Workability (Slump) : 100 mm
- Exposure condition : Moderate
- Degree of supervision : Good
- Type of aggregate : Washed Crushed Angular
- Maximum cement content : 450 kg / m³

Step 2 Test Data for materials

- Cement used : OPC 43 grade conforming to IS: 8112
- Specific Gravity of cement : 3.15
- Specific Gravity of coarse aggregate : 2.74
- Specific Gravity of fine aggregate : 2.70
- Water absorption of coarse aggregate : 1.25 %

Step 3 Target Strength for Proportioning

Target mean strength = Characteristic strength + 1.65 x S

S = Standard deviation (values of s given in table 1 of IS: 10262 -2009)

For M-35 grade of concrete, Standard Deviation = 5.0 N/ mm².

Target Mean Strength = 35 + 1.65 x 5.0

= 43.25 N/mm²

Step 4 Selection of Water/Cement Ratio

From table 5 page no. 20 of IS 456, maximum water-cement ratio = 0.50

Therefore adopted water cement ratio = 0.45

Step 5 Selection of Water Content

Maximum water content = 186 ltr (From table 2 of IS 10262 – 2009)

Therefore water content adopted for design = $186 + 6/100 \times 186 = 197$ Litre

Step 6 Selection of Cement Content

Water – cement Ratio = 0.45

Cement Content = $197/0.45 = 437.7 \text{ kg/m}^3$

Min. Cement Content = 300 kg (from table 5 IS 456 for moderate condition)

As $437.7 \text{ kg/m}^3 > 300 \text{ kg/m}^3$,

Hence O.K

Step 7 Proportioning of volume of coarse aggregate and fine aggregate content

From table 3 of IS 10262:2009 volume of coarse aggregate (20mm) and fine aggregate (Zone II) for water cement ratio of 0.5 = 0.62

Based on experience water cement ratio = 0.45

Therefore volume of coarse aggregate is to be increased to decrease the fine aggregate content, therefore increase in coarse aggregate content due to decrease in water cement ratio

= $(0.5 - 0.45 = 0.05) = 0.01$

Therefore volume of coarse aggregate = $0.62 + 0.01 = 0.63$

Volume of fine aggregate = $1 - 0.63 = 0.37$

Step 8 Mix Calculations

1. Volume of concrete = 1 m^3

2. Volume of cement = Mass of cement / Sp. Gravity $\times 1/1000$
 = $437.7/3.15 \times 1/1000$
 = 0.138 m^3

3. Volume of Water = Mass of Water / Sp. Gravity $\times 1/1000$
 = $197/1 \times 1/1000$
 = 0.197 m^3

4. Volume of all in aggregate = $[(1 - (2 + 3))]$
 = $[1 - (0.138 - 0.197)] = 0.665 \text{ m}^3$

5. Mass of Coarse Aggregate = (4) $\times$ Vol. of Course Aggregate $\times$ Sp. Gravity $\times 1000$
 = $0.665 \times 0.63 \times 2.74 \times 1000 = 1147.92 \text{ kg}$

6. Mass of Fine Aggregate = (4) $\times$ Vol. of Fine Aggregate $\times$ Sp. Gravity $\times 1000$
 = $0.665 \times 0.37 \times 2.70 \times 1000 = 664.33 \text{ kg}$

Step 9 Mix Proportion

Cement = 437.7 kg

Water = 197 ltr

Fine Aggregate = 664.33 kg

Coarse Aggregate = 1147, 92 kg

Water - Cement Ratio = 0.45

Step 10 Design Mix Ratios

Cement = $437.7 \text{ kg}/437.7 \text{ kg} = 1$

Fine Aggregate = $664.33 \text{ kg}/437.7 = 1.51$

Coarse Aggregate = $1147, 92 \text{ kg}/437.7 = 2.62$

Water = 197 ltr

Therefore M35 Design Ratio Is = 1: 1.51:2.62

Mix Proportions

For this study, five different concrete mixes were prepared incorporating crumb rubber as a partial replacement for cement by weight. The replacement levels were 0% (reference mix), 4%, 8%, 12%, and 16%. The base concrete mix was proportioned for M35 grade in accordance with the guidelines of IS: 10262–2009. Each mix was designed to maintain a constant water–cement ratio, ensuring comparability of results across different replacement levels.

