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DEVELOPMENT OF SUSTAINABLE CONCRETE BY INCORPORATING SUGARCANE BAGASSE ASH AND STONE DUST

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Abstract: This study presents the mechanical behaviour and durability properties of environment-friendly M25 grade concrete by partial replacement of Ordinary Portland Cement (OPC) with Sugarcane Bagasse Ash (SCBA) and replacement of fine aggregate with Stone Dust. The workability, compressive strength and water absorption capacity of concrete mixes were determined from the cube specimens with different percentages of replacement (4-16%). The decrease in workability was observed due to the angular shape and absorption characteristics of the SCBA and Stone Dust. On the other hand, the ternary blended concrete with 8% SCBA and 12% Stone Dust replacement showed improved compressive strength, reaching 37.34 MPa at 28 days compared to 32.59 MPa for the reference mix. It was found that the combination of the pozzolanic activity of SCBA and the micro-filling ability of Stone Dust contributed to the production of additional C-S-H gel, resulting in enhanced mechanical properties and reduced water absorption capacity of the ternary blended concrete. Thus, due to its positive characteristics, this ternary blended concrete can be considered as a potential construction material for the modern building and construction industry.

Keywords: Sugarcane Bagasse Ash, Stone Dust, Sustainable concrete, Agricultural/Industrial waste material.

1. INTRODUCTION

The global construction industry encounters a tremendous challenge at present: meeting the growing need for infrastructure while reducing the industry's impact on the environment. Concrete has been the most common construction material used throughout the construction industry. The production of OPC is highly energy-intensive, and it emits large amounts of carbon dioxide into the atmosphere. It is well known that the production of concrete emits a lot of carbon into the air, contributing to climate change. Researchers are currently looking into alternative sustainable concrete products. These materials employ industrial and agricultural by-products as replacements for some of the raw materials in concrete production.

Two such materials that have the potential to partially replace cement in concrete production are Sugarcane Bagasse Ash and Stone Dust. Bagasse Ash, which is obtained by burning bagasse, has been found to have a high degree of pozzolanic activity and can be used as an alternative to cement. Bagasse is a fibrous waste material generated as a by-product during sugar extraction from sugarcane. Stone Dust, on the other hand, is produced as a by-product during the crushing of aggregates and may be utilised as a substitute for river sand.

1.1 Sugarcane Ash in Concrete

In the search for better, high-performance, and environment-friendly concrete, Sugarcane Bagasse Ash is a new alternative material. Previously considered as industrial waste, SCBA has the ability to transform into a great supplementary cementitious material that can alter ordinary concrete into an advanced and enhanced construction composite.

Further down the line, the fineness of SCBA, when ground down to a specific level and added to cement, reacts with calcium hydroxide that is generated during hydration to create additional calcium silicate hydrate gel. As a result, the compressive strength of concrete increases progressively over time. Moreover, the microstructure of concrete is modified due to the inclusion of SCBA, leading to a reduction in the overall porosity and permeability of the material. As a result, concrete with SCBA becomes more resistant and durable than the original version.

In addition, due to the reduction of cement content in concrete, a significant amount of greenhouse gas emissions is reduced, making it a more environmentally friendly building material.

1.2 Stone Dust as Fine Aggregate Replacement

Stone dust, a by-product generated during the stone crushing process in quarries, is often discarded into landfills as waste. However, it contains fine particles which can be utilised in concrete to fill the voids in concrete, hence increasing the density and reducing the porosity.

It is an effective method to replace a portion of natural sand with stone dust since

- It can improve the particle size distribution and reduce the voids content in the resulting fresh concrete;
- Improve the compressive strength of hardened concrete because of the higher packing density;
- Prevent the bleeding and segregation of concrete;
- Reduce the cost and conserve the use of natural sand and help to recycle the industrial wastes.

Moreover, the over-exploitation of river sand has led to environmental pollution and has been restricted by the government recently.

1.3 Combined Use of Sugarcane Ash, Stone Dust

The utilisation of Sugarcane Bagasse Ash (SCBA) and Stone Dust in concrete can be viewed as a way of producing a ternary blend, which is not only high-performing but also eco-friendly. Here, SCBA acts as a Supplementary Cementitious Material (SCM), whereas Stone Dust serves as a sustainable alternative to natural fine aggregates.

In terms of benefits, their joint use in concrete production can be linked to both the pozzolanic and the filler effect, which are explained by the fact that the reactive Silicon dioxide (SiO_2) of SCBA consumes Calcium Hydroxide [$Ca(OH)_2$] from the cement paste, thus generating additional Calcium Silicate Hydrate (C-S-H) gel. Meanwhile, the ultrafine particles of Stone Dust fill the gaps between larger sand grains.

Studies show that the most efficient way is to replace 10-15% of cement with SCBA and 20-40% of sand with Stone Dust.

Although the high specific surface of these materials can lead to increased water demand, their use in concrete production is often associated with improved compressive strength and reduced permeability.

Moreover, this practice helps to divert significant volumes of agricultural and industrial waste from landfills as well as conserve natural resources such as sand and gravel, making it a highly sustainable solution for modern construction.

