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Mechanical Properties of Concrete when cured with Carbon dioxide

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***Abstract:** The 5% of global CO_2 emissions are from cement industries. To reduce these emissions of CO_2, there is a necessity for sequestration of CO_2 into stable forms. The research focuses on using CO_2 as a curing agent. This paper summarizes the mechanical properties of concrete when cured in artificial CO_2 environment i.e. by using dynamic pressurized CO_2 curing chamber and Dry ice.The research includes designing a concrete mix of M25 grade as per IS 10262:2009. In this research, the effect of carbonation was analysed by CO_2 curing and dry ice curing. The experimental study on water cured, CO_2 cured and dry ice cured specimens for compressive strength, split tensile strength and flexural strength were carried out. The results show that 90% of compressive strength was achieved for 8 hours of CO_2 cured specimens when compared to 28 days of water cured specimens.*

***Keywords:** cement industry, pollution, CO_2 sequestration, carbonation, CO_2 curing, dry ice, penetration, compression strength, split tensile strength and flexural strength.*

I. INTRODUCTION

Cement production alone contributes approximately 5% of global CO_2 emissions. The emitted carbon dioxide can be partially reused as a curing agent in concrete by initial age curing which results in the formation of thermodynamically stable compounds of calcium carbonates. Concrete is known to possess the ability to absorb atmospheric carbon dioxide. The process of absorption of CO_2 into the concrete is called carbonation. [1] Early-age CO_2 curing develops strength, increased surface hardness, and reduced surface permeability to water, as well as the reduction of efflorescence to concrete products. [2] The reactions of carbonation between carbon dioxide and calcium compounds result in the formation of stable calcium carbonate as a permanent fixture.[3]

Don MacMaster and Oscar Tavares [3] study quantify carbon sequestration levels in concrete by creating various curing methodologies. A special CO_2 curing chamber was arranged to enable acceleration reaction by the use of carbon sequestration. The CO_2 curing chamber was arranged with a thermocouple and vacuum system, thermocouples for observing temperature and humidity and pressure.

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Testing samples were cast and cured in CO_2 curing chamber for 2 hours. Initially, tests were compared with traditional kiln-cured specimens at 100% CO_2 and at 20 psi of pressure. During the 2-hour curing period, continuous checking of relative humidity, temperature and weight gain were performed.

At 2-hours of CO_2 curing, the maximum temperature was reached to 30°C from 18.9°C and remained constant till the end. The relative humidity reached a maximum at the start of the curing test and decreased at 30 minutes and increase after 30 minutes until the end of the 2-hour.

Vibhas Bambroo et al., [4] conducted experimental research to find the absorption of carbon dioxide in concrete beams. For this, a metallic curing chamber is prepared with an outlet and inlet valves and a pressure gauge was attached to note the pressure inside the chamber. The samples were cast and cured in a CO_2 curing chamber for 4 hours and 8 hours and were compared with the samples that are cured in water for 28 days. After 4hours and 8hours of CO_2 curing the compressive strength was showed to increase by 12.3% and 27.7% and for 8hours of CO_2 curing the flexural strength was showed to increase by 1.8% than samples cured in water.

Ming-Gin Lee [5] conducted a study on the size effect of Cylinder on the Compressive Strength of Concrete by CO_2 Curing. In this study cylinders with three different sizes were cast, cured in CO_2 and tested at various curing timings. The CO_2 cured cylinders showed higher compressive strength compared to water cured cylinders.

Y. Shao [6] investigated the viability of using reused CO_2 in concrete through the curing process. The curing process is carried to two ways Open-inlet system and closed system using pressurized flue gas of low concentration. Precast specimens are cured in the chamber, in open-inlet system CO_2 gas with high purity is passed into a closed chamber at a pressure of 21psi and in a closed system flue gas containing 14% of Co_2 is passed at a pressure of 72psi. The gas is passed in seven cycles with a time period of 30-40 minutes. The results show that the concrete products cured in CO_2 show better results for mechanical properties.

Carbonation of concrete: Carbonation shows improved strength and durability of cement products. Carbonation may not be useful in non-reinforced cement products. Carbonation process may be useful for non-reinforced cement products. But due to carbonation the pH of cement paste reduces, the steel used in concrete loses its passivity and becomes liable to corrosion. Carbonation is a process by which CO_2 reacts with water and forms $Ca(OH)_2$. Calcium silicate and aluminates hydrates react with CO_2 and produce calcium carbonate and hydrates of silicates and aluminates and water.