Table2.7 Properties of Mix Design

Mix	Compressive Strength (7 days)	Compressive strength (28 days)	Slump
M35	23.070 N/mm ²	34.880 N/mm ²	65.0 mm

2.3 Mix Designation Adopted

The mix designation and quantities of various materials for each designed concrete mix have been mentioned in Table

Table 2.8 Mix Designation

Grade of concrete	Mix Designation	Percentage by wt.	
		FINE AGGREGATE	CRUMB RUBBER
M-25	RM0	100%	0%
	RM4	96%	4%
	RM8	92%	8%
	RM12	88%	12%
	RM16	84%	16%

Table 2.9 Quantity of material per cubic meter for different Mixes

Material kg/m ³	RM0	RM4	RM8	RM12	RM16
Cement	437.7	437.7	437.7	437.7	437.7
Natural Coarse Agg.	1147.9	1147.9	1147.9	1147.9	1147.9
Marble Dust	0	26.57	53.14	79.71	106.29
Fine Agg.	664.33	637.75	611.18	584.61	558.03
Water	197	197	197	197	197

2.4 Factors Considered While Mix Design

The following factors were taken into account during the concrete mix design process:

- Grade designation** – specifying the characteristic compressive strength requirement of concrete.
- Type of cement** – as it significantly influences the rate of strength development and long-term durability.
- Maximum nominal size of aggregates** – selected to be as large as possible within the limits prescribed by IS 456:2000, in order to reduce water demand and enhance economy.
- Cement content** – limited appropriately to minimize shrinkage, cracking, and creep.
- Workability requirements** – ensured for proper placing and compaction, depending on the size and shape of the structural section, quantity and spacing of reinforcement, and methods of transportation, placing, and compaction.

2.5 Batching, Mixing, and Casting of Specimens

A systematic procedure was followed during the batching, mixing, and casting operations to ensure uniformity and accuracy. The coarse and fine aggregates were first weighed with an accuracy of ± 0.5 grams. The concrete was then prepared by hand-mixing on a watertight platform. Initially, the coarse and fine aggregates were mixed thoroughly, after which cement was added and blended until a uniform color was achieved. Water was then carefully added to avoid any loss during mixing.

The prepared mix was placed into clean and oiled moulds in three layers, with each layer compacted using a vibrating table. Vibration was stopped immediately once a thin film of cement slurry appeared on the surface.

The specimens were kept in their moulds for the first 24 hours under ambient conditions. They were then demoulded carefully to avoid edge breakage and subsequently placed in a curing tank at an ambient temperature of 27 ± 2 °C for further curing until testing.

2.6 Quality Control

The quality of concrete was monitored through statistical evaluation of test results. Variations in compressive strength generally arise due to differences in the properties of mix ingredients, as well as inaccuracies during batching, mixing, placing, curing, and testing. A smaller difference between the mean and minimum strengths of the mix indicates better quality control and allows for a reduction in cement content without compromising performance. This variation factor, therefore, serves as a direct measure of the degree of quality control maintained during concrete production.

2.7 Testing on Physical Properties of Materials

2.7.1 Cement

Specific Gravity of Cement

Specific gravity is defined as the ratio of the density (mass per unit volume) of a material to the density of a reference substance (usually water for liquids and solids). For cement, kerosene is often used instead of water as the reference medium, since water reacts with cement. The specific gravity of cement helps in identifying its quality and uniformity, and it is generally expected to be around **3.15 for Ordinary Portland Cement (OPC)**.

Procedure

- Weigh the empty specific gravity bottle and record the weight as W_1 .
- Fill the bottle up to half its volume with cement and record the weight as W_2 .
- Add kerosene oil to fill the bottle completely and record the combined weight as W_3 .
- Empty the bottle, clean it thoroughly, dry it, then fill it completely with kerosene oil and record the weight as W_4 .

$$\text{Specific Gravity} = \frac{(W_2 - W_1)}{(W_3 - W_4)}$$

Therefore specific gravity of cement = 3.15



Figure 3.5 Specific Gravity Bottle

2.7.2 Standard Consistency of Cement

Definition:

Consistency refers to the amount of water required to prepare a workable paste of cement mortar or cement concrete. It ensures that the cement paste has adequate strength and workability when used in structures. The standard consistency is determined using **Vicat's Apparatus**.

