

Investigation on the behaviour of ternary blended concrete with scba and sf

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Abstract. It is a well-known fact that India is one of the countries with agriculture as its primary profession. In the recent past, many agro-based industries have been developed and they continue to grow. Sugarcane industry is one among them. With an increase in the number of industries, pollution of all sorts has also increased enormously. Sugarcane, which is heated after being used in the manufacture of sugar, leads to the formation of ash as an industrial waste known as Sugar Cane Bagasse Ash (SCBA). Since SCBA possesses pozzolanic properties, it can be used as a partial replacement for cement in concrete, in order to reduce the emission of Carbon dioxide (CO_2) into the atmosphere caused during the production of cement. In this current research, a Ternary Blended Concrete (TBC) comprising SCBA and Silica Fume (SF) as the replacement materials for cement has been taken up for study, subjecting it to the following two conditions: i) elevated temperature and ii) curing under sea water. The above parameters have been chosen so as to investigate the behavior of TBC with respect to its resistance to very high temperatures in the incidence of fire accidents and its suitability for construction in coastal areas. Specimens of concrete mixes were subjected to elevated temperatures followed by different cooling regimes; various tests were conducted on those specimens such as compressive test, shrinkage test and sorptivity test. TBC was found to exhibit better results in all such conditions.

1. Introduction:

Cement is the most energy-intensive material produced in the world, next only to steel and aluminium. Cement industry consume raw materials rich in silica, iron, calcium and aluminium. For this reason, it has been intensely involved in finding ways to use waste merchandises in the manufacture of cement, both as raw material and secondary fuel alike[1]. Sugar manufacturing process is one of the major agro industries in India. Initiatives are evolving worldwide to control and regulate the supervision of sub-products, residuals and industrial waste so as to preserve the environment from the point of view of contamination as well as the maintenance and care of natural eco-system[11,19]. In recent times the use of recycling materials as ingredients of concrete has been gaining familiarity because of inflexible environmental legislation. The most prominent among these is Sugar Cane Bagasse Ash (SCBA), obtained as a finely ground powder produced by burning the waste from the sugarcane industry[2].

Usage of Silica Fume (SF) as a Pozzolanic material has become widespread over the recent years, because, when used in certain percentages, it has proved to enhance various properties of concrete like cohesiveness, strength, permeability and durability both in the fresh as well as hardened states[12,18]. To enhance the concrete strength and obtain superior durability - due to its silica (SiO_2) content - SF



was selected as another mineral admixture which too acts as a replacement for cement[3]. The subsequent concrete mix is named as Ternary Blended Concrete (TBC).

Furthermore, in modern years, it is indispensable for dissimilar infrastructural establishments to embrace varying gradations of persistence heights, like confrontation to elevated temperatures, exposure to saline atmosphere, augmented wind speed, and so on[4,17]. In this regard, to meet those necessities, several developments to traditional concrete cement has become more essential[5,8]. In this regard, when concrete structures are exposed to environment and elevated temperatures, they undergo many conflicting changes in their physical properties like volume dissimilarities due to shrinkage, expansion and creep due to water loss, fracture and micro-cracking due to huge internal stress and thereby leading to loss of strength in the structure. Hence, the authors have taken up this work of experimentally studying the behaviour of TBC[7,9].

This research was carried out with single-mindedness on exposing specimens, made of different TBC mixes, to the effect of curing them in sea water, then exposing them to elevated temperature levels; finally, they were brought to the room temperature level with two different cooling regimes, viz., air cooling and water cooling[6,10].

2. Materials And Properties:

The materials that have gone into the making of TBC were initially tested for their physical and chemical properties so as to ensure their compatibility[8].

2.1 Cement:

Ordinary Portland Cement (OPC) with trade name India Cements - 53-grade was used for the entire work, preserving it in a dry place, exercising special care that it does not get affected by atmospheric moisture and humidity. The physical properties of cement are listed in Table 1.