II. RESEARCH SIGNIFICANCE

CO_2 emissions in the environment is increasing day by day. This increase in concentration has been reached the permissible limit standards and is leading to global warming. 5% of the global CO_2 emissions are from the cement industry. The research focused on reducing CO_2 emissions by sequestering them inside the concrete.

Carbonation is an accelerated curing process that injects CO_2 gas into the curing chamber and transforms the gaseous CO_2 into solid calcium carbonates (CaCO3) at ambient temperature, diffuses the carbon dioxide into the fresh concrete under low pressure.

$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$

$C_3S + 3CO_2 + H_2O \rightarrow C\text{-}S\text{-}H + 3CaCO_3$

$C_2S + 2CO_2 + H_2O \rightarrow C\text{-}S\text{-}H + 2CaCO_3$

A. Preparation of Curing Chamber

A metallic curing chamber of sizes 1000mm×500mm×500mm with an outlet and inlet and withholding pressure of $2kg/cm^2$ was prepared. To know the pressure that is maintained in the chamber, a pressure gauge was fixed.

Fig: 1 Carbonation chamber

III. MATERIAL PROPERTIES

A. Cement

The materials should satisfy the IS 10262-2009 code provisions. Cement used in the research was Ultra Tech OPC 53grade, confirming to IS 4031-1996 code the physical properties are listed in the table below

Table: 1 physical properties of cement

S.NO	Description	observations
1	Specific gravity of cement	3.15
2	Fineness of cement	8
3	Standard consistency of cement	33%
4	Initial setting time of cement	90 minutes
5	Final setting time of cement	350 minutes
6	Compressive strength of cement(Mpa)	
	3days	25.2
	7days	39.4
	28days	54.5

B. Aggregates

The fine aggregate used in the research was of zone2 of confirming IS 383-1970. The physical properties of FA are listed below in the table

Coarse aggregate used in this was angular of size 12.5mm confirming to IS 383-1970. The physical properties of Coarse aggregate are listed below in the table

Table: 2 Test results of aggregates

S.NO	Description	Fine aggregate	Coarse aggregate
1	Specific gravity of fine aggregate	2.55	2.61
2	Water absorption of fine aggregate	0.76	0.55
3	Bulk density of compacted aggregates	1.62	1.61
4	Bulk density of loosely packed aggregates	1.44	1.49
5	Fineness modulus of Fine Aggregates	2.11	7.2

IV. CONCRETE MIX DESIGN

Concrete mix design is done as per IS 10262. The mix quantities are listed in the table below:

Table: 3 MIX PROPORTIONS

Grade designation	Cement (kg/m^3)	F.A (kg/m^3)	C.A. (kg/m^3)	w/c ratio	Target strength
M25	300	738.7	1233.7	0.47	31.6

V. EXPERIMENTAL PROCEDURE

The testing specimens for compressive strength, split tensile strength flexural strength was cast. The specimens are cured in water and tested for 1day, 7days, and 28days. The specimens are cured in CO_2 curing chamber and Dry ice for 4, 6, 8 hours and tested for compression strength, split tensile strength and flexural strength. The specimens are cured in CO_2 and dry ice for 4, 6, and 8 hours and in water for 28days and tested for compressive strength. The results of CO_2 and Dry ice cured are compared with water cured.

A. Tests on fresh properties of concrete

Concrete is said to be workable when it is easily placed homogeneously without Segregation. Workability of freshly mixed concrete commonly determined by slump cone test and compaction factor.

- The slump cone value is 30mm.
- Compaction factor value is 0.86.

B. CURING SETUPS

a) Water curing setup

The cubes, cylinders, and beams are cast and cured for 1day, 7days, and 28days and tested.

b) Dry ice curing and CO_2 curing setup

The cubes, cylinders, and beams are cast and cured for 2hours- 8hours. For dry ice curing artificial CO_2 curing, the environment was created by using dry ice. The specimens are kept in Thermocole box along with dry ice and it should be airtight with masking tape to avoid contact with the outside temperature. The casted specimens are placed in carbonation chamber and pure CO_2 gas is passed into chamber at a pressure of 2kg/cm^2 and cured for 2hours-8hours in CO_2 curing chamber and tested for mechanical properties**.** The specimens are cured in CO_2 and Dry ice for 4 hours, 6 hours and 8 hours and in water after 28 days and tested for compressive strength.