Procedure:

- Weigh approximately **400 g of cement** and mix it with a measured quantity of water. The time for gauging should be between **3 to 5 minutes**.

- b) Fill the **Vicat's mould** with the prepared cement paste and level the surface using a trowel.
- c) Lower the plunger of the apparatus gently until it just touches the surface of the paste.
- d) Release the plunger, allowing it to penetrate into the cement paste freely.
- e) Note the reading on the graduated scale.
- f) Repeat the process with fresh samples of cement and different water quantities until the plunger penetrates to a depth of **5 to 7 mm** from the bottom of the mould.

Result:

The percentage of water added corresponding to this penetration is taken as the **standard consistency of cement**.

Standard Consistency

$$(P) = \frac{W}{C} \times 100$$

$$P = \frac{(120/400) \times 100}{100} = 30$$

$$P = 30\%$$

Where:-

P = Calculate percentage of water

W = Quantity of water added

C = Quantity of cement used



Fig 2.6 Vicat's Apparatus

2.7.3 Setting Time of Cement

The setting time of cement is determined using Vicat's Apparatus. It indicates the time taken by cement paste to transition from a plastic state to a hardened state, which is critical for mixing, transporting, placing, and compacting cement concrete in construction work. The setting time is classified into:

A) Initial Setting Time

Definition:

The **initial setting time** is the time interval between the moment water is added to cement and the moment when the needle fails to penetrate the paste to a depth of **35-37 mm from the top of the Vicat mould**.

Procedure:

- a) Prepare a paste of **400 g of cement** with **0.85 times the water required for standard consistency**.
- b) The time of gauging shall not be less than **3 minutes** and not more than **5 minutes**; it must be completed before any signs of setting occur.
- c) Count the time of gauging from the instant water is added to cement until filling of the mould begins.
- d) Fill the **Vicat mould** with the prepared paste and level the top surface.
- e) Slightly shake the mould to expel trapped air.
- f) During filling, only the operator's hands and gauging trowel shall be used.
- g) Immediately place the mould on a non-porous resting plate beneath the rod bearing the **initial setting needle**.
- h) Lower the needle and release it quickly, allowing it to penetrate into the paste.
- i) Initially, the needle will completely pierce through the paste.
- j) Repeat the procedure at regular intervals until the needle penetrates only **5 ± 0.5 mm** from the bottom of the mould.
- k) The time elapsed between adding water to cement and this stage is recorded as the **initial setting time**.

B) Final Setting Time

Definition:

The **final setting time** is the time interval between the moment water is added to cement and the moment when the cement paste hardens sufficiently such that a **1 mm square needle** makes no impression on the surface, while the **annular ring attachment** fails to make any impression.

Procedure:

- a) Replace the needle of Vicat's apparatus with the **annular ring attachment**.
- b) Lower the needle gently and release it.
- c) Repeat this process at regular intervals until the annular ring fails to leave an impression on the paste surface.
- d) The time elapsed from the moment of adding water to this stage is recorded as the **final setting time**.

Table 3.10 Values of Consistency, Initial and Final Setting Time

S.NO	WEIGHT OF CEMENT (gms)	CONSISTENCY PERCENTAGE	INITIAL SETTING TIME(mins)	FINAL SETTING TIME(hours)
01	400	32%	55	8
02	300	30%	45	6
03	400	29%	47	7
04	300	28%	50	6.5
05	400	27%	48	7.6

2.7.4 Sieve Analysis of Aggregates**Objective:**

Sieve analysis is conducted to determine the particle size distribution of fine and coarse aggregates. This test helps in calculating the Fineness Modulus (FM), which indicates the average size of particles in the aggregate mixes. The procedure is carried out as per IS: 2386 (Part I) – 1963.

Apparatus Used:

1. A set of IS sieves of standard sizes:
 - 80 mm, 63 mm, 50 mm, 40 mm, 31.5 mm, 25 mm, 20 mm, 16 mm, 12.5 mm, 10 mm, 6.3 mm, 4.75 mm, 3.35 mm, 2.36 mm, 1.18 mm, 600 μ m, 300 μ m, 150 μ m, and 75 μ m.
2. Balance or scale with an accuracy of **0.1%** of the test sample weight.
3. Oven (capable of maintaining $110^{\circ}\text{C} \pm 5^{\circ}\text{C}$).
4. Tray and soft brush.

