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An Experimental Investigation on SCBA Ternary Blended Concrete by Carbon Dioxide Curing

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Abstract: This study reports the usage of sugarcane bagasse ash (SCBA) and Silica fume as supplementary cementitious material for manufacturing concrete with high performance. Due to this, the agricultural and industrial wastes can be utilized in concrete. Cement is replaced with 0% 10%, 5%, 15%, 20% and 25% by SCBA and 10% of silica fume respectively. The present research focuses on using CO_2 as a curing agent. The paper summarizes the mechanical properties of SCBA ternary blended concrete when cured in artificial CO_2 environment i.e. by using dynamic pressurized CO_2 curing chamber and Dry ice. The results show that 80%, 85% and 83% of the compressive strength, split tensile strength and flexural strength was achieved when the specimens are cured in CO_2 curing chamber for 8 hours when compared with the samples that are cured in water for 28days. Further, the results show that 73%, 85% and 63% of the compressive strength, split tensile strength and flexural strength was achieved when the specimens are cured in Dry ice for 8hours when compared with the samples that are cured in water for 28days.

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

I. INTRODUCTION

Portland cement is mostly used construction building material because of its high compressive strength. The cement industry produces 5% of CO_2 emissions, which is a major reason for global warming and the greenhouse effect [1].Hence if pozzolanic materials like SCBA and silica fume are replaced with some of these raw materials having similar composition, the cement production may be reduced without affecting its quality and can reduce emissions of CO_2 [2]. Bagasse ash, the by-product of sugar factories which came after burning waste bagasse which is extracted of sugar from sugarcane. Bagasse ash contains mainly aluminium and silica. SCBA was found to shows better results of concrete for water tightness and strength with a certain percentage of replacement and fineness, due to greater silica content in SCBA. [3] Silica fume (SF) can also be called as micro silica, a fine powder and a by-product that is collected from ferrosilicon alloy production. Currently, global output of silica fume is between 1 and 1.5 M tonnes per annum [4] by replacing of silica fume with cement in concrete showed improved results in strength, durability and reduction in cement production.

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The concrete which is replaced with 10% to 20% of silica fume was found to the optimum replacement percentage with cement [5]. Cement production alone contributes about 5% of CO_2 emissions. The emitted carbon dioxide can be partially reused as curing agent in concrete by initial age curing which results in the formation of thermodynamically stable compounds of calcium carbonates. The previous literature says that carbon sequestration can shorten the curing cycle, increase compressive strengths, reduce energy requirements, reduce efflorescence, reduce embodied water requirements, and use carbon sequestration methodology within the concrete products industry. The reactions of carbonation between CO_2 and CA compounds results in the formation of stable calcium carbonate as a permanent fixture [6].

Alaa M. Rashad [7] has studied the silica fume and slag effect on abrasion resistance and compressive strength of HVFA concrete by replacing class C fly ash, silica fume and GGBS with cement. Total of 8 mixes were casted; conventional and mixes with various percentages of fly ash and silica fume. From the results, concrete mixture with 10% of slag and silica fume gave great results for compressive strength at all ages. Vishal S. Ghutke [8] had determined the Impact of silica fume in concrete. The main aim of the research was to find the optimal percentage of silica fume that can be replaced with cement. The results concluded that optimum compressive strength was achieved when the cement replacement is done by 10% of silica fume and the strength decreases when cement the replacement is done with silica fume at above 15%. If the percentage of silica fume increased in concrete the workability decreases.

R. Srinivasan [9] had studied experimentally the characterization of SCBA in concrete by replacing of bagasse ash to cement with various percentages i.e. 5% to 25%. Tests are done for workability and strength of concrete. From the results, optimum compressive strength achieved by replacing with 10% of SCBA and by increasing the percentage of SCBA in cement the workability decreases. Lavanya M.R [10] conducted a study on the compressive strength properties of concrete by replacing of cement with various percentages of SCBA. The main objective is to test the feasibility of Bagasse ash replacing it with cement. The research is done by replacing of cement with different percentages i.e. 5% to 30% of SCBA by changing of water-cement ratios. It was concluded that by replacing of cement with 15% of SCBA at 0.35 water-cement ratio shows improved results for strength. Ansia S Hameed [11] had invested strength of M40 grade cement concrete using SF and SCBA. In the present study, initially, samples casted by binary mixes by replacing silica fume at various percentages i.e. 5% to 25% with cement and finding an optimal percentage of silica fume.

