

# Performance of CO<sub>2</sub> Cured Sugar Cane Bagasse Ash Concrete in Marine Environment

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**Abstract** A large amount of industrial and agro wastes mostly end up in landfills and not much attention is given to these wastes, which cause environmental problems. Few of the industrial and agro by-products such as fly ash, sugar cane bagasse ash and silica fume act as pozzolanic materials in preparation of blended cements which provide satisfactory alternative results in waste management. The main goal of this research is to check the durability properties of carbon dioxide cured sugar cane bagasse ash concrete when exposed to marine environments. A set of different concrete mixes were prepared by partially replacing the cement with various percentages of sugarcane bagasse ash (0%, 5%, 15%, 25%) and 10% of silica fume in each mix and then these specimens were cured in water for 28 days, in CO<sub>2</sub> gas for 8 hours and in dry ice for 8 hours. After curing, these specimens are exposed to seawater for a period of 28 days, 90 days and 120 days, and then tests are conducted for compressive, tensile, and flexural strength. The test results indicate that replacement of cement with 5% bagasse ash & 10% silica fume showed better effective results when compared to all other percentages of replacements. The specimens cured in CO<sub>2</sub> gas showed similar results as that of water cured specimens while the specimens cured with dry ice showed a loss in strength.

**Keywords** SCBA, Silica Fume, CO<sub>2</sub>, Gas Curing Dry Ice Curing

## 1. Introduction

Reducing the usage of natural resources by partially replacing cement with different pozzolanic material such as silica fume, sugar cane bagasse ash, and replacing water with carbon dioxide for curing, it was found that 80% of strength was achieved for 8hrs of CO<sub>2</sub> curing compared with 28 days water curing specimen [1]. Durability properties have studied for recycled aggregate concrete specimens cured with carbon dioxide, it was shown that compressive strength at 72 hrs of CO<sub>2</sub> cured concrete was similar to 90 days water curing and split tensile strength showed higher results compared to 90 days water cured results, higher chloride penetration resistance was observed [2]. To achieve the rapid strength two curing methods were followed for the concrete made up of recycled aggregates. samples cured with pressurized carbon dioxide curing showed better results than flow through carbon dioxide curing [3], [4]. This work aims to examine the potential absorption of concrete by carbon dioxide. For this study, dry ice was used [5]. After 2hrs of curing the compressive strength of dry ice cured samples was 22.12% more than the water cured samples [6]. Green concrete using aggro waste [SCBA] for a water-cement ratio of 0.42 showed that at 15% of replacement the strength of concrete showed best results at 28 days of curing compared to other percentages (5%,10%,20%,25%), at 28 days of curing for 20%,25% replacement samples

showed less split tensile strength [5], [7]. Investigated the possibility of sugarcane bagasse ash, micro silica as replacement of cement for lightweight weight concrete for a water-cement ratio of 0.4. for 15%, 20% and 25% bagasse ash showed 8%, 24%, 35% reduction in compressive strength. 13% of increase in compressive strength was observed for 5% replacement. Due to the low ability to occupy space, the water absorption was increased by increasing the percentage of replacement. 5% of bagasse ash replacement showed optimum results compared to other percentages of replacements [8]. In order to study the potential of the reuse of industrial wastes, Hermawan et.al studied the mechanical and dimensional properties of cement bonded particles cured with CO<sub>2</sub> gas and it was found that C<sub>3</sub>S hydration was accelerated due to CO<sub>2</sub> curing which improves the strength of concrete [9]. Suitability of sea water for curing and compressive strength of concrete was found that a loss of 6% was observed for seawater cured samples at 180 days of curing, 10% loss was observed when concrete made with seawater and cured with plain water [9]. Studied the fluence of sea water, sea sand for curing and mixing for concrete and it was found that there is a slight increase in compressive strength of concrete mixed with fresh water and cured in sea water at 90 days of curing and no change was observed in tensile strength of concrete, and there is a decrease in flexural strength of concrete was observed [10]. Ultra-high performance of concrete made of sea water, sea sand and silica fume for cement replacement was used and the results showed that the concrete made with sea water, sea sand, white cement and silica fume, quartz powder achieved 28 days cube strength [11]. There is a slight decrease in compressive strength and elastic modulus of concrete made with sea water compared to fresh water curing [12]. Types of aggregate affect the concrete volume and the water permeability of concrete [13].