Procedure:

- a) The aggregate sample was dried in an oven at a temperature of **110 °C (230 °F)** to remove moisture.
- b) The dried sample was weighed accurately.
- c) The sample was sieved successively using the standard set of sieves, starting from the largest size sieve.
- d) Each sieve was shaken separately over a clean tray for at least **2 minutes**, or until only a trace amount passed through. Sieving was carried out using a variety of motions – left to right, forward and backward, circular (both clockwise and anti-clockwise), with intermittent jolting, to ensure thorough separation.
- e) Lumps of fine material, if present, were gently broken down with fingers against the side of the sieve. A soft brush was used to clear sieve openings without damaging the mesh.
- f) After sieving, the material retained on each sieve, including particles dislodged during cleaning, was carefully collected and weighed.

Observation & Calculation:

- The weight of material retained on each sieve is recorded.
- The percentage retained and cumulative percentages retained are calculated.

- The **Fineness Modulus (FM)** is obtained by summing the cumulative percentage retained on standard sieves and dividing by 100.

Coarse Aggregate Sieve



Fine Aggregate Sieve



Fig 3.7 IS-Sieves

2.8 Workability

Workability of concrete is defined as the property of fresh concrete that determines the ease with which it can be mixed, placed, compacted, and finished without segregation or bleeding. It represents a composite property influenced by several parameters including the proportions and quality of water, cement, aggregates, admixtures, and supplementary materials.

The main factors affecting workability are:

- **Water-cement ratio** – Workability generally increases with higher water content due to better lubrication of particles.
- **Aggregate characteristics** – The size, shape, grading, and surface texture of aggregates significantly affect workability. Angular and rough-textured aggregates reduce workability, while rounded and smooth aggregates improve it.
- **Air-entraining agents** – These improve cohesiveness and reduce the tendency to segregate.
- **Mix proportions** – Proper proportioning of fine aggregates, coarse aggregates, and cement enhances workability.

Workability can also be expressed in terms of consistency, i.e., the degree of wetness of fresh concrete. When unsupported, fresh concrete tends to flow and settle vertically; this reduction in height is measured as slump.

Workability is determined by the following standard tests:

- a) **Slump Cone Test**
- b) **Compaction Factor Test**

2.8.1 Slump Cone Test

The slump test is one of the most widely used methods for assessing the consistency of fresh concrete. Though it does not directly measure workability, it provides an indication of uniformity of the mix and helps detect variations in concrete quality.

Apparatus Required:

- Slump cone (frustum of cone, 300 mm height, 200 mm base diameter, 100 mm top diameter)
- Tamping rod (16 mm diameter, 600 mm length, rounded at one end)
- Trowel
- Measuring scale

Procedure:

1. Place the slump cone on a smooth, non-absorbent surface.
2. Fill the cone with fresh concrete in **three equal layers**.
3. Compact each layer with **25 strokes** of the tamping rod, ensuring uniform distribution.
4. After filling, strike off the excess concrete to make the surface level with the top of the cone.
5. Hold the cone firmly during filling to prevent movement.
6. Immediately after filling, **lift the cone vertically** and slowly, allowing the concrete to slump.
7. Measure the decrease in height of the slumped concrete relative to the mould using the tamping rod and scale. The difference in height is recorded as the **slump value** (nearest 5 mm).

Types of Slump:

- **True Slump:** Concrete subsides uniformly and maintains its shape (desired result).

- **Shear Slump:** The top portion of the concrete shears off and slips sideways.
- **Collapse Slump:** The concrete collapses completely, indicating excessive water content or high workability mix unsuitable for slump test.

Workability Range as per Slump Values:

- Very low (0–25 mm): Used in road construction.
- Low (10–40 mm): Suitable for foundations with little reinforcement.
- Medium (50–90 mm): Suitable for reinforced concrete placed with vibration.
- High (>100 mm): Used for heavily reinforced structures, pumping, and situations requiring high workability.