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Then ternary mixes are prepared by replacing silica fume at 10% with cement and various percentages i.e. 5% to 10% of SCBA and tests are conducted on fresh and strength properties. From the results, workability of concrete decreases with increase in the percentage of SCBA to cement. The optimum strength was achieved at 10% replacement of silica fume with cement for the binary mix and replacing of cement with 10% of SF and 10% of SCBA for ternary concrete mix.Seyed Alireza Zareei [12] investigated the utilization of SCBA by replacing cement in ordinary, lightweight and self-compacting concrete. The samples were prepared by replacing of SCBA at various percentages i.e. 5% to 25% to cement. From the results, the strength increases with 5% replacement of SCBA for ordinary and lightweight concrete and self-compacting concrete increases the impact by 50%.

Vibhas Bambroo [13] conducted an experimental research to check effect of carbonation on concrete beams. For this, a metallic chamber was prepared with an outlet and inlet and a pressure gauge was attached to note the pressure inside the curing chamber. The tested samples were made and were cured in CO_2 curing chamber 4hours and 8hours and tested. The CO_2 cured samples were compared with the water cured samples. After testing the results indicate that the samples cured in a CO_2 curing chamber show better results than water cured specimens.

II. RESEARCH SIGNIFICANCE

The CO_2 emissions in the environment are increasing day by day. The increase in concentration has reached the permissible limit standards and is leading to global warming. Cement production involves about 5% of the CO_2 emissions. The study focuses on reducing CO_2 emissions by sequestering them inside the concrete.

Carbonation accelerates the curing process, increases the mechanical strength of concrete by introducing CO_2 gas into the curing chamber at ambient temperature and diffuses the CO_2 into the fresh concrete under low pressure in the formation of the gaseous CO_2 into solid calcium carbonates ($CaCO_3$).

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

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

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

A. Preparation of curing chamber

A metallic CO_2 curing chamber 1000mm×500mm×500mm with an outlet and inlet withholding pressure of 2kg/cm^2 was prepared. The pressure gauge was fixed to the chamber to understand the pressure inside the curing chamber.

Fig: 1 CO_2 curing chamber

III. MATERIAL PROPERTIES

A. Cement

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

Table: 1 Test results 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	Final setting time of cement	350 minutes
5	Initial setting time of cement	90 minutes
6	Compressive strength of cement(MPa)	
	3days	25.2
	7days	39.4
	28days	54.5

B. Aggregates

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

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

Table: 2 Test results of fine aggregates

S.NO	Description
1	specific gravity of fine aggregate
2	Water absorption of fine aggregate
3	Bulk density of compacted aggregates
4	Bulk density of loosely packed aggregates
5	Fineness modulus of Fine Aggregates

Table: 3 Physical properties of SCBA and Silica Fume

S.NO	Description	SCBA	Silica Fume
1	Specific gravity	2.2	2.2
2	Density	575 Kg/m^3	1400 kg/m^3
3	Mean size particle	0.1-0.2µm	0.15 µm
4	Mean specific area	2500 m^2/Kg	1500-3000 m^2/Kg

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5	Colour	Dark black	Light to Dark Grey

Table: 4 Chemical properties of SCBA

S.NO	Component	Symbol	Percentage
1	Silica	Sio2	63.00
2	Alumina	Al_2O_3	31.50
3	Ferric oxide	Fe_2O_3	1.79
4	Manganese oxide	MnO	0.004
5	Calcium oxide	Cao	0.48
6	Magnesium oxide	MgO	0.39
7	Loss of ignition	LOI	0.71

Table: 5 Chemical properties of Silica fume

S.NO	Component	Symbol	Percentage
1	Silica	Sio2	85
2	Alumina	Al_2O_3	1.12
3	Ferric oxide	Fe_2O_3	1.46
4	Calcium oxide	Cao	0.2-0.8
5	Magnesium oxide	MgO	0.2-0.8
6	Sodium oxide	Na_2O	0.5-1.2
7	Loss of ignition	LOI	0.6