India contributes 6.6% (4<sup>th</sup> largest) of total world CO<sub>2</sub> emissions, there is a need to capture and use CO<sub>2</sub> in the right way [14]. Major sources for carbon emissions are fossil fuels and cement manufactures. Most of the world's energy generating from the combustion of fossil fuels and it is the major source for greenhouse gases like CO<sub>2</sub> etc., it is necessary to develop various methods to use these gases in different practices [15]. Using Carbon dioxide for curing of concrete offers a better substitute for water [16].

CO<sub>2</sub> is a waste product produced from the industry, therefore CO<sub>2</sub> has to be either stored under the earth or beneath the sea and it will be a problem at any point of time, instead of that in the proposed research a large portion of CO<sub>2</sub> will go into the concrete and it forms a stable compound and a part of it may go into the atmosphere but it will be comparatively less and this is how it will effectively utilize the Carbon dioxide.

## 2. Materials

### 2.1. Cement

53 grade OPC cement was used for this research, which is having a specific surface area of 313 m<sup>2</sup>/kg, and physical properties test results are shown in Table 1.

**Table 1.** Physical properties of cement

Specific gravity	3.1
Fineness of cement	8
Standard consistency of cement	31%
Final setting time of cement	320 minutes
Initial setting time of cement	85 minutes
Compressive strength at 28 days (MPa)	52.5

### 2.2. Aggregates

Natural crushed stones of angular shape were used as coarse aggregates and river sand with a fineness of 2.73 from Zone 2 was used as fine aggregates.

### 2.3. Silica Fume and Bagasse Ash

Sugar cane bagasse having Specific gravity of 2.1 and specific surface area of 2500m<sup>2</sup>/kg, particle mean size of 0.1-0.2µm was used. Specific gravity of 2.1, specific surface area of 1500-3000m<sup>2</sup>/kg silica fume was used. Table 2 gives the chemical properties of cement, SCBA and silica fume.

**Table 2.** Chemical properties of cement, SCBA, SF

Chemical Compound	Cement	SCBA	Silica Fume
SiO <sub>2</sub>	20.12	63.00	85
Al <sub>2</sub> O <sub>3</sub>	5.77	31.50	1.12
Fe <sub>2</sub> O <sub>3</sub>	3.45	1.79	1.46
Na <sub>2</sub> O	0.34	-	0.5
CaO	63.68	0.48	0.8
MgO	0.3	0.4	0.8
LOI	1.47	0.71	0.6

## 3. Methodology

### 3.1. Experimental Procedure

Concrete cubes of size 100mmX100mmX100mm, cylinders of size 150mmX300mm, prisms of size 100mmX100mmX500mm for a water-cement ratio of 0.45 with SCBA replacement of 0%,5%,15%,25% and silica fume of 10% for each mix were casted. These specimens are cured in carbon dioxide gas, Dry ice for 8 hrs and in water for 28 days. These specimens were placed in seawater for 28 days, 90 days, 120 days. All the specimens were tested for compressive, split tensile strength, flexural

strength as per Indian standards [16] – [18].

### 3.2. Curing Methods

#### 3.2.1. Water Curing

After casting all the test specimens were cured in water for 28 days for the analysis of test results. Fig 1 shows the water immersion curing of test specimens.



Figure 1. Water Curing

#### 3.2.2. Carbon dioxide gas curing:

The process of using carbon dioxide for curing is called carbonation. The carbonation helps to gain rapid strength and improve mechanical properties of concrete. This curing is done by two methods. A carbon dioxide cylinder was used for pressurized curing and Dry ice (solid form of  $\text{CO}_2$ ) was used for moist curing. 1000mm×500mm×500mm size metallic chamber with a pressure capacity of  $2\text{Kg}/\text{cm}^2$  was used for pressurized curing. The specimens are kept in  $\text{CO}_2$  chamber for 8 hours and maintained the same pressure till the end of curing as shown in Fig 2.