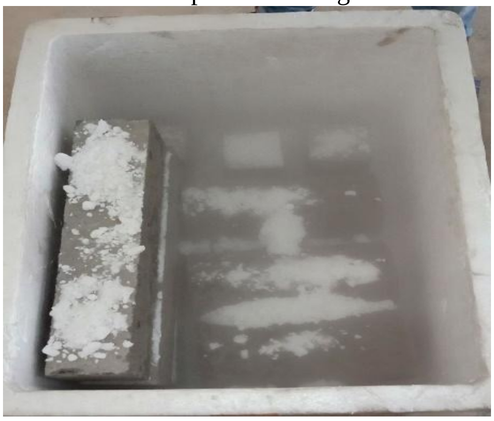

Fig 2. Specimens cured in Dry ice

Fig 3. Specimens in the carbonation chamber

VI. RESULTS AND DISCUSSIONS

A. Water cured Results

The compressive strength, Split tensile strength and Flexural strength results of specimens cured in water are tested for 1 day, 7 days and 28 days are tabulated below

Table 4. Results of water cured specimens

Time intervals	Compressive strength(Mpa)	Split tensile strength (Mpa)	Flexural strength (Mpa)
1 day	14.3	1.57	2.14
7 days	19.31	2.6	3.33
28 days	33.23	3.6	3.6

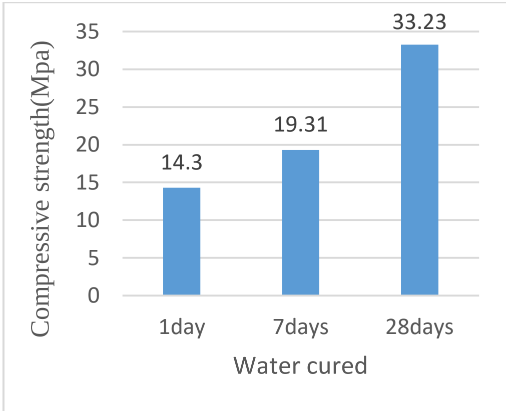

Fig 4. Compressive strength results of water cured specimens

The compressive strength results of water cured are tabulated and shown in the above figure. From the above figure, the design compressive strength is achieved for 1 day and 28 days. As the curing age increases, the strength of concrete increases by 64% and 7% for 1 day and 28 days curing compared to design strength and for 7 days the strength achieved was nearer to design strength of concrete.

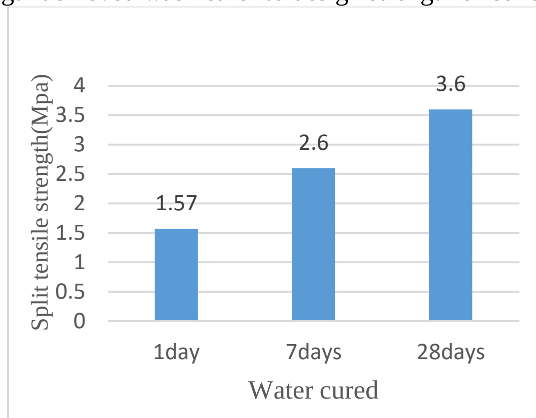

Fig 5. Split tensile strength results of water cured specimens

The split tensile strength results of water cured are tabulated and shown in the above figure. From the figure, it was observed that split tensile strength results for 1 day, 7days and 28days curing was 1.57Mpa, 2.6Mpa and 3.6Mpa.

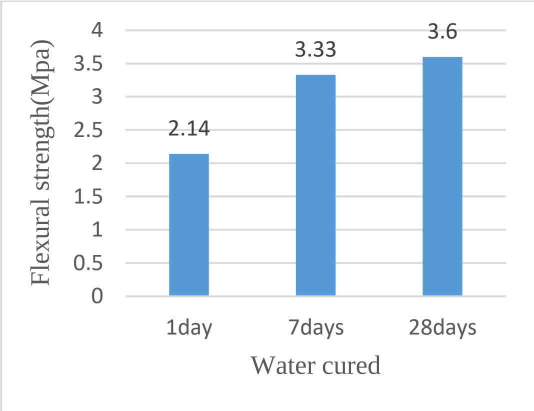

Fig 6. Flexural strength results of water cured specimens

The Flexural strength results of water cured are tabulated and shown in the above figure. From the figure, it was observed that Flexural strength results for 1 day, 7days and 28days curing 2.14Mpa, 3.33Mpa and 3.6Mpa.