Table 1. Physical properties of Cement

S No	PROPERTY	VALUE
1	Specific Gravity	3.15
2	Fineness of cement	8.55%
3	Soundness (Le-Chatlier Test)	3.8 mm
4	Setting Time	Initial
		Final
		180 min
		250 min

2.2 Sugarcane Bagasse Ash:

In the sugarcane industries, bagasse is itself is used as a main fuel in their boilers - obviously for economic reasons - to obtain outlet steam parameters of 87 kg/cm^2 and 515°C , which results in the formation of SCBA as a by-product. SCBA taken from NCS Sugarcane Limited, located at Bobbili in the state of Andhra Pradesh has been used in this research work. Later on, it was pulverized in a ball mill to bring it to less than the fineness of cement. Table 2 depicts the physical properties of SCBA.

Table 2. Physical Properties of SCBA

S. No	PROPERTY	VALUE
1	Density (kg/m^3)	578
2	Specific gravity	2.6
3	Mean size particle	$0.11\text{-}0.21\mu\text{m}$
4	Mean specific area	$2450\text{m}^2/\text{kg}$
5	Particle shape	Spherical

2.3 Silica Fume:

Silica fume is a vague (non-crystalline) polymorph of SiO_2 . SF is collected as a by-product of the ferrosilicon and silicon alloy production. Due to its ultrafine nature, consisting of particles which are spherical in shape with an average diameter of 150 nm, it exhibits pozzolanic properties. Hence, it is widely used as cement replacement in the manufacture of concrete. In table 3 the physical properties are listed down in Table 3.

Table 3. Physical properties of silica fume

S. NO.	PROPERTY	VALUE
1.	Specific Surface	20 cm^2/gm
2.	Bulk Density (kg/m^3)	600 – 640
3.	Specific Gravity	1.8

2.4 Coarse Aggregate:

Locally available crushed granite, sieved through a 20 mm sieve, was used as the coarse aggregate. It was then washed to remove dust and dirt, and dried under surface dry conditions. The aggregates were tested as per the Indian Standard Specifications IS: 383-1970. The properties of the coarse aggregate used for this research are listed down in Table 4.

Table 4. Properties of Coarse Aggregate

S. No	PROPERTY	VALUE
1	Specific gravity	2.64
2	Water absorption	3.72%
3	Fineness modulus	7.3

2.5 Fine Aggregate:

River sand which was available locally, conforming to Zone-II of IS 383-1970 standards, has been used as fine aggregate throughout this experimental work. It was ensured that the fine aggregate was inert, clean and free from any carbon-based matter, silt and clay. Its properties are shown in Table 5.

Table 5. Properties of Fine aggregate

S. No.	PROPERTY	VALUE
1	Specific gravity	2.62
2	Fineness modulus	2.69

2.6 Sea Water:

Sea water, free from oil and organic matter, was collected from Rushikonda located in Visakhapatnam, India. Its pH value was 8.04 implying that it is alkaline; and its salinity was 17.6. The pH of sea water was maintained constant throughout the curing period.

2.7 Chemical Admixture:

To achieve good workability of concrete, the super plasticizer Conplast SP-430 obtained from Astrra Chemicals, Chennai was used[13,17]. The specific gravity was varying from 1.220 to 1.225 at 30°C in the absence of chloride. The various physical properties of Conplast SP- 430, as provided by the supplier, are as listed in Table 6.

Table 6. Properties of Conplast SP-430

S. No.	Description	Property
1	Appearance	Brown liquid
2	Specific Gravity (BSEN 934-2)	1.18
3	Water soluble chloride (BSEN 934-2)	Nil
4	Alkali content (BSEN 934-2)	Typically < 55g. Na ₂ O-equivalent/ litre of admixture

3. Experimental Procedure

3.1 Mix Proportioning:

The experimental part of this research work has been carried out by partially replacing cement with SCBA and SF [14,16]. The mix design of M25 grade of concrete was made using IS: 10262:2009. The chosen water cement (w/c) ratio was 0.48. The air entrained in the mix was approximately taken as 1%. The mix proportion of concrete thus arrived at is given in Table 7.