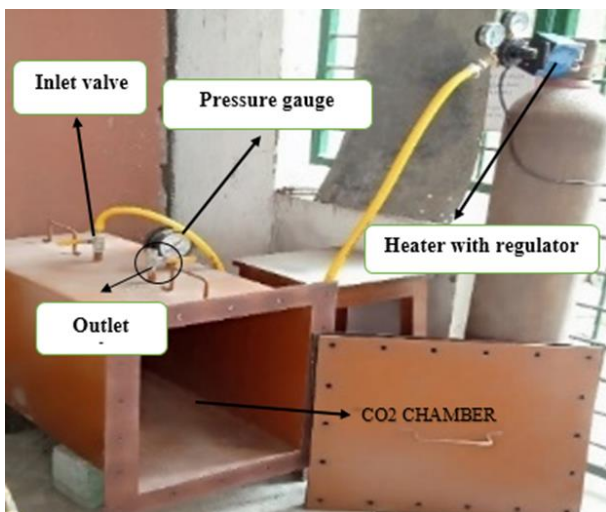


Figure 2. Carbon dioxide chamber

#### 3.2.3. Dry ice curing

The cubes, cylinders and prisms are cast and cured in dry

ice for a period of 8 hours as indicated in Fig. 3A. The specimens are placed in dry ice chamber and sealed tightly to avoid air entering inside and cured for 8 hrs. After curing these specimens are placed in seawater for 28 days, 90 days and 120 days for testing.



Figure 3. Dry ice curing

## 4. Results and Discussions

### 4.1. Tests on Fresh Concrete

To check the workability of concrete slump and compaction factor tests were conducted for freshly mixed concrete. Slum and compaction factor test results are 32mm and 0.94 respectively.

### 4.2. Tests on Hardened Concrete

The compressive strength split tensile strength, flexural strength of concrete specimens cured with water,  $\text{CO}_2$  gas and Dry ice samples were tested after 28 days, 90 days, 120 days of immersion in sea water.

#### 4.2.1. Compressive strength:

At 120 days of exposure to sea water the concrete mix made of 10% of silica fume, 5% Bagasse ash showed higher results compared to all other concrete mixes. For 5% of replacement, there is an increase in compressive strength up to 20.5% for water curing, 17.5% for gas curing and 17.8% for dry ice curing compared to conventional mix at 120days exposure to sea water. There is a decrease in compressive strength for a mix made with 15% replacement of cement with bagasse ash showed 11.6%, 17.5%, 12.8% for water, gas and dry ice curing compared to conventional mixes at 120 days in sea water. For 25% replacement, the strength decreased up to 23.9% for water, 34.6% for gas and 36.33% for dry Ice cured specimens compared with conventional mixes. Compared to water curing gas, dry ice curing showed less strength at a 120days period. Gas cured mixes showed strength loss of 2.5%. For 0% replacement, 5.9% for 5% replacement, 8.93% for 15% and 13.74% for 25% of replacement compared to water cured specimens. At 120 days of

exposure to seawater dry ice cured specimens showed strength loss of 4.5% for 0% replacement, 7.6% for 5% replacement, 8.8% for 15% replacement, 20.1% 25% replacement compared to water curing. Compared to dry ice curing, gas curing specimens showed a less strength loss and it was observed that there is an increase in loss of strength when the percentage of replacement increases. Fig. 4, Fig. 5 and Fig. 6 indicates the compressive strength of concrete cured with water, gas and sea water respectively.

