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Experimental Study on Compressive Strength of Magnesium Oxychloride Cement Mortar Using Stone Crushed Powder by Varying Molar Ratio

Pavan Kumar Marupakula[1], Sai Kiran Rachamalla[2]
[1]Post Graduate Student and [2]Assistant Professor, Department of Civil Engineering, Anurag University, Ghatkesar, Hyderabad, Telangana, 500039, India

Abstract: ***One of the major consumers of natural resources and a significant contributor to CO_2 emissions is the construction sector. The manufacture of cement and building materials was found to be the source of the highest greenhouse gas emissions. In order to lessen the damaging effects of the building industry on the environment, this paper seeks to determine whether magnesium oxychloride cement (MOC) may be used as a mortar substitute for regular Portland cement. A thorough review of the literature, an experimental investigation, and an internal structure analysis based on the ideal molar ratio are all part of the research technique. In this study, MOC cement with powdered stone is experimentally investigated utilizing various molar ratios with phases 3 and 5. In the first set of results usage of unheated magnesium oxide powder, SEM image shown some amount of MgO left inactive and compressive strength depicted lower values. Eventually, a modification was implemented in order to boost compressive strength. In order to improve the reaction or gel formation that would boost the compressive strength, the MgO powder was heated and added to the cement. Different molar ratios produced various compressive strength values in the mortar cubes. Two ideal molar ratios are chosen from each phase, SEM and EDXA are used to analyse the micro structure. The MgO_6 octahedral crystal structures of Phases 3 and 5 are visible in the SEM pictures as double and tripple ribbons of shared edges with water molecules and chloride anions. The percentage of elemental weight in the specimens is displayed by EDXA.***

Keywords: OPC, MOC, Molarity, Compressive strength, Magnesium Oxide (MgO), Magnesium Chloride ($MgCl_2$), Micro Structure Analysis, SEM, EDXA.

I. INTRODUCTION

Portland Ordinary cement is now widely employed in vibrant infrastructure due to its low cost, dependability, and high strength. Portland cement has nonetheless been perceived as a harmful substance due to the huge carbon footprint during its production process and the significant amount of water used during its conformation process, and research interest in creating low-carbon cement has grown.

Magnesium oxychloride cement (MOC), one of the low-carbon cement alternatives, has a good chance of replacing Portland cement due to its superior qualities, such as decreased CO_2 emission and the absence of sticky drying. MOC also stands out for having a low alkalinity, a quick setting time, and exceptional mechanical strength. Magnesium chloride hydrate, one of the raw components of magnesium oxychloride cement, is the main derivative and waste of the potash industry. The complete disposal of magnesium chloride hydrate into the lake wastes precious magnesium resources and produces environmental concerns akin to the deposit of solid waste and the destruction of biodiversity. Consequently, the operation of magnesium oxychloride cement may efficiently utilize waste magnesium chloride while reducing environmental dangers. Magnesium oxychloride (MOC) cement, first discovered by Sorel in 1867, is a type of air hardening gel material formed from light burned magnesium oxide (MgO), magnesium chloride ($MgCl_2$), and water (H_2O).

A. Sources and Occurrence of Magnesium Chloride ($MgCl_2$)

The hydrated $MgCl_2$ can be extracted from brine or ocean water. The typical active magnesia used for MOC materials is calcined from magnesite at 700-900 degrees Celsius. The extraction of potassium fertilizer in the salt lake area will result in a large amount of magnesium chloride waste liquid. Many magnesium leftovers will be produced during the extraction of lithium carbonate products from salt lake brine. For every tonne of potash fertilizer produced, 8-10 tonnes of magnesium chloride are produced.

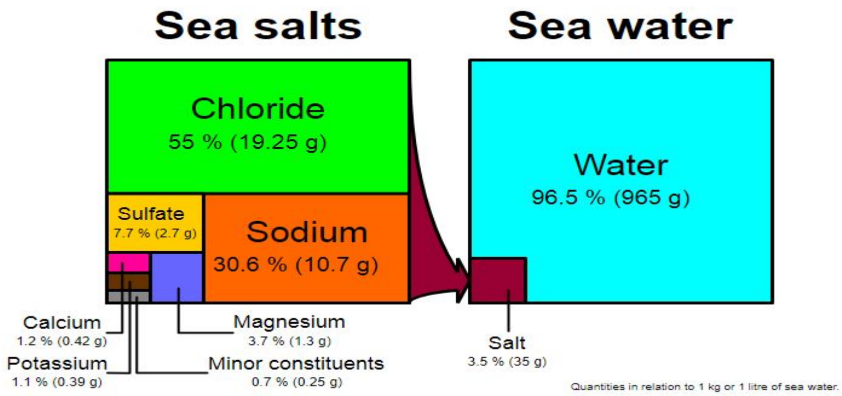

Figure 1: Amount in relation to 1 kilogram or 1 litre of salt water.

B. *Sources and Occurrence of Magnesium Oxide (MgO)*

The majority of magnesium oxide produced today is made from minerals that are found in nature through a process called calcination. The most typical kind of magnesite is $MgCO_3$. Seawater, brine deposits underground, and deep salt beds where the production of magnesium hydroxide, $Mg(OH)_2$, are additional significant sources of magnesium oxide.

Magnesium oxide through moist route:

1) Caustic-calcined at 600 –1300 °C
2) Deadly burnt, 1600 –2200 °C
3) Fused, greater than 2800 °C.

Magnesium oxide through dry pathway:

a) Lightly burnt, 700 to 1000 °C
b) Hardly burnt, 1000 –1500 °C
c) Dead-burned, 1500 to 2000 °C

C. *Objective of Work*

The main aim of the present study is to determine the compressive strength of magnesium oxychloride cement mortar using stone crushed powder by varying molar ratio to arrive at ideal molar ratio with highest strength and analyse the internal structure of the cube using SEM and EDXA.

Hence, to achieve the objective, the work has been carried out in the following stages:

- In the first stage, the molar ratio of 3:1 $MgO:MgCl_2$ and 5:1 $MgO:MgCl_2$ were selected by varying molarity using unheated MgO and crushed stone powder.
- In the second step, cubes of size 70x70x70 mm^3 were cast in the requisite numbers and were left to cure in the open air for 7, 14, and 28 days.
- In the third stage, the cubes were subjected to testing under compressive testing machine and if any flaws or improvements required were examined and experimental work is carried out accordingly.
- Finally, the tested specimens internal structure is analyzed using SEM and EDAX.

II. LITERATURE REVIEW AND METHODOLOGY

Conclusion of literature on comprehensive study:

In this group the detailed study of magnesium oxychloride cement mortar is described. This includes the history of magnesium oxychloride cement, the numerous materials used to make magnesium oxychloride cement mortar, and the variables that affect the various qualities of magnesium oxychloride cement. Moreover, various casting and curing techniques are described. The high levels of CO_2 released during portland cement production set new records.

The large use of cement in the construction industry can be decreased by using cement containing magnesium oxychloride. The components that can be utilized in the manufacturing of magnesium oxychloride cement are magnesium oxide powder derived from the calcination of naturally existing minerals, most typically magnesite, and magnesium chloride from brine or fertilizer industries. For the preparation of magnesium oxychloride cement mortar, a variety of cementitious materials including fly ash, GGBS, Alko fine, Meta kaolin, Fumed silica, rice-husk ash, granite powder, river sludge, industrial residue, etc. are employed. Depending on what is readily available on the market, fine aggregate such as fine sand, coarse sand, stone crushed powder or robo sand is employed. Due to its greater availability, stone-crushed powder is the main ingredient used to prepare magnesium oxychloride cement mortar and cost effectiveness.

Conclusion of literature on experimental work:

This group is categorized based on the detailed methodology of experimental work. This involves mix design procedure, method of chemical handling, casting, and curing of magnesium oxychloride cement. It is described how the researchers used various substitutions and molarities. Using MgO, $MgCl_2$, F.A, and pozzolonic ingredients in various molar ratios, MOC cement mortar is mixed. Internal bonding and compressive strength metrics are impacted by varying molar ratios. Magnesium oxychloride cement mortar's growth of strength is mostly due to the concentration of molarity solution and replacement of F.A. Unlike traditional methods, ambient air curing is used.

