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Performance Of M25 Grade Of Concrete With Calcium Magnesium Carbonate As Partial Replacement To Cement

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Abstract: Concrete is one of the most widely used construction materials globally, valued for its exceptional compressive strength, durability, and adaptability in diverse structural applications. However, the environmental consequences of conventional cement production—particularly its significant carbon dioxide (CO_2) emissions—have driven the need for more sustainable alternatives. In response, this study explores the feasibility of using Calcium Magnesium Carbonate (CMC) powder as a partial or complete substitute for cement in concrete mixtures. The primary objective is to assess the mechanical performance of concrete when CMC powder is incorporated at varying replacement levels: 0% (control), 10%, 20%, 30%, 40% and 50% by volume.

A comprehensive experimental program was conducted, evaluating key mechanical properties through compressive strength, split tensile strength, and flexural strength tests. The findings reveal that partial cement replacement with CMC powder at 30% mixes demonstrating the optimal strength retention and workability. Beyond this threshold, however, a gradual reduce in mechanical performance was observed—particularly at 40% & 50% replacement levels—due to the reduced cementitious binding capacity in the mixture.

The primary objective is to evaluate the mechanical properties of concrete incorporating CMC powder as a partial replacement to cement. The study concludes that CMC powder can serve as a viable, eco-friendly partial replacement for cement, with 20–30% substitution offering an effective balance between sustainability and structural integrity. These findings contribute to the growing body of research on low-carbon concrete technologies and highlight the potential of carbonate-based materials in reducing the environmental footprint of construction. Further investigation is recommended to optimize mix designs, assess long-term durability, and explore industrial scalability.

Index Terms – Calcium Magnesium Carbonate (CMC) powder, Compressive Strength, Split Tensile Strength, Flexural Strength

I. INTRODUCTION

India's rapidly growing population has significantly escalated the demand for infrastructure, exerting considerable pressure on the availability of conventional construction materials. Concrete—composed of cement, water, fine and coarse aggregates, and sometimes admixtures—continues to be the most extensively used construction material owing to its strength, durability, and adaptability. Among its various grades, M25 concrete, which achieves a characteristic compressive strength of 25 MPa after 28 days of curing, is widely applied in residential, commercial, and institutional structures.

With rising environmental concerns, the construction sector is progressively embracing green building practices that emphasize the sustainable use of materials and efficient waste management. A major issue is the excessive and unsustainable extraction of essential raw materials such as river sand and limestone—used for cement manufacturing—which has led to serious ecological consequences. These issues highlight the pressing need for alternative materials that can enhance the sustainability of concrete without compromising its performance.

In response to these challenges, the present study explores the mechanical properties and long-term durability of M25 grade concrete incorporating calcium magnesium carbonate powder as a partial replacement for cement. This naturally occurring mineral exhibits high compressive strength, chemical stability, and favourable binding characteristics, making it a viable option for producing more environmentally responsible concrete.

II. MATERIAL

2.1 CEMENT

As the primary binding agent in construction materials, cement demonstrates three essential functional properties: setting capability, hardening characteristics, and material adhesion. In our experimental work, we specifically employ 53 Grade cement, which when combined with fine aggregates produces mortar, or with sand and coarse aggregates forms concrete - the focus material of this investigation.

The cement classification system holds particular relevance for our study, as materials are typically designated by either:

(i) Chemical composition
(ii) Functional application
(iii) Characteristic properties
(iv) Historical nomenclature (e.g., Portland cement derives from its visual similarity to Portland stone)

From an experimental materials science perspective, cement's value lies in its dual adhesive/cohesive properties that enable aggregate consolidation. Our research builds upon the historical development that began with Smeaton's 1790 discovery of hydraulic properties in clay-containing limestone - a finding that revived ancient Roman cement technology and led to Parker's subsequent commercialization of hydraulic cement.

Figure 1 Ordinary Portland Cement

Name of Compound	Chemical Composition	Abbreviation
Tricalcium Silicate	$3CaO.SiO_2$	C_3S
Dicalcium Silicate	$2CaO.SiO_2$	C_2S
Tricalcium Aluminate	$3CaO.Al_2O_3$	C_3A
Tetracalcium Alumino Ferrite	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF