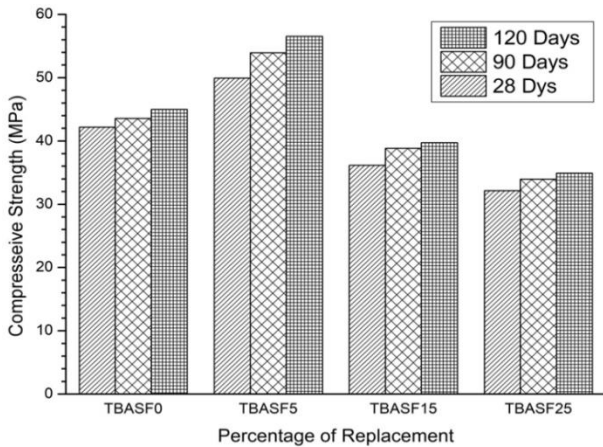


Figure 4. Compressive Strength of Water cured specimens

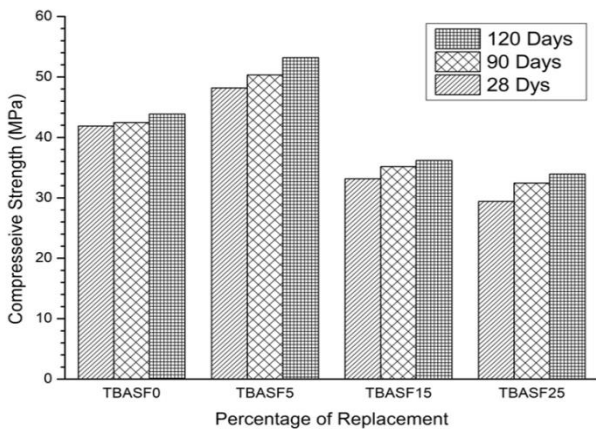


Figure 5. Compressive Strength of CO<sub>2</sub> gas cured specimens

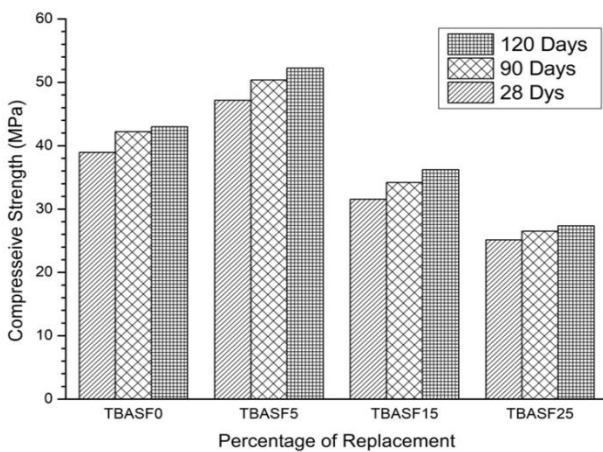


Figure 6. Compressive Strength of Dry Ice cured specimens

4.2.2. Split tensile strength

The split tensile strengths of the concrete for various percentages of SCBA are shown in Fig. 7, Fig. 8, and Fig.9. At 5% of replacement, the concrete specimens showed an increase in strength approximately 2%, 11%, 18% for water, gas, dry ice curing respectively compared to conventional mixes. For a replacement of 15% the strength was decreased approximately from 7% - 11%, 8% - 15%, 14% - 16% for water, gas, dry ice cured specimens respectively compared to conventional mixes. For the replacement of 25%, the water cured specimen's strength loss was ranged between 20%-22% compared to a conventional mix, 8% -20% loss was observed in gas curing compared with conventional mix of gas cured specimens and 18%-21% of strength loss was observed between conventional and bagasse ash 25% mixes cured with dry ice curing. Figure 7, 8 and 9 indicates the split tensile strength of concrete cured with water, gas and sea water respectively.