Methodology

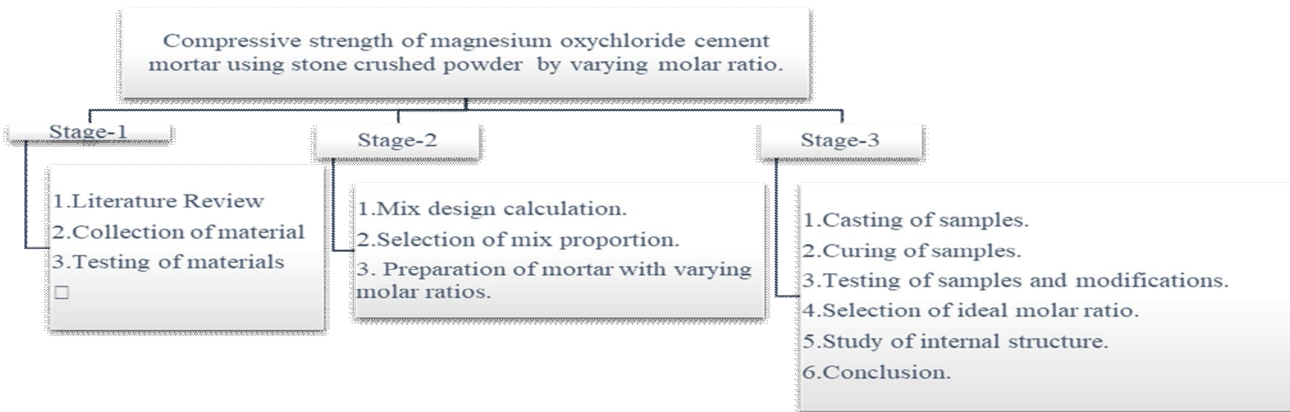

Figure 2: Methodology

III. MATERIALS

Magnesium Oxide: Magnesium oxide, often known as an inorganic magnesia, is a solid white mineral that is hygroscopic and occurs naturally as periclase. It is a combination of a lattice of Mg^{2+} ions and O^{2-} ions bonded together by ionic bonding and has the empirical formula MgO.

Magnesium Chloride: A non-organic substance having the formula $MgCl_2$, magnesium chloride is a mineral. These salts are white or colourless solids with a high water solubility.

Fine Aggregate: When quarry rocks are broken down into tiny pieces, a mixture of various minerals known as stone crushed powder or robo sand is produced.

Water: The chemical name for water is H_2O, and it is an inorganic substance. It is an almost colourless, transparent, odourless, and tasteless chemical compound.

a. Properties of Magnesium oxide(MgO)

- Magnesium oxide' s molecular formula is MgO
- Molecular Mass of magnesium oxygen - 40.30 g/mol
- Density of magnesium oxygen - 3.59 g/cm^3
- Melting Point is 714 °C
- Boiling Point is 1090°C

b. Properties of Magnesium Chloride ($MgCl_2$)

- The molar mass of $MgCl_2$ is 95 g/mol.
- Density of magnesium chloride is 2.32 g/cm$^{3.}$
- The boiling point of magnesium chloride is 1412 °C.
- The melting point is 714°C

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a. Magnesium Oxide powder

b. Magnesium Chloride crystals

c. Stone crushed powder

d. Water

Figure 3: Materials used.

c. Stone crushed powder

- It is a combination of different minerals.
- Density- 2.85 g/cm$^{3.}$
- Specific gravity- 2.9
- Water absorbtion-6.5%
- Moisture content- 1%

d. Water (H_2O)

- The water molecules have hydrogen bonding between them.
- The melting and boiling point of water are 0° and 100° C respectively.
- The three states of water are - solid state, liquid state and gaseous state.
- The density of water is known to be as 1 g/ml, at 4° C.
- Molar Mass of water- 18 g/mol

A. Molarity

Different molar ratios used with stone crushed powder replacing river sand

3-Phase

$3MgO$	+	$MgCl_2$	+	$4H_2O$	$\rightarrow$	$3Mg(OH)_2 \cdot MgCl_2 \cdot H_2O$	311 phase
$3MgO$	+	$MgCl_2$	+	$5H_2O$	$\rightarrow$	$3Mg(OH)_2 \cdot MgCl_2 \cdot 2H_2O$	312 phase
$3MgO$	+	$MgCl_2$	+	$6H_2O$	$\rightarrow$	$3Mg(OH)_2 \cdot MgCl_2 \cdot 3H_2O$	313 phase
$3MgO$	+	$MgCl_2$	+	$7H_2O$	$\rightarrow$	$3Mg(OH)_2 \cdot MgCl_2 \cdot 4H_2O$	314 phase
$3MgO$	+	$MgCl_2$	+	$8H_2O$	$\rightarrow$	$3Mg(OH)_2 \cdot MgCl_2 \cdot 5H_2O$	315 phase
$3MgO$	+	$MgCl_2$	+	$9H_2O$	$\rightarrow$	$3Mg(OH)_2 \cdot MgCl_2 \cdot 6H_2O$	316 phase
$3MgO$	+	$MgCl_2$	+	$10H_2O$	$\rightarrow$	$3Mg(OH)_2 \cdot MgCl_2 \cdot 7H_2O$	317 phase
$3MgO$	+	$MgCl_2$	+	$11H_2O$	$\rightarrow$	$3Mg(OH)_2 \cdot MgCl_2 \cdot 8H_2O$	318 phase
$3MgO$	+	$MgCl_2$	+	$12H_2O$	$\rightarrow$	$3Mg(OH)_2 \cdot MgCl_2 \cdot 9H_2O$	319 phase
$3MgO$	+	$MgCl_2$	+	$13H_2O$	$\rightarrow$	$3Mg(OH)_2 \cdot MgCl_2 \cdot 10H_2O$	3110 phase
$3MgO$	+	$MgCl_2$	+	$14H_2O$	$\rightarrow$	$3Mg(OH)_2 \cdot MgCl_2 \cdot 11H_2O$	3111 phase
$3MgO$	+	$MgCl_2$	+	$15H_2O$	$\rightarrow$	$3Mg(OH)_2 \cdot MgCl_2 \cdot 12H_2O$	3112 phase

5-Phase

5MgO	+	$MgCl_2$	+	$4H_2O$	→	$5Mg(OH)_2\cdot MgCl_2\cdot H_2O$	511 phase
5MgO	+	$MgCl_2$	+	$5H_2O$	→	$5Mg(OH)_2\cdot MgCl_2\cdot 2H_2O$	512 phase
5MgO	+	$MgCl_2$	+	$6H_2O$	→	$5Mg(OH)_2\cdot MgCl_2\cdot 3H_2O$	513 phase
5MgO	+	$MgCl_2$	+	$7H_2O$	→	$5Mg(OH)_2\cdot MgCl_2\cdot 4H_2O$	514 phase
5MgO	+	$MgCl_2$	+	$8H_2O$	→	$5Mg(OH)_2\cdot MgCl_2\cdot 5H_2O$	515 phase
5MgO	+	$MgCl_2$	+	$9H_2O$	→	$5Mg(OH)_2\cdot MgCl_2\cdot 6H_2O$	516 phase
5MgO	+	$MgCl_2$	+	$10H_2O$	→	$5Mg(OH)_2\cdot MgCl_2\cdot 7H_2O$	517 phase
5MgO	+	$MgCl_2$	+	$11H_2O$	→	$5Mg(OH)_2\cdot MgCl_2\cdot 8H_2O$	518 phase
5MgO	+	$MgCl_2$	+	$12H_2O$	→	$5Mg(OH)_2\cdot MgCl_2\cdot 9H_2O$	519 phase
5MgO	+	$MgCl_2$	+	$13H_2O$	→	$5Mg(OH)_2\cdot MgCl_2\cdot 10H_2O$	5110 phase
5MgO	+	$MgCl_2$	+	$14H_2O$	→	$5Mg(OH)_2\cdot MgCl_2\cdot 11H_2O$	5111 phase
5MgO	+	$MgCl_2$	+	$15H_2O$	→	$5Mg(OH)_2\cdot MgCl_2\cdot 12H_2O$	5112 phase