2. Research Gap Identification

Although there is a growing body of literature on the topic of waste utilisation in construction, there are several gaps in information regarding the concurrent application of Sugarcane Bagasse Ash (SCBA) and Stone Dust in high-performance concrete.

Firstly, the majority of the research conducted so far has focused on the impact of these materials used in two combinations only: as a replacement for cement or sand. Consequently, there is insufficient data pertaining to the combined effects of SCBA and Stone Dust in a ternary mix.

In particular, information regarding the interplay of the pozzolanic activity of SCBA and the micro-filling potential of Stone Dust is required to identify the optimal mixture.

Additionally, long-term durability data are lacking, as are data on increases in mechanical strength, workability, and sorptivity for this particular combination. Lastly, many researchers tend to utilise laboratory-grade materials, but the impact of different calcination temperatures of SCBA and the variations in the mineralogy of Stone Dust from different geological settings are of interest to bridge the gap between academic research and the industrial application of recycled materials.

3. Objectives of the Research:

The main objective of this study is to evaluate the workability and the performance of a sustainable concrete produced by partial replacement of Ordinary Portland Cement (OPC) with Sugarcane Bagasse Ash (SCBA) and replacement of fine natural sand with Stone Dust.

The specific objectives of the study are:

1. To assess the fresh-state workability and flow characteristics of the concrete mixes.
2. To examine the effect of using SCBA and Stone Dust as waste material on the hardened properties of concrete.
3. To evaluate the durability and refinement of capillary pores in the developed concrete mixes; their unidirectional water absorption properties were measured using the sorptivity test.

4. Experimental Investigation and Methodology

4.1 Experimental Design

The experimental study focuses on the effect of sugarcane ash and stone dust on the physical properties of the concrete. The major objective of this experiment is to design the control and modified mix of M25 grade concrete and analyse their properties, both fresh and hardened, and later evaluate the strength of the concrete by performing some tests. The study consisted of cube samples prepared according to the IS and ASTM standards. The experiments included the replacement of sugarcane ash with 4%,8%, 12%, and 16% of fine aggregate, and the substitution of sand by stone dust with 4%, 8%, 12%, and 16% by weight of cement. Through these experimental trials and calculations, the research aims to identify the maximum use of waste materials and the best proportion that would provide the concrete with improved safety and soundness quality.

4.2 Material Collection and its Properties

This research work describes the proportions of M25, consisting of cement, fine aggregates, and coarse aggregate. In this mix design, a portion of the cement is replaced with sugarcane ash, and Natural River sand is partially replaced with stone dust, among other alternatives. Below are the details of all the materials used in the research work, including the properties and the materials required to prepare the samples.

4.2.1 Cement

Cement is a binding material that is obtained by calcining lime and clay, which are later mixed with water and sand to yield mortar or mixed with sand, aggregates, and water to yield concrete. It is a binding material generally used in construction to bind the aggregate. The raw materials used in cement production are limestone, shells, chalk, or marl, and clay, slate, shale, iron oxide, and silica sand. The main ingredients in cement are clay and limestone because they contain the required amount of silicates and aluminates of lime.

The raw materials are heated to 14000C in a rotary kiln to produce hard cylindrical aggregates called clinkers. The clinkers are then ground and mixed with gypsum to produce cement. About 2-4% of gypsum is added to the clinkers. The cement produced is called ordinary Portland cement (OPC). The BIS classifies cement into OPC, Rapid Hardening Cement, Portland Pozzolana, Hydrophobic Portland Cement, Portland Slag Cement, Sulphate Resisting Cement, and Low Heat Portland Cement.

The current study used OPC 43 grade cement, which conforms to IS 8112:2013. The OPC is divided into three grades: OPC grade 33, OPC grade 43, and OPC grade 53. The grade of cement indicates the strength of the cement in megapascals (MPa) after 28 days of setting. The properties of OPC are discussed below.

Table 4.2.1 Properties of Cement

S.No.	Description	Values Obtained	Requirement as per IS 1489 (Part 1): 1991
1.	Specific Gravity	3.15	3.12-3.16
2.	Consistency	32%	26%-33%

4.2.2 Fine aggregates

In this study, fine aggregate was obtained from Pathankot sand from a local building material supplier in Amritsar. Prior to its use in the concrete mixes, the sand was tested for physical properties and suitability for structural concrete. The tests were done by sieve analysis, specific gravity, fineness modulus, and grading zone in accordance with IS:383-1970. In this case, it was found that the sand met the standard requirements for concrete. Its particle size, grading, cleanliness, and other qualities were suitable for the concrete mixes for workability, strength, and overall performance.