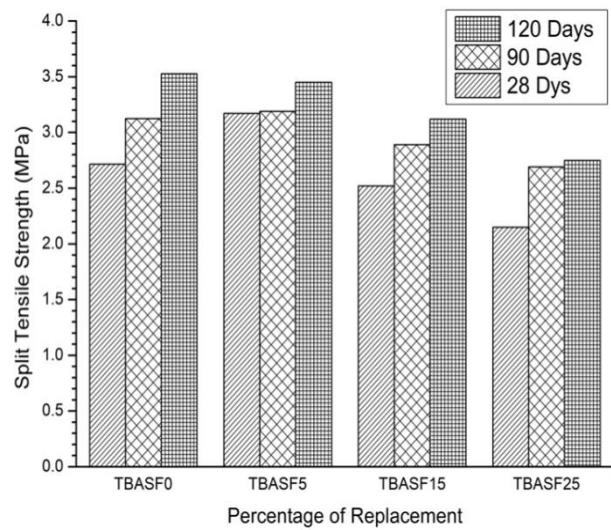


Figure 7. Split tensile strength of water cured specimens

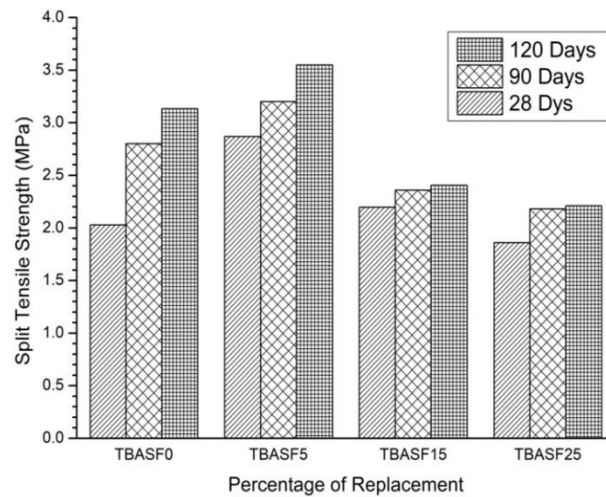


Figure 8. Split tensile strength of water CO<sub>2</sub> gas cured specimens

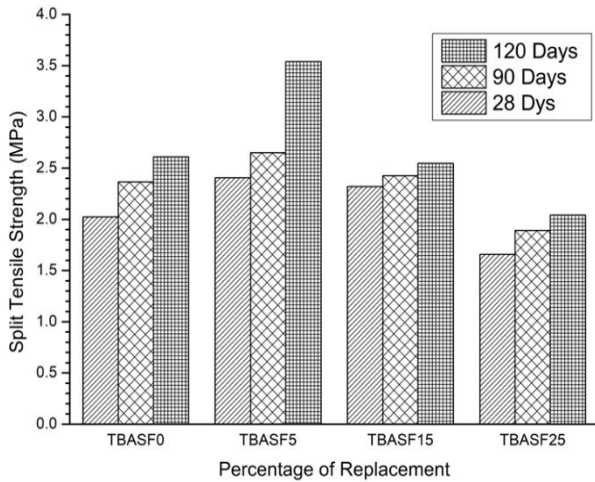


Figure 9. Split tensile strength of Dry ice cured specimens

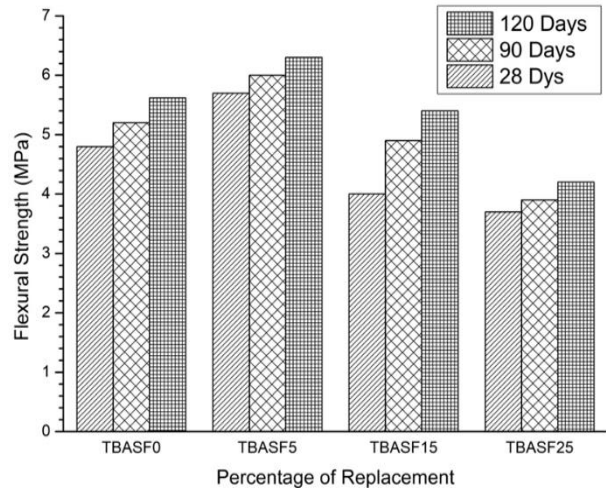


Figure 11. Flexural strength of CO<sub>2</sub> gas cured specimens

#### 4.2.3. Flexural strength

The flexural strengths of concrete specimens with various percentages of SCBA as shown in Fig. 10, Fig. 11, Fig. 12. It was observed that at 5% SCBA replacement there is an increase in strength approximately up to 7%-9% compared to a conventional mix cured in water, 10%-11% strength was increased for gas cured specimens compared with gas cured conventional mix and 10%-15% strength increased for dry ice cured concrete specimens compared with conventional concrete specimens cured with dry ice. For 15% replacement of cement with SCBA, the strength was decreased (4% for water cured specimens, 3% for gas cured specimens and 4% for dry ice cured specimens) at the age of 120 days. For 25% replacement of cement with SCBA, at the age of 120 days, there is a decrease in strength varies approximately 17% for water curing, 20% for gas curing, and 25% for dry ice curing specimens.

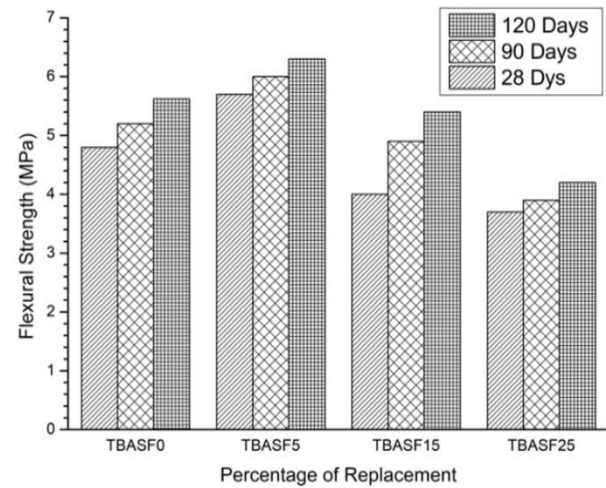