IV. CONCRETE MIX DESIGN

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

Table: 6 MIX PROPORTIONS

Grade designation	cement (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)	W/C	Target strength (MPa)
M 30	360	812.33	1176.02	0.45	38.25

V. EXPERIMENTAL PROCEDURE

An experimental investigation on SCBA ternary blended concrete is done by curing specimens in water, CO_2 gas and Dry ice. Cement is replaced with various proportions of SCBA i.e. 0%, 5%, 15%, and 25% and 10% of silica fume. The testing samples for compressive strength, split tensile strength and for flexural strength were casted. The reference samples were cured in water for the required number of days (7day, 28 days and 56 days as per the requirement) before testing for compressive strength, split tensile strength and flexure strength. Samples will be cast and exposed to CO_2 (in the form of dry ice i.e. solid form of CO_2 and gaseous form) in the Chamber for 4hours, 6hours and 8hours. These samples will be then tested for compressive strength, split tensile strength and flexural strength to understand the effect of CO_2 curing. These results will be compared with the reference cubes cured in water.

A. Tests on fresh properties of concrete

Concrete is known to be workable when it is easily compacted and placed homogeneously without Segregation. Workability for freshly mixed concrete commonly evaluated 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 7day, 28days and 56days and tested.

b) Dry ice curing and CO_2 curing setup

The cubes, cylinders and beams are cast and cured for 4hours, 6hours and 8hours. For dry ice curing artificial CO_2 curing, 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 outer temperature.

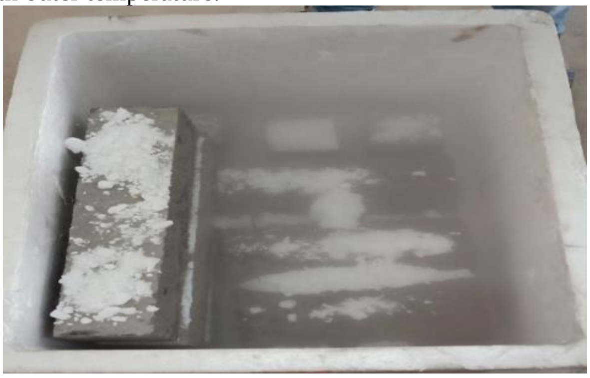

Fig: 1 Specimens cured in Dry ice

Fig: 2. Specimens in the CO_2 curing chamber

The casted specimens are placed in CO_2 curing chamber and pure CO_2 gas is passed into chamber at a pressure of 2kg/cm^2 and cured for 2 hours, 4 hours, 6 hours and 8 hours in carbonation chamber and tested for mechanical properties.

VI. RESULTS AND DISCUSSIONS

This chapter describes the results for compressive strength, split tensile strength and flexural strength. The samples that are cured in water and were tested after 7days, 28days and 56days.

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The specimens that are cured in CO_2 curing chamber and Dry ice for 4hours, 6hours, 8hours and tested for compression strength, split tensile strength and flexural strength. The detailed discussion of results for water cured, CO_2 and Dry ice cured specimens is done with tables and figures.

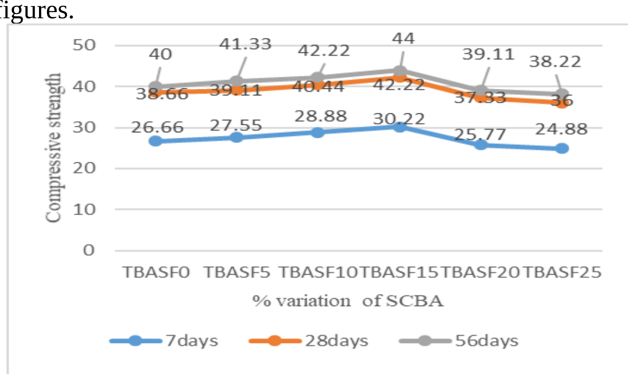

Fig: 3.Compressive strength results of water cured specimens

The compressive strength results of water cured shown in the above figure. From the above figure, it was perceived that the compressive strength was for mix TBASF15 by 9.2% than conventional mix for 28 days of curing. At 15% and 10% replacements of SCBA and silica fume with cement shows better results for Compressive strength.