B. *Mix design calculations*

Calculation of MOC cement and crushed stone powder quantity required for mortar in 1:3 ratio for a volume of $1m^3$:

Mortar ratio Cement : F.A = 1:3
Volume of mortar = $1m^3$
Density of MOC cement = 1200 kg/m^3
$1m^3$ = 35.31 cubic feet.
1.33 is multiplication co-factor of wet volume of cement to find dry volume of mortar

Cement:
Dry mortar volume = wet volume × 1.33 = 1 × 1.33 = 1.33 m^3
Weight of cement = part of cement used × dry mortar volume × density of cement
Weight of cement = (1/4) x1.33x1200 = 400 kg

Fine aggregate:
Volume of stone crushed powder in m^3 = (3/4)× 1.33 = 0.997m^3
Volume of stone crushed powder in cubic feet = 0.997 ×35.3147 = 35.22 Cubic feet
1 cubic feet of stone crushed powder = 46 Kg
35.22 Cubic feet of stone crushed powder = 46 Kg × 35.22 = 1620 Kg

Sample calculation

3-Phase

3MgO = 120gm
$MgCl_2$ = 95gm
Total cement required = 400kg
MgO required = 223kg
$MgCl_2$ required = 176.7kg

5-Phase

5MgO = 200gm
$MgCl_2$ = 95gm
Total cement required = 400kg
MgO required = 267kg
$MgCl_2$ required = 126.82kg

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OPC cement mortar ratio

OPC Cement : crushed stone powder = 1:3. Initially physical tests were conducted on OPC cement and 9 samples of OPC cement mortar cubes using crushed powder were casted for 7, 14 and 28 days compressive strength performance in order to compare the strength values with MOC cement mortar.

Figure 4: OPC cement mortar samples

C. MOC cement Mortar Ratio

MOC Cement : Stone crushed powder = 1:3. Initially physical tests were conducted on OPC cement and 9 samples of OPC cement mortar cubes using stone crushed powder were casted for 7, 14 and 28 days for testing strength.

Figure 5: Sequential mixing of mortar materials

The mortar materials are hand mixed and filled in mortar cubes by which a total of 216 cubes were casted. The matrix mix was first prepared by dry-mixing unheated magnesium oxide powder, magnesium chloride crystals, stone crushed powder thoroughly and then water was added slowly to make it a homogeneous mixture till the crystals completely dissolve in it giving a uniform texture.

Unheated MgO Phase 3

- 36 mortar cubes were casted for 7 days compressive strength with molarity ratio $MgO:MgCl_2:H_2O$ - 3:1:4, 3:1:5, 3:1:6, 3:1:7, 3:1:8, 3:1:9, 3:1:10, 3:1:11, 3:1:12, 3:1:13, 3:1:14, 3:1:15. (unheated magnesium oxide powder)
- 36 mortar cubes were casted for 14 days compressive strength with molarity ratio $MgO:MgCl_2:H_2O$ - 3:1:4, 3:1:5, 3:1:6, 3:1:7, 3:1:8, 3:1:9, 3:1:10, 3:1:11, 3:1:12, 3:1:13, 3:1:14, 3:1:15. (unheated magnesium oxide powder)
- 36 mortar cubes were casted for 28 days compressive strength with molarity ratio $MgO:MgCl_2:H_2O$ - 3:1:4, 3:1:5, 3:1:6, 3:1:7, 3:1:8, 3:1:9, 3:1:10, 3:1:11, 3:1:12, 3:1:13, 3:1:14, 3:1:15. (unheated magnesium oxide powder)

Unheated MgO Phase 5

- For molar ratios $MgO:MgCl_2:H_2O$ -5:1:4, 5:1:5, 5:1:6, 5:1:7, 5:1:8, 5:1:9 mix was dry and unable to work with the specimens.
- 18 mortar cubes were casted for 7 days compressive strength with mole to mole ratio $MgO:MgCl_2:H_2O$ - 5:1:10, 5:1:11, 5:1:12, 5:1:13, 5:1:14, 5:1:15. (heated magnesium oxide powder)
- 18 mortar cubes were casted for 14 days compressive strength with mole to mole ratio $MgO:MgCl_2:H_2O$ - 5:1:10, 5:1:11, 5:1:12, 5:1:13, 5:1:14, 5:1:15. (heated magnesium oxide powder)
- 18 mortar cubes were casted for 28 days compressive strength with mole to mole ratio $MgO:MgCl_2:H_2O$ - 5:1:10, 5:1:11, 5:1:12, 5:1:13, 5:1:14, 5:1:15. (heated magnesium oxide powder)
- The cube moulds were demoulded after 24 hours and were kept for air curing at ambient curing condition i.e at room temperature. The cubes were left for air curing for 7,14 and 28 days compressive strength respectively.

Figure 6: MOC cement mortar specimens.

D. Observations from Previous test Results

The samples were unable to achieve sufficient strength because unheated magnesium oxide powder was employed in the mortar cement paste. Due to environmental factors and seasonal weather patterns, the cast samples weren't completely dry. The cement mortar showed declining strength values as the water ratios rose. Several of the samples failed the UTM test because the water ratios in those samples were greater. When a batch of cubes were tested for compressive strength performance after 7, 14, and 28 days of curing, it was discovered that the numbers were extremely low and that some alterations needed to be made.

E. Changes Adopted from Observations

Oven dried magnesium oxide powder or light burnt magnesium oxide powder heated at 210 degree celsius is used in the mortar mix.Ensured moisture content in robo sand is less than 1%. Ensure the magnesium chloride is evenly broken down into smaller particles.

Figure 7: Heated MgO powder

Figure 8: Heated MgO samples

Heated MgO Phase 3

- 36 mortar cubes were casted for 7 days compressive strength with mole to mole ratio $MgO:MgCl_2:H_2O$ - 3:1:4, 3:1:5, 3:1:6, 3:1:7, 3:1:8, 3:1:9, 3:1:10, 3:1:11, 3:1:12, 3:1:13, 3:1:14, 3:1:15. (heated magnesium oxide powder)
- 36 mortar cubes were casted for 14 days compressive strength with mole to mole ratio $MgO:MgCl_2:H_2O$ - 3:1:4, 3:1:5, 3:1:6, 3:1:7, 3:1:8, 3:1:9, 3:1:10, 3:1:11, 3:1:12, 3:1:13, 3:1:14, 3:1:15. (heated magnesium oxide powder)
- 36 mortar cubes were casted for 28 days compressive strength with mole to mole ratio $MgO:MgCl_2:H_2O$ - 3:1:4, 3:1:5, 3:1:6, 3:1:7, 3:1:8, 3:1:9, 3:1:10, 3:1:11, 3:1:12, 3:1:13, 3:1:14, 3:1:15. (heated magnesium oxide powder)

Heated MgO Phase 5

- Molarity ratio $MgO:MgCl_2:H_2O$ -5:1:4, 5:1:5, 5:1:6, 5:1:7, 5:1:8, 5:1:9 mix was dry and unable to work with the specimens.
- 18 mortar cubes were casted for 7 days compressive strength with molarity ratio $MgO:MgCl_2:H_2O$ - 5:1:10, 5:1:11, 5:1:12, 5:1:13, 5:1:14, 5:1:15. (heated magnesium oxide powder)
- 18 mortar cubes were casted for 14 days compressive strength with molarity ratio $MgO:MgCl_2:H_2O$ - 5:1:10, 5:1:11, 5:1:12, 5:1:13, 5:1:14, 5:1:15. (heated magnesium oxide powder)
- 18 mortar cubes were casted for 28 days compressive strength with molarity ratio $MgO:MgCl_2:H_2O$ - 5:1:10, 5:1:11, 5:1:12, 5:1:13, 5:1:14, 5:1:15. (heated magnesium oxide powder)

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F. Test on Cement Mortar

The strength of cement can be effectively studied by performing compressive strength test on cement mortar cube.

Compressive Strength:
Compressive strength of concrete was determined by subjecting the concrete specimens under loading in a Compression Testing Machine (CTM) after 7,14 and 28 days of curing to determine the strength attained in 28 days to concrete.