Figure 12. Flexural strength of Dry ice cured specimens

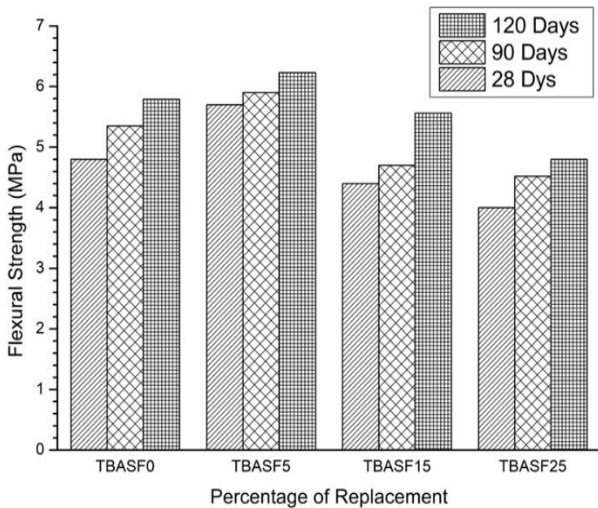


Figure 10. Flexural strength of water cured specimens.

## 5. Conclusions

Based on the above investigations, the following conclusions can be summarized as follows:

1. Due to the larger surface area of SCBA compared to cement particles, there is a decrease in workability as the percentage of replacement SCBA increases.
2. 8 hours of carbon dioxide curing achieved compressive strength compared to that of 28 days of conventional cured specimens.
3. There is 20.5% increase in compressive strength of concrete mix made of 5% SCBA, 10% silica fume replacement compared to conventional mix cured with water, 17.5% increase in compressive strength for 5% SCBA, 10% silica fume replaced mix compared to conventional gas cured mix and similarly 17.8% improvement was observed for dry ice cured specimens.
4. As the percentage of replacement increases, the strength loss also more.

5. At 120 days of seawater exposure the 15% SCBA concrete showed strength loss up to 20% where as 25% SCBA concrete showed up to 40% loss was observed.
6. The samples cured with water, CO<sub>2</sub> gas (8hrs) showed similar results. Whereas, dry ice cured samples showed less strength compared to CO<sub>2</sub> gas, Water cured mixes.

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