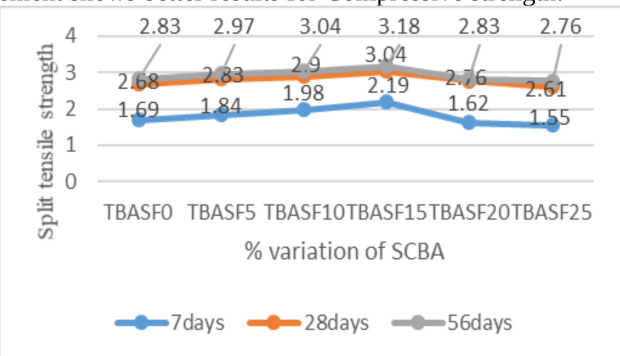

Fig: 4. Split tensile strength results of water cured specimens

The Split tensile strength results of water cured are shown in above figure. From the above figure, it was perceived that Split tensile strength was increased for mix TBASF15 by 13.4% than conventional mix for 28 days of curing. At 15% and 10% replacements of SCBA and silica fume with cement shows better results for split tensile strength.

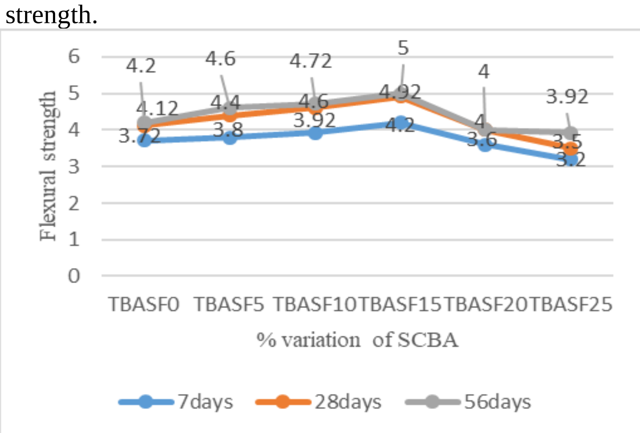

Fig: 5. Flexural strength results of Water cured specimens

The Flexural strength results of water cured are shown in the above figure. From the above figure, it was perceived that the Flexural strength was increased for mix TBASF15 by 19.4% than conventional mix for 28 days of curing. At 15% and 10% of replacements of SCBA and silica fume with cement shows better results for Flexural strength.

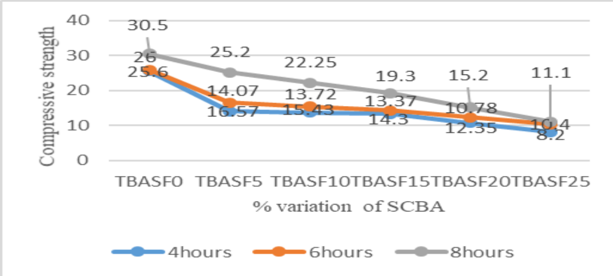

Fig: 6. Compressive strength results of CO_2 cured specimens

The compressive strength results of CO_2 cured are shown in the above figure. From the above figure it was perceived that the compressive strength was decreased in order 4hours, 6 hours and 8 hours of CO_2 curing for the mixes TBASF0, TBASF5, TBASF10, TBASF15, TBASF20 and TBASF25. From the results, it was known that the compressive strength decreases by increasing the percentages of SCBA and silica fume in concrete with increase in curing time when the specimens are cured in CO_2.

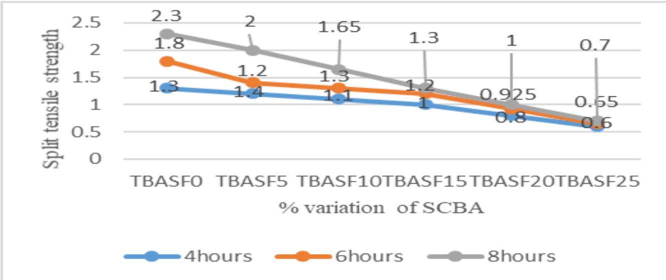

Fig: 7. Split tensile strength results for CO_2 cured specimens

The Split tensile strength results of CO_2 cured are shown in the above figure. From the above figure it was perceived that the Split tensile strength was decreased in order 4 hours, 6 hours and 8 hours of CO_2 curing for the mixes TBASF0, TBASF5, TBASF10, TBASF15, TBASF20 and TBASF25. From the results, it was known that the Split tensile strength decreases by increasing the percentages of SCBA and silica fume in concrete with increase in curing time when the specimens are cured in CO_2.