Table 7. Mix proportion of ternary blended concrete

Cement (kg)	SCBA (kg)	CA (kg)	FA (kg)	Water (litres)
350	-	1221.2	738.2	164

3.2 Casting of specimens:

With the above mix ratio, the materials were weighed, mixed in the mixing machine, while adding water and SP for different replacement levels; the mix thus obtained was cast into specimens of standard sizes using steel moulds [15]. The slump was found to be 50-75mm for fresh concrete. Curing of the specimens was taken up by demoulding them after 24 hours. The nomenclature followed in this literature for the specimens of various replacement levels of SBCA and SF is listed in Table 8.

Table 8. Quantity of cement replaced

Specimen Series	% Replacement of	
	SCBA	SF
A	0%	0%
B	5%	10%
C	10%	10%
D	15%	10%
E	20%	10%
F	25%	10%
G	30%	10%

Following were the different kinds of specimens prepared, and subjected to various tests. A total of 570 cubes of (150 x 150 x 150) mm were cast for the different replacements which are to be exposed to different temperature levels. For the case of sea water curing, 90 numbers of cube specimens of the same size were cast. For testing the shrinkage values of TBC, a total of 90 beam specimens of size (150 x 75 x 75) mm were cast. For finding the sorptivity values of TBC, a total of 90 cube specimens of size (75 x 75 x 75) mm were primed. The process of casting of specimens is illustrated in Fig. 1.



Figure 1: Casting of TBC specimens

3.3 Exposure to Elevated temperatures:

For subjecting them to elevated temperatures, the cube specimens, after having been cured for 28 days, were kept in the bogie furnace and exposed to the temperature levels of 200°C , 300°C , 500°C and 700°C for one hour each. After having taken out from bogie furnace, they were set for cooling in different cooling regimes such as air cooling and water cooling[11]. For air cooling, the cube specimens were allowed to cool naturally and for water cooling they were cooled by spraying water on them. The process of exposure to high temperatures has been depicted in Fig. 2(a).



Figure 2: Experimental Setup

3.4 Sea-water curing:

To understand the compatibility of TBC for applications in marine environments, the cube specimens, after being cured for 28 days, were taken to sea water curing for 28 days. Immediately after the curing, the specimens were subjected to testing for compressive strength. Sea water curing is illustrated in Fig. 2(c).

3.5 Shrinkage Test:

After demoulding, the samples were preserved in water curing for 7 days for enabling an early reading[15]. Thereafter, they were kept in aeration so that the amount of shrinkage of concrete can be observed as its age increases. With the help of shrinkage apparatus, as shown in Fig. 2(d), the amount of increase in shrinkage was calculated. The readings were taken for 7, 28 and 56 days and the values are illustrated in Fig. 5.

3.6 Sorptivity Test:

Sorptivity of the concrete material can be found by measuring the capillary rise absorption rate on practically homogeneous material. In this test the water was used as the test fluid. The cubes are primed and were immersed in water for 28 days' curing[18]. Specimens of size 70 mm × 70 mm × 70 mm, after they are dried either in an oven at a temperature rate of 85°C or in sunlight, the specimens are immersed in water, maintaining the water level with not more than a 5 mm above the base of the specimen.

Flow of water from the marginal surface was prevented, by sealing the specimen appropriately with either a non-absorbent plaster or coating[12]. The amount of water absorbed at a time period of 30 minutes was noted by placing the specimen on top pan balance which can weigh up to an accuracy level of 0.1 mg. The surface water in the specimen was wiped off within 30 seconds with a dampened tissue. The experimental setup for the sorptivity test is shown in Fig. 2(b).