B. CO_2 cured and Dry ice cured Results

The Compressive strength, Split tensile strength and Flexural strength results of CO_2 cured and Dry ice cured specimens that are tested for 2 hours, 4 hours, 6 hours and 8 hours are tabulated below:

Table 5. Compressive strength results for CO_2 cured and dry ice cured specimens

Time intervals	CO_2 cured(Mpa)	Dry ice cured(Mpa)
2 hours	1.77	1.32
4 hours	2.43	1.86
6 hours	2.63	2.05
8 hours	3.23	2.52

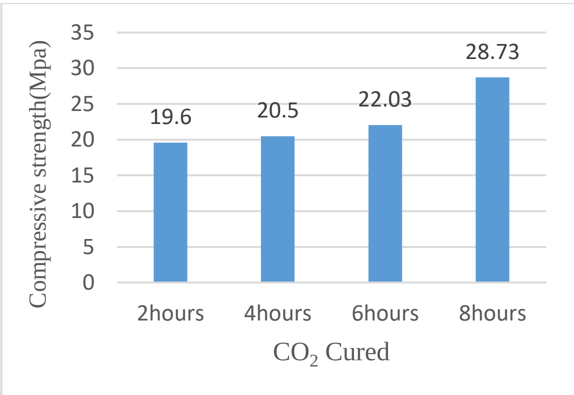

Fig 7. Compressive strength results for CO_2 cured

The compressive strength results of CO_2 cured are tabulated and shown in the above figure. From the above figure, it was found that 90% of compressive strength was achieved for 8 hours of CO_2 curing compared to 28days water cured specimens.

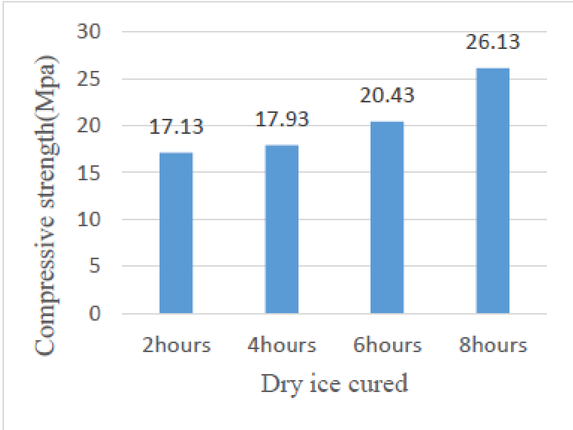

Fig 8. Compressive strength results for Dry ice cured specimens

The compressive strength results of CO_2 cured are tabulated and shown in the above figure. From the above figure, it was found that 82% of compressive strength was achieved for 8 hours of CO_2 curing compared to 28days water cured specimens.

Table 6. Split tensile strength results for CO_2 cured and dry ice cured specimens

Time intervals	CO_2 cured(Mpa)	Dry ice cured(Mpa)
2 hours	19.6	17.13
4 hours	20.5	17.93
6 hours	22.03	20.43
8 hours	28.73	26.13

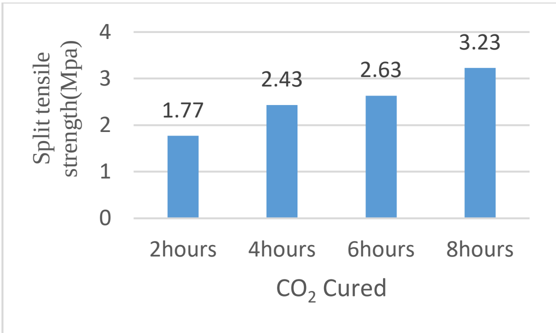

Fig 9.split tensile strength results for CO_2 cured specimens

The split tensile strength results of CO_2 cured are tabulated and shown in the above figure. From the figure, it was observed that split tensile strength results for 2hours, 4hours, 6hours and 8hours curing was 1.77Mpa, 2.43Mpa, 2.63Mpa and 3.23Mpa respectively. It was found that 92% of tensile strength was achieved for 8 hours of CO_2 curing when compared to specimens cured in water for 28days.