Figure 9: Compressive Testing Machine

IV. RESULTS

A. Results of OPC and MOC Cement Mortar Cubes

This module involves the comparision of test results of OPC and MOC cement mortar cubes using stone crushed powder.

Table 1: Comparision of compressive strength of OPC cement mortar and MOC cement mortar

S.No	Observations	OPC cement using Robo sand	MOC cement using Robo sand
1	Sample prepared on Date	5/7/2022	5/7/2022
2	Weight of cement content gm	200	200
3	Weight of sand content gm	600	600
4	Weight of water required = (P/4 + 3.0)% of combined weight of sand & cement ml	94	100
5	Size of sample L × B × H mm^3	70x70x70	70x70x70
6	Cross sectional area of specimen mm^2	70x70	70x70
7	Load at fracture P KN (7days)	105	72
8	Compressive strength = P/A N/ mm^2 (7days)	21.4	14.69
9	Load at fracture P KN (14days)	120	85
10	Compressive strength = P/A N/ mm^2 (14days)	24.48	17.3
11	Load at fracture P KN (28days)	135	90
12	Compressive strength = P/A N/ mm^2 (28days)	27	18.36

Table 1 shows the comparision of compressive strength of OPC cement mortar and MOC cement mortar cubes for 7, 14 and 28 days. The compressive strength of MOC cement is less than OPC cement.

B. Results of Unheated 3 Phase MOC Cement Mortar Cubes

This module shows the compressive strength test results of MOC cement mortar cubes using unheated magnesium oxide powder.

Table 2: Compressive strength of 3 phase MOC cement mortar cubes using unheated magnesium oxide powder.

S.No	Molar ratio $MgO:MgCl_2:H_2O$	7 days compressive load KN	14 days compressive load KN	28 days compressive load KN	28 days compressive strength N/mm^2
1	3:1:4	60	75	80	16.33
2	3:1:5	50	55	60	12.24
3	3:1:6	42	50	52	10.61
4	3:1:7	40	42	45	9.18
5	3:1:8	35	40	43	8.78
6	3:1:9	30	33	40	8.16
7	3:1:10	28	35	40	8.16
8	3:1:11	25	26	30	6.12
9	3:1:12	20	25	30	6.12
10	3:1:13	-	-	-	-
11	3:1:14	-	-	-	-
12	3:1:15	-	-	-	-

Table 2 shows the comparision of compressive loads of MOC cement mortar cubes for 7, 14 and 28 days and compressive strength for 28 days. The highest compressive strength is attained at 3:1:4 and least at 3:1:12.

C. Results of Unheated 5 phase MOC Cement Mortar Cubes

This module shows the compressive strength test results of MOC cement mortar cubes using unheated magnesium oxide powder.

Table 3: Compressive strength of 5 phase MOC cement mortar cubes using unheated magnesium oxide powder.

S.No	Molar ratio $MgO:MgCl_2:H_2O$	7 days compressive load KN	14 days compressive load KN	28 days compressive load KN	28 days compressive strength N/mm^2
1	5:1:4	-	-	-	-
2	5:1:5	-	-	-	-
3	5:1:6	-	-	-	-
4	5:1:7	-	-	-	-
5	5:1:8	-	-	-	-
6	5:1:9	-	-	-	-
7	5:1:10	45	75	100	20.41
8	5:1:11	42	55	70	14.29
9	5:1:12	34	45	60	12.24
10	5:1:13	30	32	35	7.14
11	5:1:14	25	30	40	8.16
12	5:1:15	20	25	30	6.12

Table 3 shows the comparision of compressive loads of MOC cement mortar cubes for 7, 14 and 28 days and compressive strength for 28 days.The highest compressive strength is attained at 5:1:10 and least at 5:1:15.

D. Results of Heated 3 phase MOC Cement Mortar Cubes

This module shows the compressive strength test results of MOC cement mortar cubes using heated magnesium oxide powder (210^o C).

Table 4: Compressive strength of 3 phase MOC cement mortar cubes using heated magnesium oxide powder (210^o C).

S.No	Molar ratio $MgO:MgCl_2:H_2O$	7 days compressive load KN	14 days compressive load KN	28 days compressive load KN	28 days compressive strength N/mm²
1	3:1:4	75	100	120	24.49
2	3:1:5	45	55	62	12.65
3	3:1:6	55	65	72	14.69
4	3:1:7	48	60	65	13.27
5	3:1:8	35	45	50	10.2
6	3:1:9	25	30	36	7.35
7	3:1:10	30	40	46	9.39
8	3:1:11	20	25	30	6.12
9	3:1:12	15	18	25	5.1
10	3:1:13	10	12	14	2.86
11	3:1:14	8	10	12	2.45
12	3:1:15	5	10	11	2.24

Table 4 shows the comparision of compressive loads of MOC cement mortar cubes for 7, 14 and 28 days and compressive strength for 28 days. The highest compressive strength is attained at 3:1:4 and least at 3:1:1.

E. Results of Heated 5 phase MOC Cement Mortar Cubes

This module shows the compressive strength test results of MOC cement mortar cubes using heated magnesium oxide powder (210^o C).

Table 5: Compressive strength of 5 phase MOC cement mortar cubes using heated magnesium oxide powder (210^o C).

S.No	Molar ratio $MgO:MgCl_2:H_2O$	7 days compressive load KN	14 days compressive load KN	28 days compressive load KN	28 days compressive strength N/mm²
1	5:1:4	-	-	-	-
2	5:1:5	-	-	-	-
3	5:1:6	-	-	-	-
4	5:1:7	-	-	-	-
5	5:1:8	-	-	-	-
6	5:1:9	-	-	-	-
7	5:1:10	50	80	120	23
8	5:1:11	45	60	80	16.33
9	5:1:12	40	45	62	12.65
10	5:1:13	38	42	50	10.2
11	5:1:14	30	35	42	8.57
12	5:1:15	28	35	45	9.18

Table 5 shows the comparision of compressive loads of MOC cement mortar cubes for 7, 14 and 28 days and compressive strength for 28 days. The highest compressive strength is attained at 5:1:10 and least at 5:1:14.

F. Graphical Representation of Results

The results obtained are represented in graphical manner .

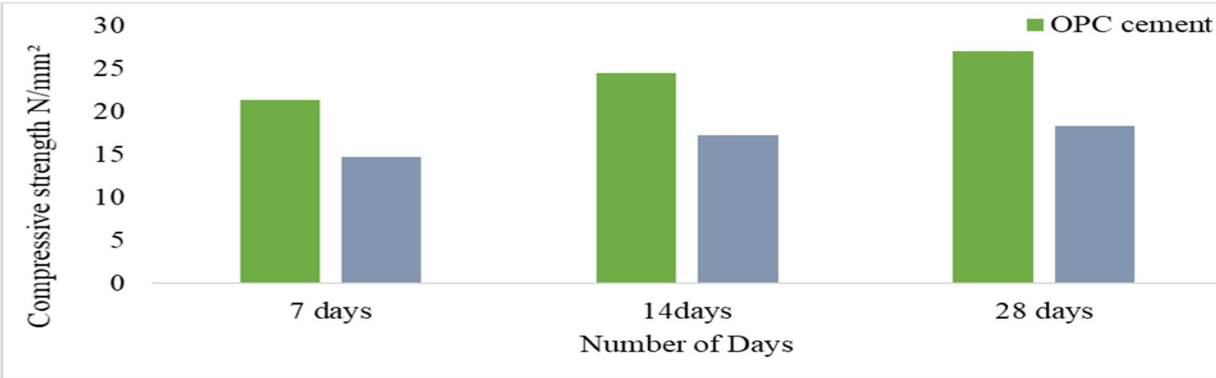

Figure 10 : Compressive strength comparision between OPC and MOC cement.

Figure 10 shows the graphical representation of compressive strength of cubic specimens of OPC and MOC cement mortars at normal consistency. The MOC cement specimens exhibit less strength than OPC cement specimens.