4. Results and Discussions:

From Fig. 3 and Fig. 4, it is obvious that for the replacement of 15% OPC with SCBA and SF, the concrete shows better densification, which leads to liberation of moisture being lesser as compared with others. The specimens cooled under the air cooling regime have proved to demonstrate better endurance properties when compared to those which underwent water cooling; this is due to the sudden thermal shock absorbed by them.

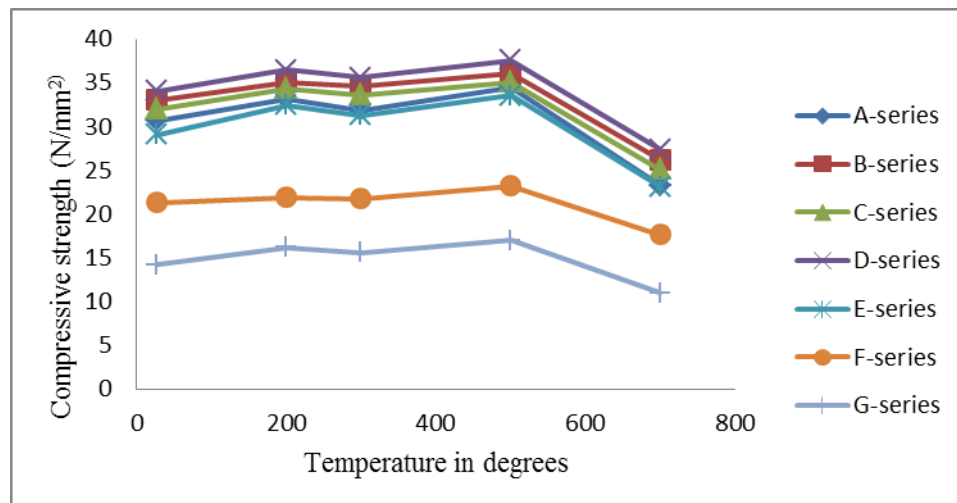


Figure 3: Compressive strength results for air-cooled specimens

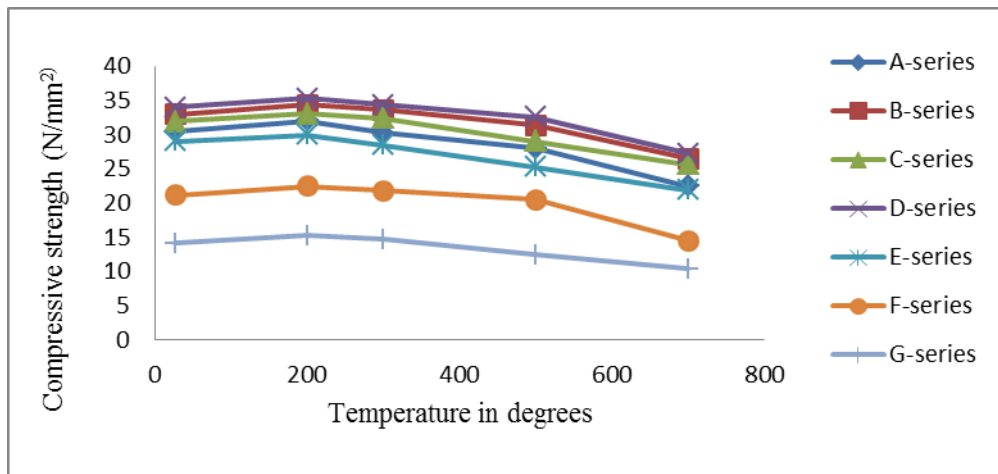


Figure 4: Compressive strength results for water-cooled specimens

Fig. 5 shows the change in length of the specimens as an effect of the drying conditions. Dampness is the most diffusing aspect of concrete to shrink; with an upsurge of time, rate at which shrinkage strain also increases. With cumulative percentage increment of SCBA and SF the amount of shrinkage is reduced.