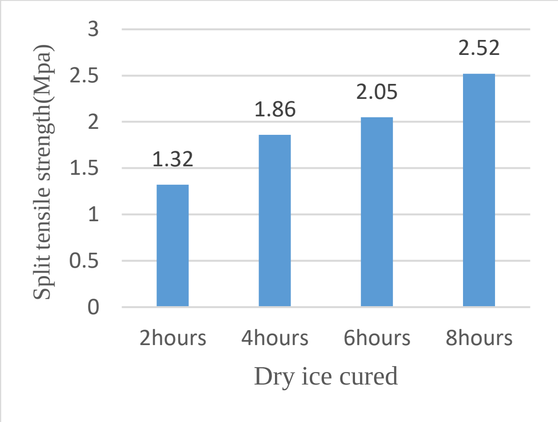

Fig 10. Split tensile strength results for Dry ice cured specimens

The split tensile strength results of Dry ice cured are tabulated and shown in the above figure. From the figure, it was observed that split tensile strength results for 2hours, 4hours, 6hours and 8hours curing was 1.32Mpa, 1.86Mpa, 2.05Mpa and 2.52Mpa respectively. It was found that 72% of tensile strength was achieved for 8 hours of Dry ice curing compared to 28days water cured specimens.

Table 7. Flexural strength results for CO_2 cured and dry ice cured specimens

Time intervals	CO_2 cured(Mpa)	Dry ice cured(Mpa)
2 hours	2.63	1.91
4 hours	2.77	2.14
6 hours	2.83	2.57
8 hours	3.38	3.04

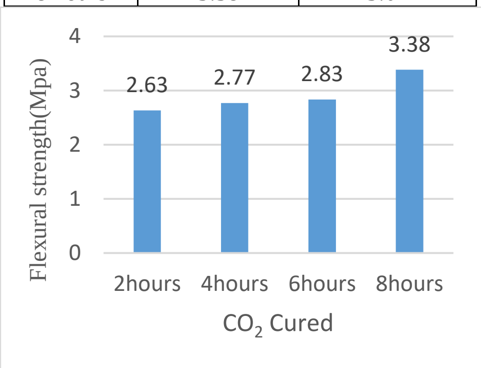

Fig 11. Flexural strength results for CO_2 cured specimens

The Flexural strength results of CO_2 cured are tabulated and shown in the above figure. From the figure, it was observed that flexural strength results for 2hours, 4hours, 6hours and 8hours curing was 2.63, 2.77, 2.83 and 3.38 respectively. It was found that 89% of Flexural strength was achieved for 8 hours of CO_2 curing compared to 28days water cured specimens.

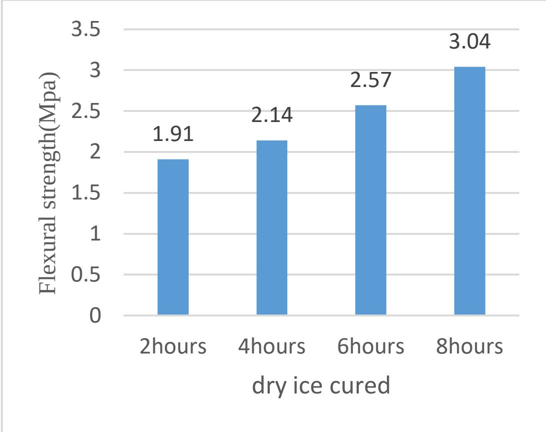

Fig 12. Flexural strength results for Dry ice cured specimens

The Flexural strength results of Dry ice cured are tabulated and shown in the above figure. From the figure, it was observed that flexural strength results for 2hours, 4hours, 6hours and 8hours curing was 1.91, 2.14, 2.57 and 3.04 respectively. It was found that 80% of Flexural strength was achieved for 8 hours of CO_2 curing compared to 28days water cured specimens.