G. 3 Phase

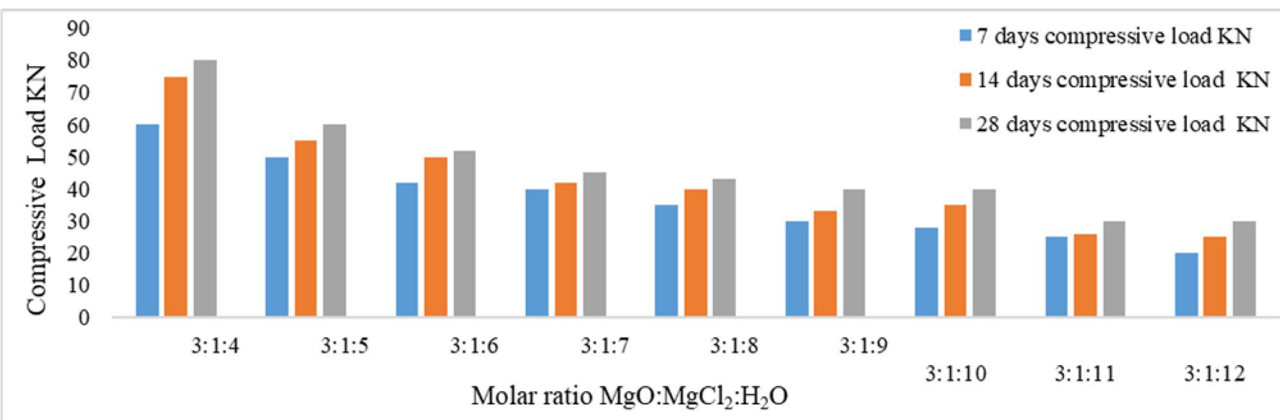

Figure 11: Compressive load using unheated MgO for 3-phase

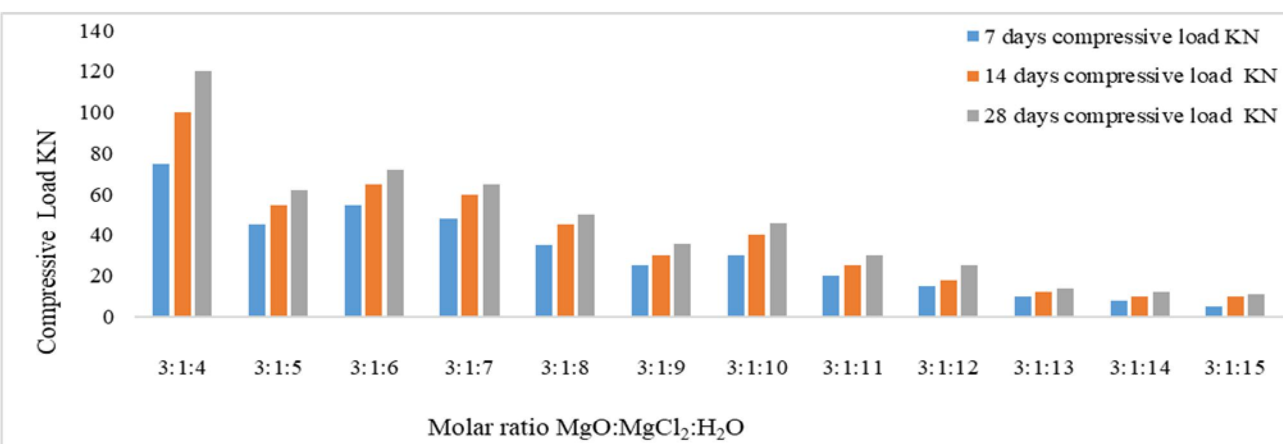

Figure 12: Compressive load using heated MgO for 3-phase

Figure 11 shows the graphical representation of Compressive load 7,14 & 28 days of cubic specimens of MOC cement mortar using unheated magnesium oxide powder. Figure 12 shows the graphical representation of Compressive load 7,14 & 28 days of cubic specimens of MOC cement mortar using heated magnesium oxide powder.The Compressive load in both the cases is in decreasing order of increasing molar ratio.

H. 5 Phase

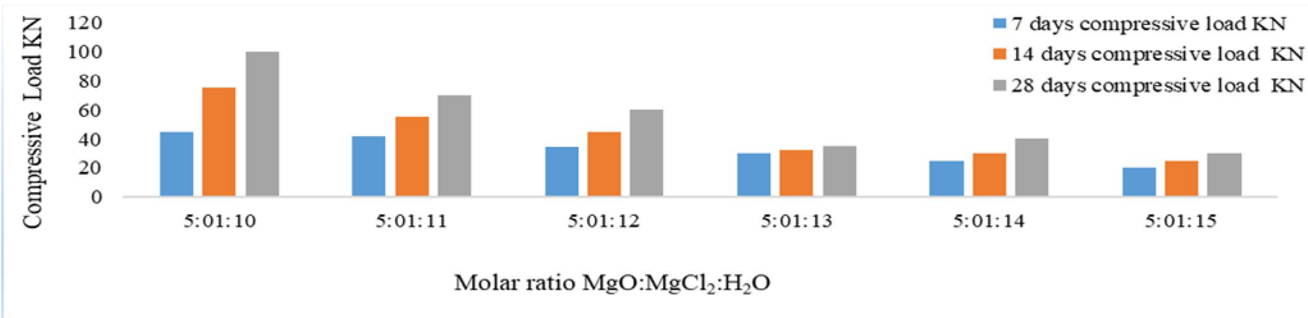

Figure 13: Compressive load using unheated MgO for 5-phase

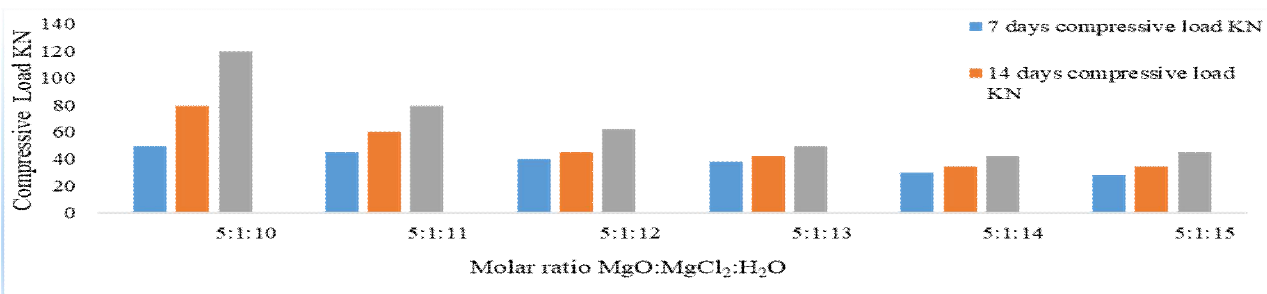

Figure 14: Compressive load using unheated MgO for 5-phase

Figure 13 shows the graphical representation of Compressive load 7,14 & 28 days of cubic specimens of MOC cement mortar using unheated magnesium oxide powder. Figure 14 shows the graphical representation of Compressive load 7,14 & 28 days of cubic specimens of MOC cement mortar using heated magnesium oxide powder.The Compressive load in both the cases is in decreasing order of increasing molar ratio.

I. 3-Phase

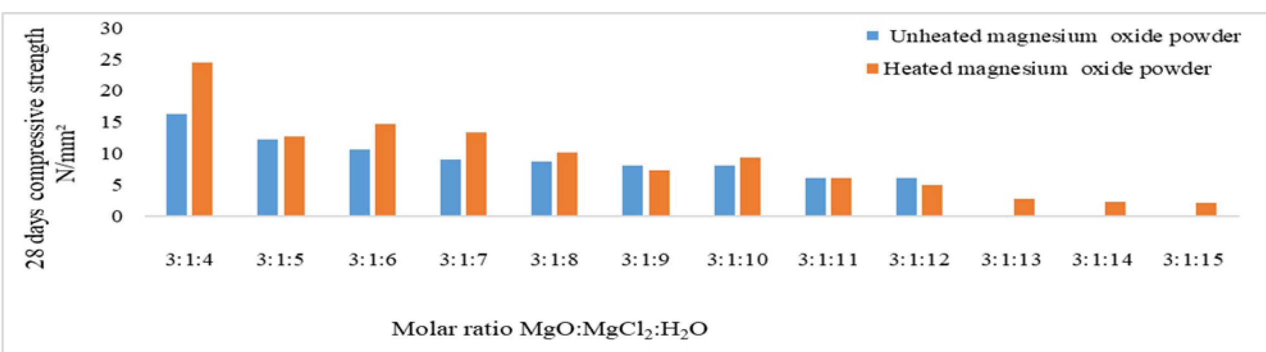

Figure 15: 28 days compressive strength comparision between heated and unheated MgO powder for 3-phase

Figure 15 shows the graphical representation of 28 days compressive strength comparision between heated and unheated MgO powder. The graphical representation depicts that the 28 days compressive strength values of 3 phase unheated MgO is less than the heated MgO powder.