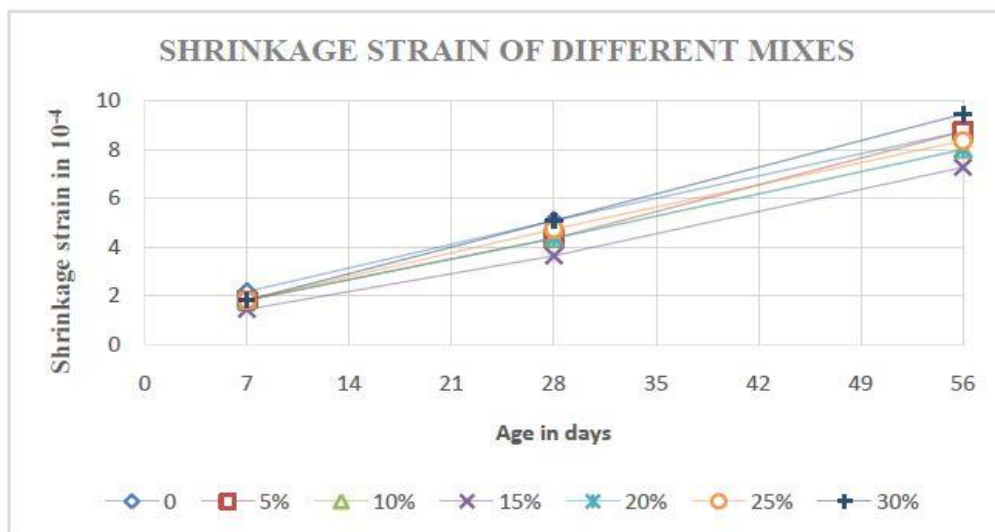


Figure 5: Shrinkage strain of all series

From Fig. 6, we could observe that compressive strength of concrete cured under normal cold water at the stages of 7th day and 28th day have shown an increase[8,10]. Those specimens which were cured in sea water have shown better performance at 7 days than those cured in normal water, whereas during the 28th day, those specimens which were cured under sea water have exhibited lesser strength than those cured using normal water.

The destructive salt ions breach into the inner portion of concrete mass and lead to a change in the mechanism of hydration process with the materialization of some vast products such as ettringite salt and also some soft composites[9]. As a result, development of micro cracks within the concrete mass, together with percolating action of newly formed composites, takes place. This eventually leads to the reduced strength, thereby resulting in the weakening of the concrete specimens in sea water environment.

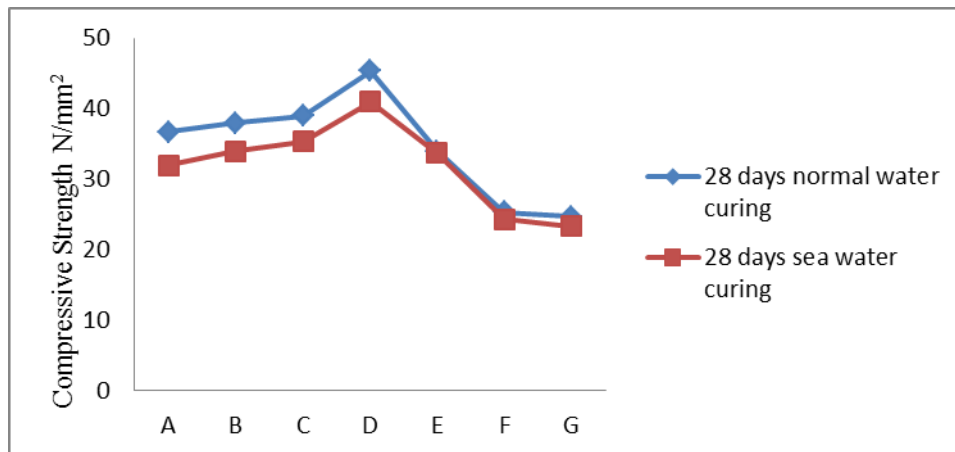


Figure 6: Comparison of compressive strength of normal water and seawater curing

A closer examination of Fig. 7 reveals the fact that TBC specimens with replacement of cement by SCBA and SF display lower sorptivity and increased water absorption levels than the traditional concrete specimens. Lower sorptivity leads to higher compressive strength owing to the formation of calcium hydroxide stored in the openings, which leads to denser matrix[1,15]. Durability of concrete is the key in destructive environments for an everlasting life. This might be the cause for the better strength results exhibited by the D-series specimens as they have lower sorptivity values.