Table 1 Typical Composition of Ordinary Portland Cement

Physical Properties of Calcium Magnesium Carbonate (Dolomite) Powder		
Property	**Value / Characteristics**	**Significance in Concrete Applications**
Chemical Formula	$CaMg(CO_3)_2$	Determines reactivity with cement phases
Particle Size (µm)	5 – 75	Influences workability and packing density
Specific Surface Area (m²/kg)	400 – 600	Affects hydration rate and strength development
Bulk Density (g/cm³)	1.2 – 1.5	Impacts mix design and fresh concrete properties
Specific Gravity	2.8 – 2.9	Slightly lower than OPC (3.15), reducing concrete density
Color	White to light gray	Improves aesthetic appeal in architectural concrete
Mohs Hardness	3.5 – 4.0	Enhances abrasion resistance in hardened concrete
Decomposition Temp. (°C)	600 – 800	Provides thermal stability in high-temperature applications
Moisture Content (%)	< 1	Reduces pre-treatment needs before mixing
Blaine Fineness (m²/kg)	300 – 450	Optimized for pozzolanic reactivity
Particle Morphology	Angular to sub-rounded, rhombohedral	Improves mechanical interlocking in cement matrix

Table 2 Physical Properties of Calcium Magnesium Carbonate Powder

2.2 FINE AGGREGATE

In this research, natural river sand has been used for the preparation of normal concrete. The sand conforms to grading zone-II as per IS: 383-1970 and has a specific gravity of 2.62. The fineness modulus of the sand is 2.72. It is important to note that the number of fines less than 0.125 mm is considered as powder and is crucial for the rheology of the concrete. To maintain the water content in the concrete, the sand is dried at room temperature for 24 hours. Furthermore, the maximum size of the fine aggregate (FA) used in this research is 4.75 mm. It is important to select the appropriate size of FA to ensure that the concrete has the desired properties. Therefore, the size of FA is an important factor to consider while preparing concrete. The testing of sand is done as per IS: 2386 – 1963.

Table 3 Properties of Fine Aggregate

Particulars	**Values**
Specific Gravity	2.62
Fineness Modulus	2.72

Figure 2 Fine Aggregate

Figure 3 Coarse Aggregate 20mm

Figure 4 Coarse Aggregate 10mm

2.3 COARSE AGGREGATE

Coarse aggregates that conform to IS: 383–2016 specifications are suitable for use in concrete. However, the maximum size of the aggregate should be selected based on the clear spacing between reinforcement bars.

Table 4 Properties of Coarse Aggregate

Particulars	Values
Specific gravity	2.74
Fineness Modulus	7.17

2.4. CALCIUM MAGNESIUM CARBONATE POWDER

Calcium magnesium carbonate powder, with the chemical formula $CaMg(CO_3)_2$, is a naturally occurring sedimentary mineral composed of both calcium carbonate and magnesium carbonate. It is typically obtained by mining and finely grinding carbonate-rich rock formations. This powder is characterized by its high compressive strength, chemical inertness, and stable behaviour in alkaline environments, making it suitable for use in construction materials.

When incorporated into concrete as a partial replacement for cement, calcium magnesium carbonate powder contributes to improved particle packing, enhanced microstructure, and better long-term durability. Its fine particle size allows for increased surface area, which can aid in hydration and reduce porosity within the concrete mix. From a sustainability perspective, the use of calcium magnesium carbonate powder helps reduce the reliance on ordinary Portland cement, thereby lowering carbon emissions and conserving natural limestone resources. These advantages support its application as an effective and environmentally responsible material in modern concrete technology.

Parameter	Value	Unit	Remarks
Appearance	Fine, white to off-white	—	Free-flowing powder
Specific Gravity	2.85 – 2.95	—	ASTM C188
Fineness (Passing 90 µm sieve)	> 95	%	IS 4031 (Part 1)
Bulk Density	900 – 1200	kg/m³	Depends on compaction
Moisture Content	< 0.5	%	Oven-dried at 105°C
pH (10% solution)	8.5 – 9.5	—	Slightly alkaline
Loss on Ignition (LOI)	42 – 45	%	Mainly CO_2 release
Calcium Oxide (CaO)	28 – 32	% by weight	Chemical analysis (XRF)
Magnesium Oxide (MgO)	18 – 22	% by weight	Chemical analysis (XRF)
Silica (SiO_2)	< 2	% by weight	Impurity
Alumina (Al_2O_3)	< 1	% by weight	Trace element
Iron Oxide (Fe_2O_3)	< 0.5	% by weight	Trace element

Table 5: Physical and Chemical Properties of Calcium Magnesium Carbonate Powder

Fig 5. Calcium Magnesium Carbonate Powder

III. EXPERIMENTAL PROGRAM

The Description of proportion of mixed design

Sl. No.	% Calcium Magnesium Carbonate Powder	Cement (kg/m³)	Calcium Magnesium Carbonate Powder (kg/m³)	Fine aggregate (kg/m³)	Coarse aggregate (kg/m³)	Water (kg/m³)	Superplasticizer (kg/m³)
1	25	236.69	78.9	716.69	799.25	125	4.2

Table 6 proportion of mixed design

Using the above mix proportions, the following procedure was adopted:

Specimen casting and curing

- Cubes: 100 × 100 × 100 mm
- Cylinders: 100 × 200 mm
- Beams: 500 × 100 × 100 mm

After casting, all specimens were demoulded and submerged in a water tank until the day of testing.