J. 5-Phase

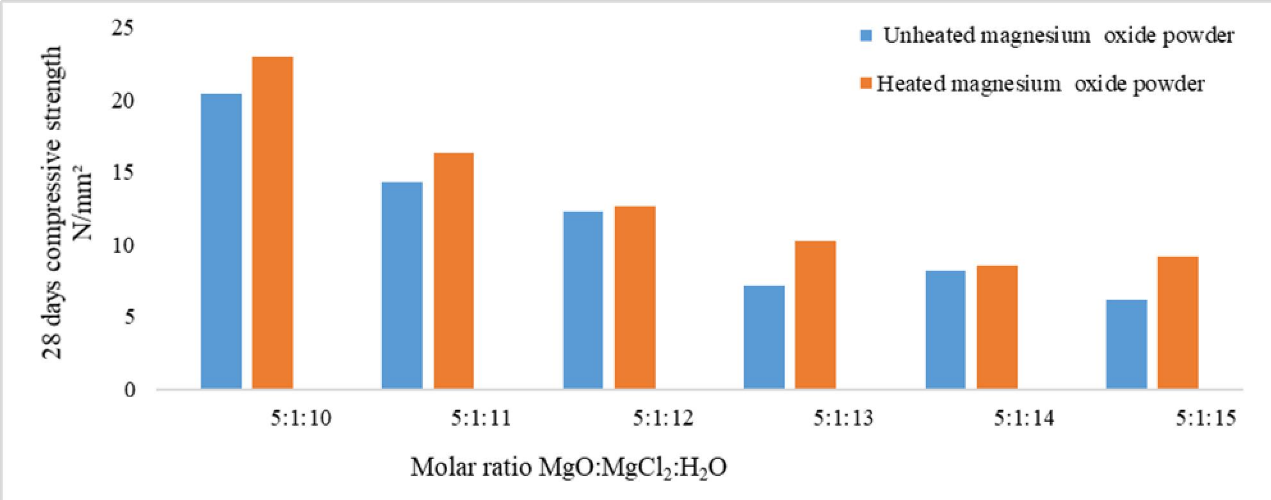

Figure 16: 28 days compressive strength comparision between heated and unheated MgO powder for 5-phase

Figure 16 shows the graphical representation of 28 days compressive strength comparision between heated and unheated MgO powder. The graphical representation depicts that the 28 days compressive strength values of 5 phase unheated MgO is less than the heated MgO powder.

K. Phase 3 and Phase 5:

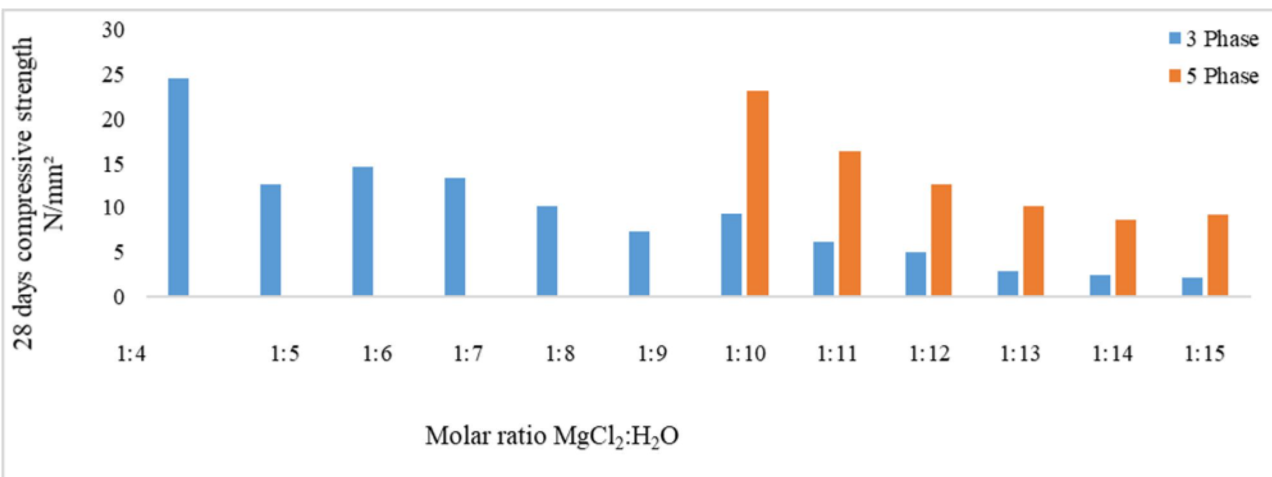

Figure 17: 28 days compressive strength comparision between 3 phase and 5 phase using heated MgO powder.

Figure 17 shows the graphical representation of 28 days compressive strength comparision between 3 phase and 5 phase using heated MgO powder.The above graphical representation depicts that the 28 days compressive strength of 3 phase MOC cement with molar ratio $MgCl_2$:H_2O - 1:4 and 5 phase MOC cement with $MgCl_2$:H_2O - 1:10 has the optimum value.

V. MICROSTRUCTURE

A. Scanning Electron Microscopy (SEM)

In scanning electron microscopy, the electrons are used to analyse tiny pictures and determine the micro structure. A sample that serves as a nucleus made up of molecules is exposed to a stream of highly charged electrons. The electrons present in the sample are ejected when this intensely charged electron beam strikes the specimen. They are referred to as secondary electrons. By attracting them, these electrons are gathered. A computer that is linked to the scanning electron microscope uses dispersed electrons to gather microscopic images.

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Different sizes, shapes and structures present in the images represents different criteria. The SEM images present below gives the micro structure of MOC cement mortar with ideal molar ratio i.e $MgO:MgCl_2:H_2O$ - 3:1:4 and $MgO:MgCl_2:H_2O$ - 5:1:10 having maximum compressive strength using stone crushed powder with heated (210°C) magnesium oxide powder.

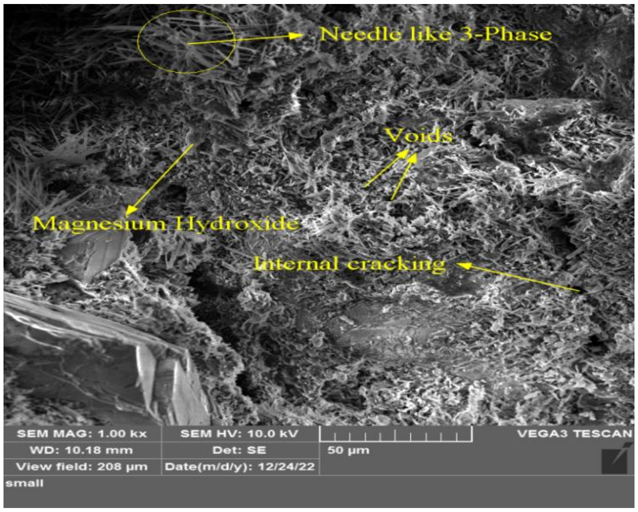

Figure 18: Internal structure of 3-Phase using heated MgO

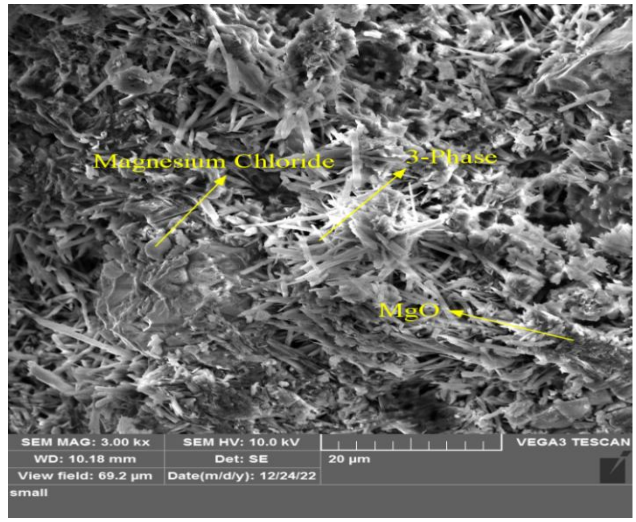

Figure 19: Double ribbons showing 3-phase formation.