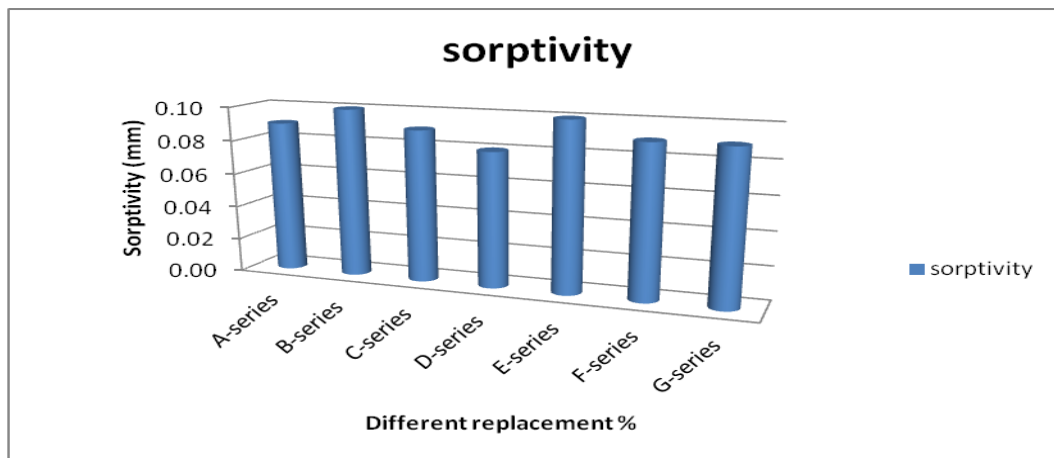


Figure 7: Sorptivity test results at 28 days

5. Conclusions:

1. From the current research, replacement of TBC at 15% SCBA and 10% SF (D-series) shows better strength properties when exposed to all the specified temperature conditions, viz., 200⁰ C, 300⁰ C, 500⁰ C and 700⁰ C.
2. For elevated temperatures in the range of 500⁰ C, under the air cooling regime and in the range of 200⁰ C for water cooling regime, TBC shows the highest compressive strength values.
3. The percentage decrease in sorptivity is found to be 0.08 mm/min^{0.5} at 28 days of curing and 0.04 mm/min^{0.5} at 60 days of curing.
4. Lower sorptivity values imply improved strength properties for TBC with the replacement of 15% SCBA and 10% SF (D-Series).

5. The 28-day compressive strength has been found to have increased by 24% for the mix containing 15% SCBA and 10% SF as replacement for cement, i.e., the D-series, when compared to the control mix for cubes cured in sea water.
6. TBC at replacement of 15% SCBA and 10% SF, namely, the D-series for OPC has shown better performance at all the ages in terms of the shrinkage strain effect.
7. Eventually, it is strongly recommended that TBC with replacement of 15% SCBA and 10% SF can be used for the contemporary constructional purposes as it has the following features:
 - It has high tolerance to elevated temperatures, thereby making it more suited to residential as well as commercial constructions where incidence of fire accidents is high.
 - It is better suited for constructions in the marine environments due to its robustness under sea water conditions.
 - This process serves as a good waste management mechanism.
 - It can serve as a preferred choice for economical construction.
 - Above all these, it can help in the reduction of carbon foot-print by making the cement manufacturing process more environment-friendly.

6. References:

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