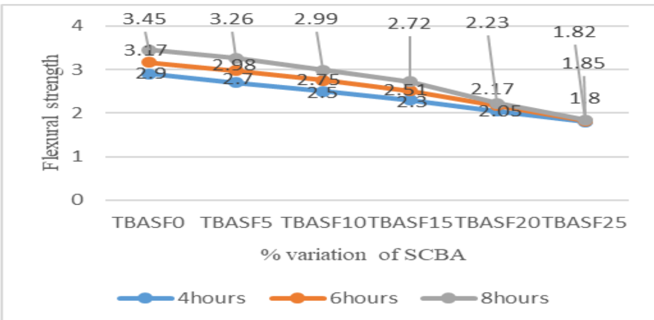

Fig: 8. Flexural strength results for CO_2 cured specimens

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The Flexural strength results of CO_2 cured are shown in the above figure. From the above figure it was perceived that the flexural strength was decreased in order 4 hours, 6 hours and 8 hours of CO_2 curing for the mixes TBASF0, TBASF5, TBASF10, TBASF15, TBASF20 and TBASF25. From the results, it was known that the flexural strength decreases by increasing the percentages of SCBA and silica in concrete with increase in curing time when the specimens are cured in CO_2.

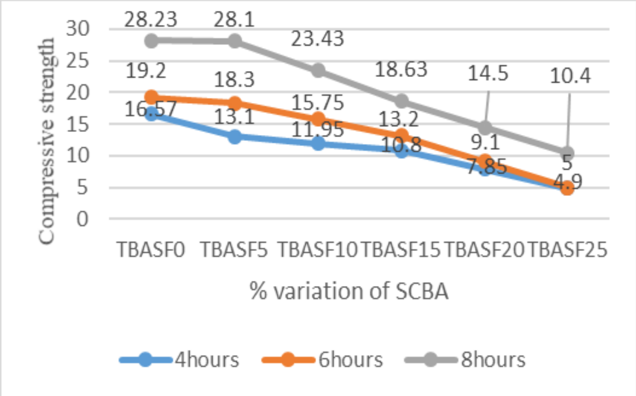

Fig: 9. Compressive strength results for Dry ice cured specimens

The Compressive strength results of Dry ice cured are shown in the above figure. From the above figure it was perceived that the compressive strength was decreased in order 4 hours, 6 hours and 8 hours of dry ice curing for the mixes TBASF0, TBASF5, TBASF10, TBASF15, TBASF20 and TBASF25. From the results, it was known that by increasing the percentages of SCBA and silica fume in concrete the compressive strength decreases with increase in curing time when the specimens are cured in dry ice.

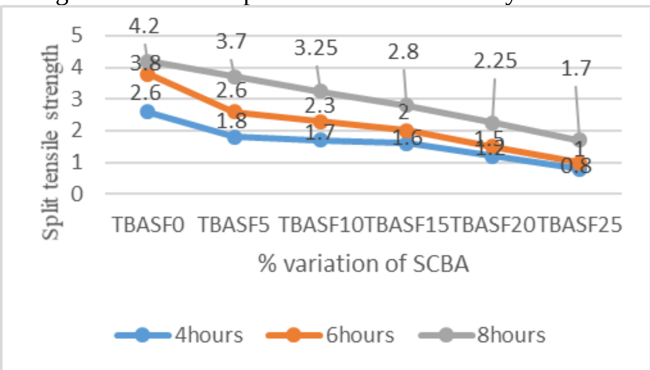

Fig: 10. Split tensile strength results for Dry ice cured specimens

The Split tensile strength results of Dry ice cured are shown in the above figure. From the above figure it was perceived that the split tensile strength was decreased in order 4hours, 6hours and 8hours of dry ice curing for the mixes TBASF0, TBASF5, TBASF10, TBASF15, TBASF20 and TBASF25. From the results, it was known that by increasing the percentages of SCBA and silica fume the split tensile strength decreases with increase in curing time when the specimens are cured in dry ice.