Mechanical tests

- Compressive strength: Tested at 28 days on cubes using a universal testing machine (UTM).
- Split tensile strength: Tested at 28 days on cylinders in the UTM.
- Flexural strength: Tested at 28 days on beam specimens in a three-point bending setup.

IV. RESULTS AND DISCUSSION

In this research, the calcium magnesium carbonate in powder form (CMCP)was used as partial replacement material to cement in concrete.

CMCP AS PARTIAL REPLACEMENT MATERIAL TO CEMENT

The compressive strength, split tensile strength, and flexural strength for concrete mixes both with and without the inclusion of CMCP.

In this context, the 'control mix' refers to the standard concrete mix that does not contain any CMC powder. Similarly, the mixes labeled as 'without calcium magnesium carbonate' also exclude the use of calcium magnesium carbonate, serving as a baseline for evaluating the effects of its inclusion.

4.1 Compressive Strength

After analyzing the test results, as percentage of CMC powder increases up to 30% the compressive strength of concrete increases. Beyond 30% and up to 50% replacement of cement with CMCP, the compressive strength decreases. The maximum percentage increase in compressive strength at 28 days is 38.57% which is for CMCP30 Mix. At 50% replacement level, the compressive strength at 28 days of CMCP50 mix is almost equal to the CMCP0 Mix i.e., the mix without calcium magnesium carbonate.

Therefore, a fifty percent of cement can be replaced with calcium magnesium carbonate powder without affecting strength adversely. The same trend is observed for 7 days compressive strength.

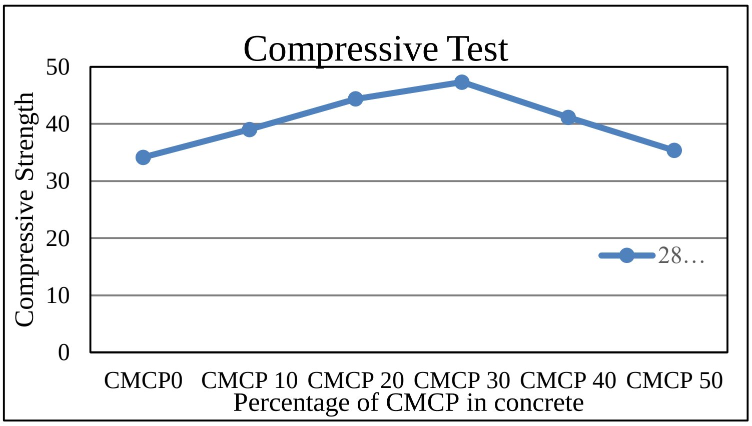

Figure 6 Compressive strength values of CMCP in concrete

Figure 7 Compressive strength test

4.2 Split Tensile Strength

Up to 30% increase in calcium magnesium carbonate powder the split tensile strength of concrete increases. Beyond 30% and up to 50% replacement of cement with calcium magnesium carbonate, the split tensile strength decreases. The maximum percentage increase in split tensile strength at 28 days is 57.04% which is for CMCP30 Mix. At 30% replacement level, the split tensile strength at 28 days of CMCP30 mix is almost equal to the CMCP0 Mix i.e., the mix without calcium magnesium carbonate. Therefore, a fifty percent of cement can be replaced with calcium magnesium carbonate powder without affecting split tensile strength adversely.