Fig 2.8 Slump Cone

The slump test was conducted to evaluate the workability of fresh concrete for different trial mixes prepared with varying percentages of crumb rubber as partial replacement of fine aggregate in M35 grade concrete. This test, being the most common method for assessing workability, provides quick and reliable information on the consistency of concrete.

The test can be carried out both in the laboratory and at construction sites. It is particularly useful for:

- Ensuring **batch-to-batch uniformity** of concrete.
- Assessing **variation in workability** with changes in mix composition.
- Indicating whether the concrete mix satisfies the required **placing and compaction conditions**.

The degree and type of slump observed (true slump, shear slump, or collapse slump) give additional information about the quality and cohesiveness of the mix. For crumb rubber-modified concrete, changes in slump values directly reflect the influence of rubber particles on the flow characteristics and cohesiveness of fresh concrete.

The measured slump values for different trial mixes with 0%, 4%, 8%, 12%, and 16% replacement of fine aggregates with crumb rubber are presented in Table 2.11.

Table 2.11 Slump Test Result

S. No.	Trial Mix Design (M35)	% of crumb rubber	Slump Values (mm)
1	Trial 1st - M1	0%	52
2	Trial 2nd - M2	4%	55
3	Trial 3rd - M3	8%	65
4	Trial 4th - M4	12%	58
5	Trial 5th - M5	16%	54

2.9 Compression Test

2.9.1 Compressive Strength Test

The compressive strength of concrete was determined in accordance with the provisions of IS: 516–1959 (reaffirmed 1999). Cubic specimens were removed from the curing tank at the ages of 7, 14, and 28 days, and tested immediately while still in saturated surface dry (SSD) condition.

Testing was performed using a 2000 kN capacity Compression Testing Machine (CTM). Each cube was positioned with its cast face placed at right angles to the direction of loading. Proper alignment of the

specimen's axis with the centre of thrust of the spherically seated plate was ensured to avoid eccentric loading.

The load was applied gradually and uniformly without shock, at a controlled rate of approximately 5 kN/second, until the specimen failed. The compressive strength of each specimen was calculated based on the maximum load carried at failure, divided by the cross-sectional area of the cube.

The average results of compressive strength for different trial mixes incorporating crumb rubber as partial replacement of fine aggregates at various curing ages are presented in Table



Fig 2.9 Compressive Testing Machine
Table 2.12 Compressive Strength of Concrete

Mix Designation	Curing Period	Load at Failure (KN)	Compressive Strength (N/mm ²)	Average Compressive strength (N/mm ²)
RM0	7days	473	22.9	22.130
		475	21.0	
		477	22.5	
	28 days	727	33.2	33.410
		729	35.0	
		721	31.9	
RM4	7days	500	20.4	21.30
		506	22.3	
		503	21.2	
	28 days	761	35.0	34.580
		763	34.9	
		759	33.8	
RM8	7 days	519	22.0	23.070
		522	23.1	
		516	24.0	
	28 days	767	34.8	34.880
		762	33.9	
		764	35.8	
RM12	7 days	411	19.3	18.3
		413	18.2	

	28 days	416	17.3	27.8
		646	29.5	
		642	27.4	
		645	26.4	
RM16	7 days	347	17.1	17.190
		343	16.2	
		344	18.1	
	28 days	519	23.9	23.650
		515	22.9	
		512	24.0	

2.10 Split Tensile Strength Test

The split tensile strength test was conducted to evaluate the tensile capacity of concrete, which is otherwise difficult to measure directly due to its brittle nature. This test was carried out in accordance with the relevant provisions of IS: 5816-1999.

The method involves applying a diametric compressive load along the length of a cylindrical concrete specimen, which induces tensile stresses perpendicular to the applied load. Failure of the specimen thus occurs in tension rather than in compression. To ensure uniform distribution of load along the line of application, plywood strips were placed between the specimen and the loading jaws of the testing machine.