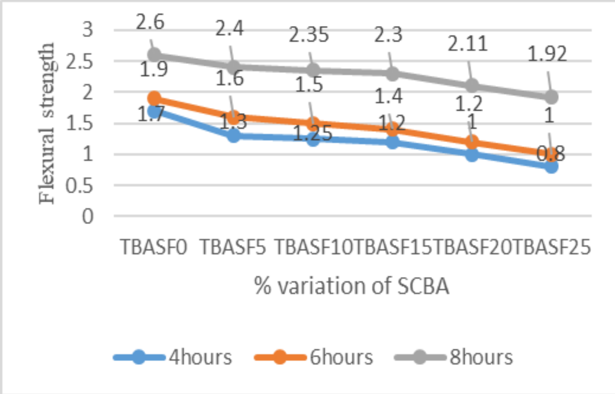

Fig: 11. Flexural strength results for Dry ice cured specimens

The Flexural strength results of Dry ice cured specimens are shown in the above figure. From the above figure it was perceived that the flexural strength was decreased in order 4hours, 6hours and 8hours of dry ice curing for the mixes TBASF0, TBASF5, TBASF10, TBASF15, TBASF20 and TBASF25. From the results, it was known that by increasing the percentages of SCBA and silica fume to concrete the flexural strength decreases with increase in curing time when the specimens are cured in dry ice.

C. Phenolphthalein Test

Phenolphthalein solution is used as a CO_2 indicator. The property of this solution is that it shows a pink colour in the presence of a base and remains colourless in the presence of acid. The concrete is basic in nature. On reaction with atmospheric moisture and CO_2, it forms mild carbonic acid (H_2CO_3) which remains colourless on the spraying of the indicator solution.

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

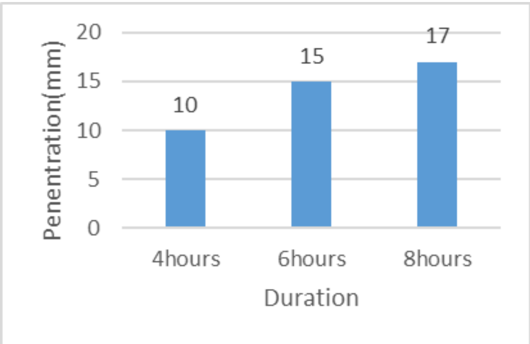

Fig: 13. Graph shows CO_2 penetration vs duration of CO_2 cured specimens

From figure 5.11 it is shown that average penetration of CO_2 has occurred at 6 hours of CO_2 curing was 15mm and for water cured specimens it found to be negligible when compared to CO_2 cured specimens. Figure 5.10 shows the penetration depth of water cured and CO_2 cured specimens. After spraying phenolphthalein, the part which turned pink indicated no absorption of CO_2 whereas the colourless part indicated CO_2 absorption.

VII. CONCLUSIONS

- Early strength occurred for the SCBA ternary blended concrete for TBASF0 when specimens are cured in CO_2 and dry ice.
- TBASF15 concrete mix showed significantly higher strength when compared with TBASF0 by 9.2%
- TBASF0 concrete cured in CO_2 for 8hours achieved 80% of strength when compared with the specimens cured in water for 28 days.
- TBASF0 concrete cured in dry ice for 8hours achieved 73% strength when compared with the specimens cured in water for 28 days.
- The compressive strength for TBASF5, TBASF10, TBASF15, TBASF20 and TBASF25 concrete mixes cured in CO_2 for 8hours the strength decreased by 17.4%, 28%, 37%, 50.2% and 63.7% when compared with TBASF0.
- The compressive strength for TBASF5, TBASF10, TBASF15, TBASF20 and TBASF25 concrete mixes cured in dry ice for 8hours the strength decreased by 0.5%, 17%, 34%, 48.7% and 63% when compared with TBASF0.
- The strength of the SCBA ternary concrete cured in CO_2 and Dry ice has been decreased with an increase of SCBA percentage.

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