Figure 8 Split tensile strength values of CMCP in concrete

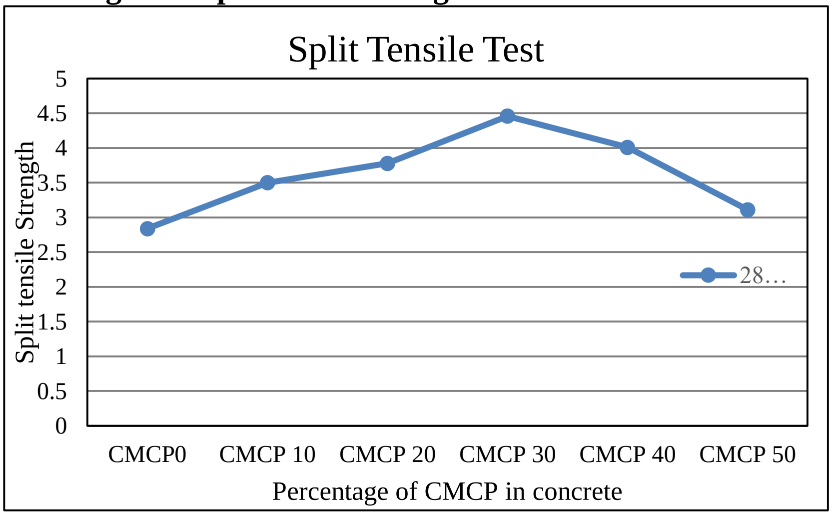

Figure 9 (a) (b) Image of Split tensile strength & Sample after Test

4.3 Flexural Strength

As percentage of calcium carbonate powder increases up to 30% the flexural strength of concrete increases. Beyond 30% and up to 50% replacement of cement with calcium magnesium carbonate, the flexural strength decreases. The maximum percentage increase in flexural strength at 28 days is 62.77% which is for CMCP30 Mix. At 50% replacement level, the flexural strength at 28 days of CMCP50 mix is equal to or slightly greater than the CMCP0 Mix i.e., the mix without calcium magnesium carbonate. Therefore, a fifty percent of cement can be replaced with calcium magnesium carbonate powder without affecting strength much adversely.

Figure 10 Flexural Test

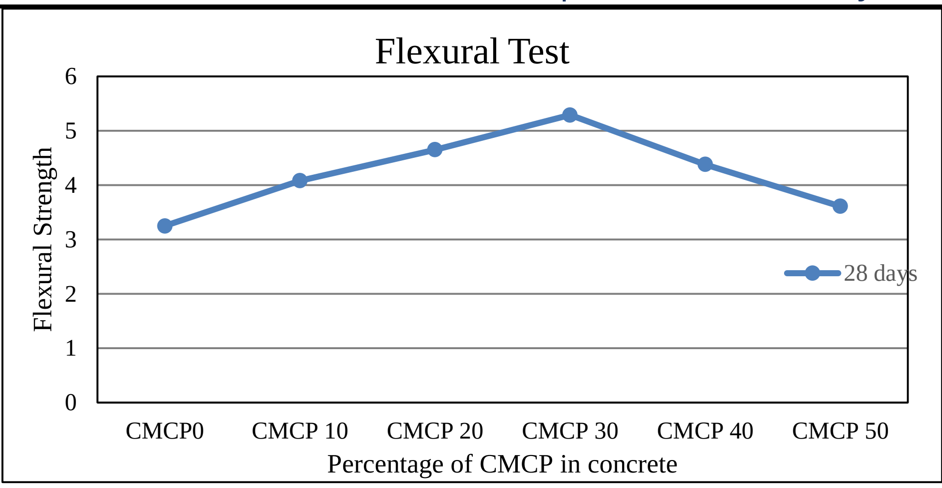

Figure 11 Flexural strength values of CMCP in concrete

4.4 UPV (ultrasonic pulse velocity):

As per IS 13311 (Part 1):1992 and international standards, ultrasonic pulse velocity (UPV) serves as a key metric for assessing concrete quality. Values exceeding 4.5 km/s signify excellent-quality concrete, characterized by high density, uniformity, and minimal flaws. Studies show that well-graded aggregates, proper curing, and optimized mix proportions consistently yield UPV in this range. These high UPV values correlate strongly with enhanced compressive strength and durability, underscoring their reliability in evaluating structural performance.

Table:7 UPV Classification for Concrete Quality

UPV Range (km/s)	Concrete Quality	Interpretation
> 4.5	Excellent	Dense, homogeneous, and free of major flaws. High strength and durability.
3.5 – 4.5	Good	Minor porosity or microcracks but structurally sound. Suitable for most applications.
3.0 – 3.5	Marginal/Doubtful	Moderate porosity, microcracking, or localized defects. Further evaluation needed.
< 3.0	Poor	High porosity, cracking, or delamination. Unsuitable for load-bearing structures.

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V. CONCLUSION

By partially replacing cement with Calcium Magnesium Carbonate (CMC) powder derived from industrial waste, this study demonstrates a sustainable approach to reducing waste disposal risks, lowering environmental impact, and minimizing concrete production costs. The following conclusions are drawn from experimental results:

1. Workability:
   - Concrete workability decreases gradually with higher CMC content, evidenced by reduced slump values (true slump) in slump cone tests and lower compaction factors.
2. Compressive Strength:
   - Optimal replacement: 30% CMC powder.
   - Cube strength increases by 38.587% at this dosage, beyond which strength declines.
3. Tensile & Flexural Strength:
   - Split Tensile Strength: Peaks at 57.04% improvement with 30% CMC replacement.
   - Flexural Strength: Reaches 62.77% enhancement at 30% CMC replacement.
   - Both properties reduced beyond the 30% threshold.
4. Material Performance:
   - Ultrasonic pulse velocity (UPV) tests confirm "Excellent" concrete quality across all CMC mixes, indicating superior density and homogeneity.
5. Environmental & Economic Impact:

- CMC powder reduces cement consumption, lowering CO_2 emissions and raw material costs.

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