The specimen was mounted carefully and loaded gradually without shock until failure occurred. The maximum load at failure was noted, and the splitting tensile strength (f_{ct}) was determined using the following formula:

$$\sigma_{sp} = \frac{2P}{\pi ld}$$

Where

P = Max. Load at failure in N

l = Length of cylindrical specimen in mm

d = Diameter of cylindrical specimen in mm



Fig 2.10 Universal Testing Machine

Table 2.13 Split Tensile Strength of concrete

Mix Designation	Curing Period	Load at Failure (KN)	Split Tensile Strength (N/mm ²)
RM0	28 Days	200	2.83
RM4	28 Days	229	3.230

RM8	28 Days	210	2.970
RM12	28 Days	195	2.750
RM16	28 days	175	2.470

3. RESULTS AND DISCUSSION

3.1 General

This chapter presents and interprets the results obtained from the experimental investigations on concrete specimens. The details regarding specimen dimensions, material preparation, and test methodologies have already been described in Chapter 3.

3.2 Discussion of Results

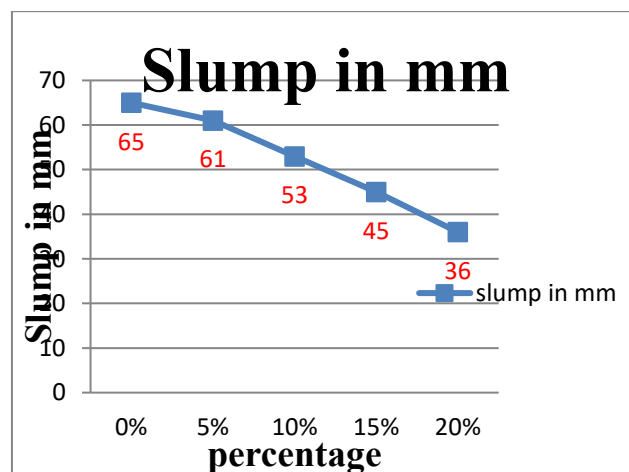
A series of concrete mixes were prepared to examine the influence of marble dust on the strength and workability characteristics of concrete. The tests conducted included compressive strength, split tensile strength, and slump test. Each of these results is discussed individually in this chapter. Graphical representations, as well as tabulated data, were provided in the preceding chapter for reference.

3.3 Slump Test

The slump test was conducted to evaluate the workability of fresh concrete, following the procedure outlined in IS: 1199-1959. The test results indicate that the addition of marble aggregates did not significantly alter the slump values. The variation in slump with different mixes is illustrated in the following figure.

Table 3.1 Slump Values of M25 Concrete with Varying Percentages of Marble Dust (Trial Mixes)

	Trial Mix Design (M25)	Percentage of Marble Dust	Slump Values (mm)
1	Trial M1	0%	52
2	Trial M2	4%	55
3	Trial M3	8%	65
4	Trial M4	1.20%	68
5	Trial M5	1.60%	54



Graph showing variation in slump

3.3 Compressive Strength of Concrete

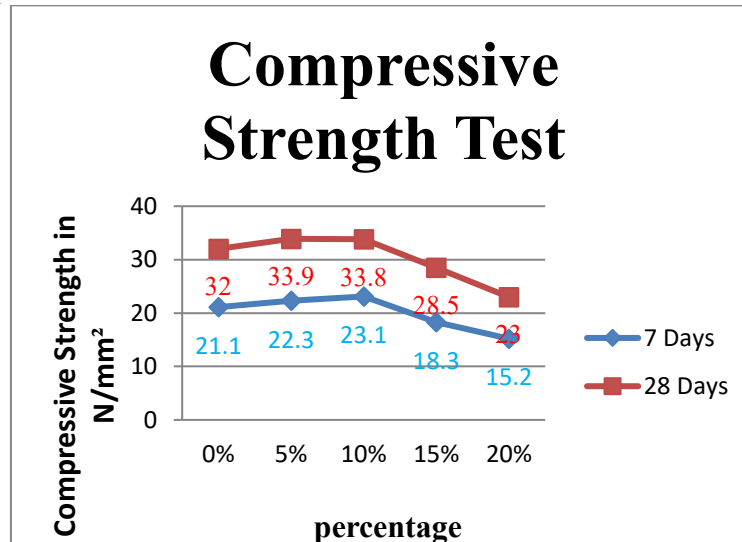
For each mix, three cubes of size 150 × 150 × 150 mm were cast and tested in a compression testing machine after 7 days and 28 days of curing to determine their compressive strength.

- **Graph 1** depicts the variation in 7-day compressive strength with the inclusion of marble dust aggregates and presents the variation in 28-day compressive strength with rubber aggregates.