When heated magnesium oxide, powdered stone, and water are combined to make a binder, the magnesium reacts with chlorides and hydroxides to form slurry. Initially in slurry state, the mixture quickly hardens. The formation of the needle-shaped crystals occurs a few minutes after hydration as a result of interactions between the magnesium, chloride, and hydroxide ions. Large crystals with double needle forms eventually develop.

Figure 18 displays the SEM image of magnesium hydroxide production and long needle-like crystals showing phase-3 creation. Figure 19 clearly depicts the SEM image of Phase 3's twin ribbon edges, which are shared by MgO_6 octahedral with water molecules and chloride anions.

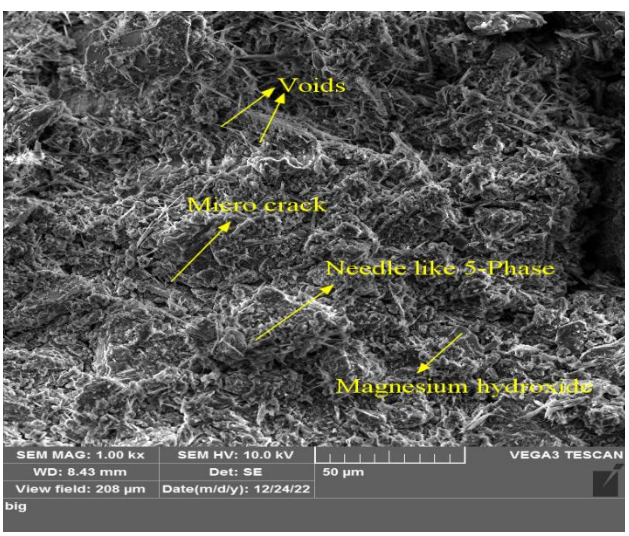

Figure 20: Internal structure of 5-Phase using heated MgO

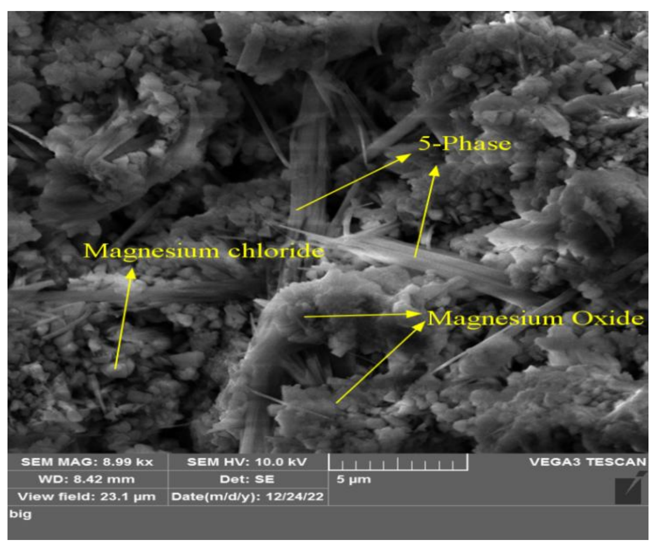

Figure 21: Tripple ribbons showing 5-phase formation.

Figure 20 depicts the SEM image showing the creation of magnesium hydroxide, along with occasional gaps, micro cracks, and long needle-like crystals that signify the formation of phase 5.

Figure 21 clearly depicts the SEM image of the Phase 5 crystal structure, which is composed of tripple ribbon edges shared by MgO_6, an octahedral crystal with water molecules and chloride anion.

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B. Energy Dispersive X-Ray Spectroscopy (EDXA)

Energy Dispersive X-Ray Spectroscopy is used to determine the weight and atomic proportion of elements contained in a sample. The X-Ray detector detects the wave length of the electrons that are lead off in this process, allowing the fraction of elements to be determined.

Table 6: Percentage of weight of elements in phase-3.

Element	O K	Na K	Mg K	Al K	Si K	S K	Cl K	K K	Ca K
Weight %	55.14	0.33	24.04	1.42	3.68	0.33	9.30	1.20	4.57

Table 6 represents the percentage of weight of elements present in the MOC cement mortar using crushed stone powder with molar ratio $MgO:MgCl_2:H_2O$ - 3:1:4 which is found to be ideal with maximum compressive strength after 28 days of air curing at room temperature. These percentage of weights are gradually divided from 100% of weight of elemental composition in MOC cement mortar.

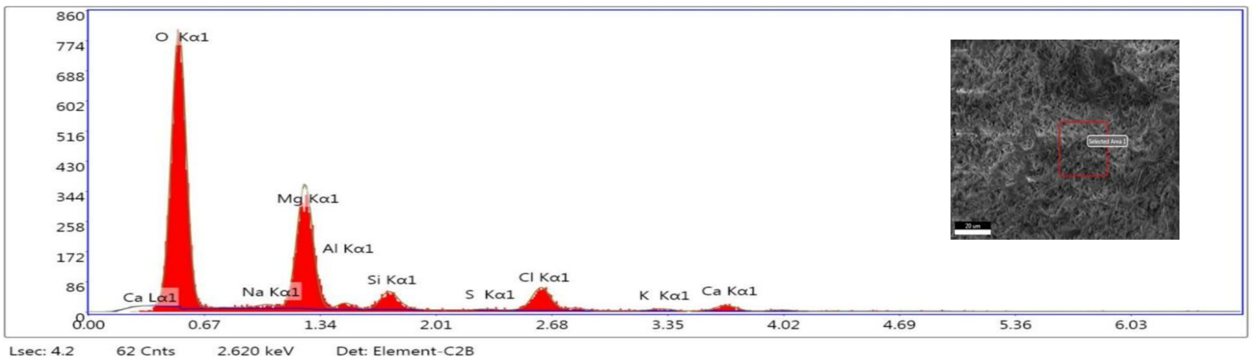

Figure 22: EDXA pattern showing elemental composition of phase-3

Figure 22 shows the elemental composition present in the cubic specimen. It comprises the percentage of each element present in the specimen out of total 100% of elemental composition. In the figure the highest percentage can be seen for oxygen element which helps in forming the oxides for other elements and also the magnesium element which helps in forming bonds with other elements.

Table 7: Percentage of weight of elements in phase-5

Element	O K	Na K	Mg K	Al K	Si K	S K	Cl K	K K	Ca K
Weight %	39.48	0.57	34.94	0.67	0.40	0.43	16.19	6.37	0.95

Table 7 represents the percentage of weight of elements present in the MOC cement mortar using stone crushed powder with molar ratio $MgO:MgCl_2:H_2O$ - 5:1:10 which is found to be ideal with maximum compressive strength after 28 days of air curing at room temperature. These percentage of weights are gradually divided from 100% of weight of elemental composition in MOC cement mortar.