Table 8. Compressive strength results of CO_2 cured and Dry ice cured specimens

Time interval	CO_2 cured	Dry ice cured
4h + 28 days water	32.2	33.5
6h + 28 days water	33.7	35.72
8h + 28 days water	35.5	37.4

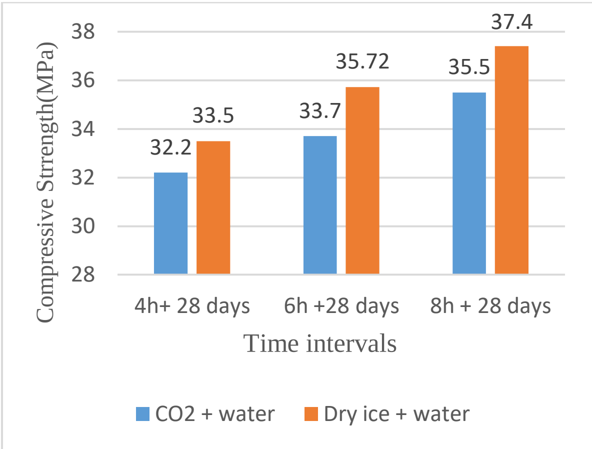

Fig 13. Compressive strength results of CO_2 + water cured and Dry ice + water cured specimens

The compressive strength results of CO_2 + water cured and Dry ice + water cured are tabulated and shown in the above figure. The results show that the target strength is reached in both curing conditions but the strength of concrete slightly decreases when cured in CO_2 (4h, 6h, 8h) + water (28 days) when compared with specimens cured in Dry ice (4h, 6h, 8h) + water (28 days).

C. TEST FOR CARBONATION

Phenolphthalein indicator solution was used to find the depth of carbonation. Concrete having higher pH due to formation of Calcium hydroxide when cement reacts with water. When phenolphthalein solution is added it turns pink.

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However it remains colourless, it indicates that concrete has undergone carbonation. The concrete specimens cured in water and CO_2 are tested for phenolphthalein are shown in figure below and the penetration depths are shown

Fig 12. Phenolphthalein test for water cured and CO_2 cured specimens

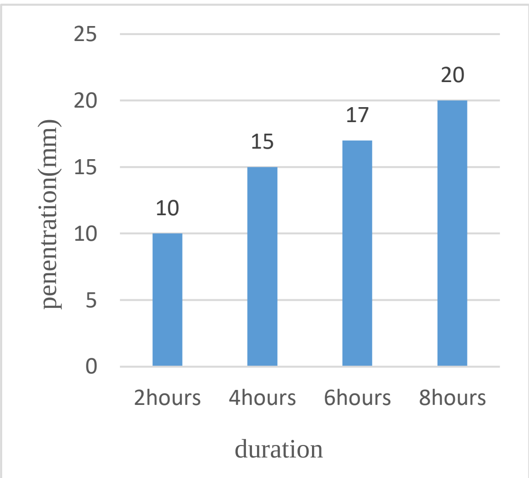

Fig 13. Graph shows CO_2 penetration vs. duration of CO_2 cured specimens

From the above figure, it is shown that average penetration of CO_2 has occurred at 2 hours of CO_2 curing was 17mm and for water cured specimens it found to be negligible when compared to CO_2 cured specimens. As time increases the porosity decreases in concrete and it needs a lot more pressure to sequester carbon dioxide inside it which is not possible to maintain at this level.

VII. CONCLUSIONS

The results from the experimental study carried out for evaluating the mechanical properties of specimens cured in water, CO_2 and Dry ice. The CO_2 and Dry ice cured specimens achieved early strength when compared to water cured specimens are summarized below:

- Compressive strength of CO_2 cured specimens for 8 hours duration has achieved 90% of the strength when compared with respect to water cured specimens.
- Split tensile strength of the CO_2 cured specimens for 8 hours duration has achieved 92% of tensile strength when compared with the specimens cured in water.
- Flexural strength of the CO_2 cured specimens for 8 hours duration has achieved 89% of flexural strength when compared with the specimens cured in water.
- The CO_2 and Dry ice cured specimens have achieved slightly higher compressive strength with an increase in the curing age of 8 hours when compared with water cured specimens.
- The compressive strength of CO_2 cured (4h, 6h, 8h) + water (28days) and Dry ice cured (4h, 6h, 8h) + water (28 days) specimens achieved target strength but the strength of CO_2 cured specimens slightly decreases when compared with Dry ice cured specimens.

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