The findings indicate a gradual decrease in compressive strength with increasing proportions of marble dust aggregates. However, the reduction in strength was not substantial when the replacement level was

limited. From the experimental analysis, it can be inferred that up to 8% replacement with marble dust can be incorporated in concrete mixes without significant compromise in compressive strength.

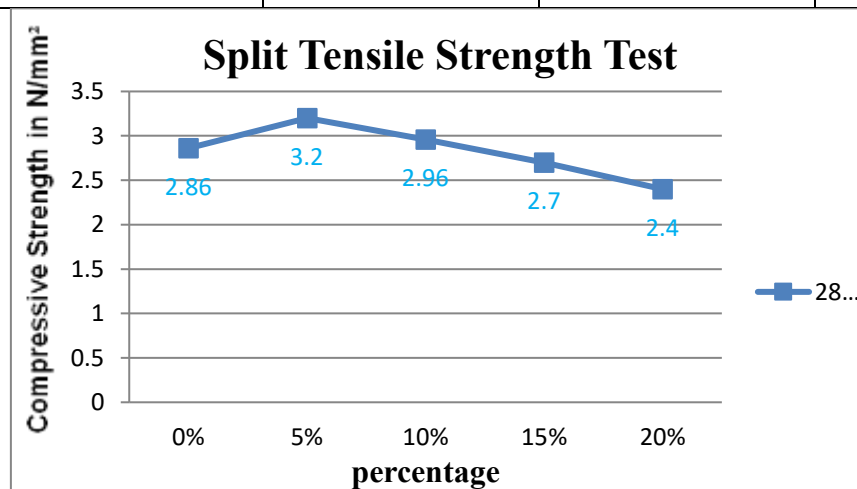
The splitting tensile strength test is performed on cylindrical concrete specimens to evaluate their tensile capacity. In this method, a compressive load is applied along the diameter of the cylinder. This loading arrangement induces tensile stresses perpendicular to the applied force, leading to failure in tension rather than compression.



Graph -1, Compressive Strength Test

Table 3.2 Split Tensile Strength of concrete

Mix Designation	Curing Period	Load at Failure (KN)	Split Tensile Strength (N/mm ²)
M1	28 Days	200	2.83
M2	28 Days	229	3.230
M3	28 Days	210	2.970
M4	28 Days	195	2.750
M5	28 days	175	2.470



Graph - 2 Split Tensile Strength

4. CONCLUSIONS

4.1 Conclusions

1. The compressive strength of concrete generally decreased with higher levels of paper sludge replacement. However, for marble dust, compressive strength improved at replacement levels of 4–8%, particularly at 28 days of curing, compared to 7 days.

2. Compressive strength was observed to increase with curing age across all replacement levels. Even in mixes containing crumb rubber, strength development continued with time.
3. The addition of marble dust reduced slump values, indicating a decline in workability. Nevertheless, partial substitution with crumb rubber (up to 8% of fine aggregate) still produced workable and satisfactory concrete.
4. Split tensile strength improved with 8% marble dust replacement, but beyond this level, a reduction was observed as replacement percentages increased further.
5. Marble dust can effectively serve as a partial replacement for fine aggregates, offering both economic and environmental benefits. However, excessive replacement is not recommended due to its adverse impact on mechanical strength properties.

4.2 Key Observations from the Study

- The fine nature of marble dust enhances the cohesiveness of concrete when used with a superplasticizer, provided that the water-cement ratio is properly maintained.
- Since marble dust is an industrial byproduct available at no cost, its utilization in construction can be considered economically viable.
- Incorporating marble dust into concrete contributes to addressing environmental issues arising from the uncontrolled disposal of marble industry waste.
- The inclusion of marble dust has only a marginal influence on the mechanical properties of concrete, which implies that no significant modifications are required in conventional production processes.
- Marble waste can also serve as an alternative raw material in clay-based product manufacturing, further reducing disposal-related concerns.
- Concrete mixes incorporating waste marble dust (WMD) as a partial replacement for fine aggregates passing through the 0.25 mm sieve exhibited improved compressive strength compared to mixes without marble dust. This improvement is attributed to the filler effect of marble dust, which accelerates hydration at early ages.
- The filler effect also reduces porosity in hardened concrete, thereby enhancing its compactness.

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