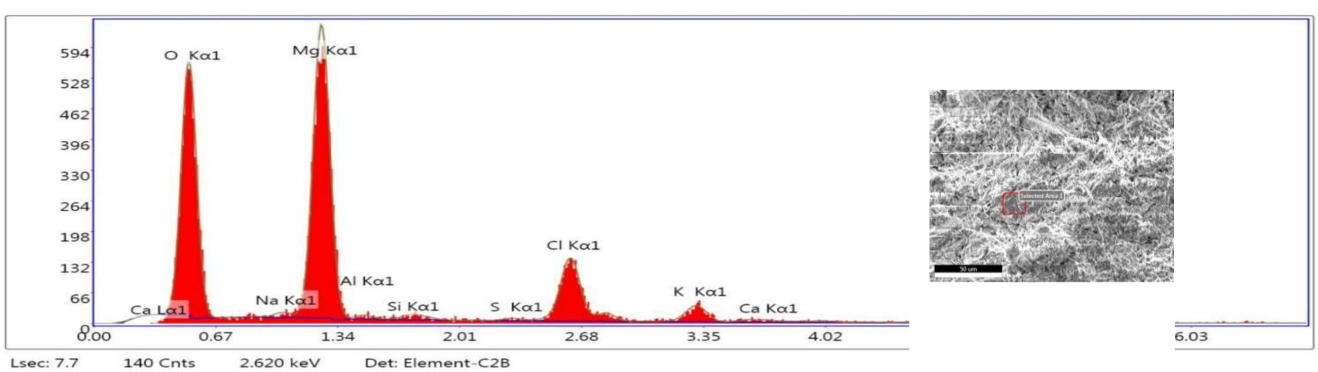

Figure 23: EDXA pattern showing elemental composition of phase-5

Figure 23 show the elemental composition present in the cubic specimen. It comprises the percentage of each element present in the specimen out of total 100% of elemental composition. In the figure the highest percentage can be seen for oxygen element which helps in forming the oxides for other elements. Even the magnesium element showing highest percentage as indicated in the stoichiometric formula which helps in forming bonds with other elements.

VI. CONCLUSION

After testing, some MgO oxide powder was left unreacted, and modifications were made to heat the MgO powder at 210°C for one hour before using it in the MOC cement to cast the specimens. Following testing, the specimens compressive strength increased. The specimens with the highest compressive strength and ideal molar ratio were chosen, and internal microstructure was analyzed using SEM and EDXA. The further work comes to the following findings.

1) It is clear from the experimental study that pozzolonic-based replacements have a beneficial effect on the compressive strength of MOC cement mortar.
2) When unheated magnesium oxide powder is used in the MOC cement mortar using crushed stone powder with varying molar ratios of 3-phase and 5-phase showed some amount of MgO left unreacted.
3) The draw back causing to loose the strength is identified and change was adopted i.e by heating the MgO powder at 210^oC for 1-2 hours in order to activate the reaction.
4) Higher compressive strength was obtained when both unheated and heated magnesium oxide powder with 3-phase with mole to mole ratio $MgO:MgCl_2:H_2O$ - 3:1:4 and 5-phase molar ratio $MgO:MgCl_2:H_2O$ - 5:1:10.This demonstrates that we can notice a significant impact on compressive strength when using light burnt magnesia
5) This demonstrates that we can notice a significant impact on compressive strength when using light burnt magnesia
6) The ideal molar ratio is obtained for 3-phase with molar ratio $MgO:MgCl_2:H_2O$ - 3:1:4 and 5-phase with molar ratio $MgO:MgCl_2:H_2O$ - 5:1:10 when MgO is heated at 210^o C and highest compressive strength values obtained than previous test results.
7) The SEM images exhibited the formation of crystal structures of Phase 3 and phase 5 by double and tripple ribbons of edges shared by MgO_6 octahedral with H_2O and Cl^- anions in the interstitial region.
8) The EDXA approach indicates the percentage of weight of the chemical constituents in the 3-phase and 5-phase MOC cement samples

Magnesium oxychloride cement as an alternative to cement has shown better results in the present study. In the previous studies used as references of this work, Magnesium oxychloride cement mortar prepared for high strength shown less strength than OPC cement But we can predict that the strength for heating of MgO at higher temperature can increase the compressive strength. At lower molarities of 3-phase and 5-phase we have obtained higher strength in both the cases using stone crushed powder along with unheated and heated MgO powder which may be cost effective and may have an ease to work.

A. Future Scope

We can predict from test results that the heating of MgO powder even at higher temperatures can exhibit good results in increasing the strength.The main draw back of MOC cement is that it cannot resists the extreme exposure to moist environmental conditions. Hence there is a need to overcome the limitation obstacle to completely use in construction industry.Even addition of super plasticizers and reducers can be studied as future research. MOC cement can even be employed in dry wall construction due to its resistance to extreme heat conditions

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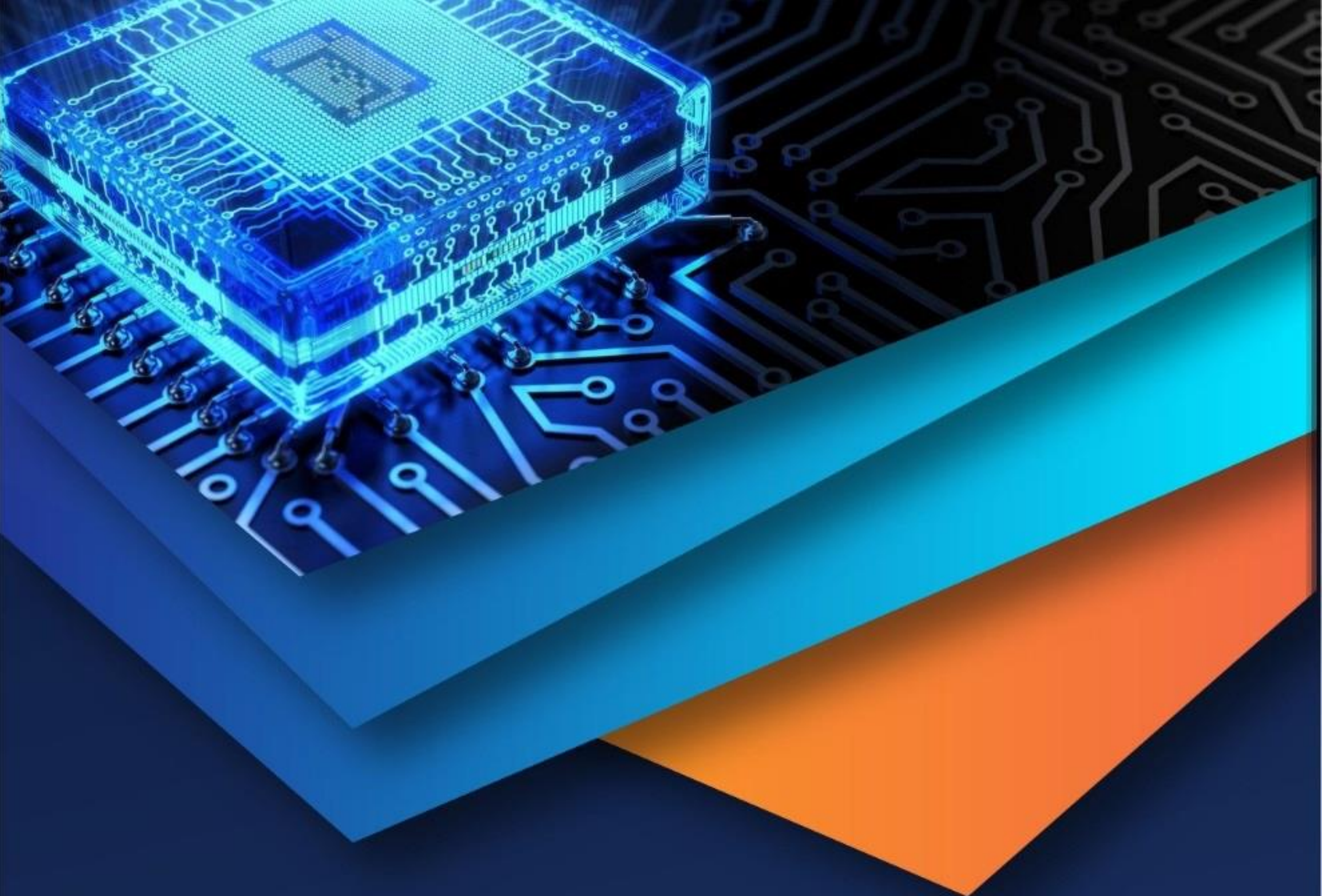
CODE BOOKS
[1] Code of practice for preparation and use of masonry mortar IS 2250 - 1981.
[2] IS: 2250 – compressive strength test for cement mortar cubes.
[3] IS: 269-2015 – specifications for 33, 43 and 53 grade OPC.
[4] Specification for coarse and fine aggregate IS 383-2016.



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