Table 4.2.2 Properties of Fine Aggregate

S.No.	Description	Values Obtained
1.	Specific Gravity	2.63
2.	Fineness Modulus	2.90
3.	Zone	II

4.2.3 Sieve Analysis of Fine Aggregate

In this research work, in order to determine the fineness modulus of the sand and to perform the grading sieve analysis has been carried out. For this purpose, IS 383:1970 has been followed. In the process of sieve analysis 2kg sand was taken and passed through different sieves having aperture sizes of 4.75 mm, 2.36 mm, 1.18 mm, 600 micron, 300 micron, and 150 micron. For shaking the sand automatically shaker was used. After the sand has been shaken, the retained mass on each sieve was weighed, and the necessary calculation was carried out. Sieve analysis of the fine aggregate is presented in Table 4.2.3

Table 4.2.3 Sieve Analysis for Fine Aggregate

S. No.	Sieve Size	Retained Mass in Sieve (gm)	% Retained in Sieve	% Passes through Sieve	Accumulated % retained in Sieve
1.	4.75mm	48	2.4	97.6	2.4
2.	2.36mm	262	13.1	84.5	15.5
3.	1.18mm	528	26.4	58.1	41.9
4.	600µm	266	13.3	44.8	55.2
5.	300µm	648	32.4	12.4	87.6
6.	150µm	186	9.2	3.2	96.5

7.	Pan	64	3.2	-	-
Total accumulated % retained in sieve					299.4

4.2.4 Coarse Aggregates

The coarse aggregates used were procured from a local material supplier in Amritsar. Crushed stone aggregates were selected with particle sizes ranging from 10-20 mm to ensure good interlocking. The aggregates were cleaned and tested for inherent physical properties such as specific gravity and water absorption to check their suitability and uniformity for concrete production and to ensure consistency of all test specimens.

Table 4.2.4 Properties of Coarse Aggregate

S. No.	Description	Values Obtained
1.	Type	Crushed
2.	Specific Gravity	2.65
3.	Fineness Modulus	7.20
4.	Maximum Size	20mm

4.2.5 Sugarcane Bagasse Ash

Sugarcane ash, often referred to as Sugarcane Bagasse Ash (SCBA), is an agricultural by-product resulting from the sugar industry's controlled incineration of bagasse, a fibrous residue left over after sugar juice extraction. Significant amounts of this by-product are formed annually in boilers via the burning process of bagasse as fuel for electricity generation. Previously regarded as waste, SCBA has attracted scientific attention in concrete studies due to its possible pozzolanic properties.

As stated in the thesis, SCBA is a fine powder consisting of amorphous silica that can participate in cementitious processes by virtue of its ability to react with calcium hydroxide released during cement hydration to produce calcium silicate hydrate gel that improves concrete's properties. Furthermore, with an appropriate amount of drying, sieving, and grinding, this industrial waste may be utilised as a cement replacement in concrete production.

Table 4.2.5 Properties of Sugarcane Bagasse Ash

Property	Value
Specific gravity	2.3
Appearance	Grey powder

Table 4.2.5 Composition of Sugarcane Bagasse Ash

Oxide	Percentage
SiO_2	78.34
Al_2O_3	8.55
Fe_2O_3	3.61

CaO	2.15
Na_2O	0.12
MnO	0.13
TiO_2	0.50
MgO	1.65
BaO	<0.16
P_2O_5	1.07
K_2O	3.46

4.2.6 Stone Dust

The use of the dust from the stone is increasing as a partial replacement for sand in concrete because of its positive contribution to the concrete's qualities, like sustainability, cost, and strength. The fine particles of the dust fill the voids and gaps, increasing the concrete's strength. Moreover, the dust reduces negative effects on the environment by using it as quarry waste instead of sand and improving the concrete's properties.

Table 4.2.6 Properties of Stone Dust

Property	Value
Specific gravity	2.62
Fineness Modulus	2.42
Appearance	Brown

4.3 PREPARATION OF SAMPLES

4.3.1 Mix Design

The concrete mix was decided as M25 grade according to the guidelines and procedures followed in IS:10262–2009. The proportions of the mix were finalised by conducting multiple trial mixes to obtain the desired workability, target strength and durability. In this experimental program, 126 concrete cube specimens were cast and tested for Slump, Compressive Strength, and sorptivity tests to meet the objective of the study and get assured experimental results.

Table 4.3.1 Design proportion of M25 grade

Water-cement ratio	Cement	Fine Aggregate	Coarse Aggregate
0.5	1	1.9	2.8

4.3.2 Mixing of Concrete

The batching of different concrete ingredients is done to ensure homogeneity of the final product. Proper mixing ensures good lubrication of aggregates by cement paste. Concrete can be mixed by hand or by machine. The types of machine mixers used include pan mixers, tilting mixers and non-tilting mixers.

In the concrete mixing process, different materials such as cement, fine aggregates, coarse aggregates, sugarcane ash, and stone dust are batched into the mixer in proportion and rotated at a given speed. Water is added intermittently during the mixing process to achieve a homogeneous mix. The mixer is run until all materials are blended thoroughly to form a homogeneous concrete mixture.

4.3.3 Casting

Before the commencement of sample casting, it is essential to make sure that the metal moulds (150x150x150mm) are properly tightened to avoid leaking during the concrete pouring process. After tightening the moulds, they need to be cleaned and oiled. Finally, the concrete mix was poured into the moulds in three layers.

To achieve homogeneity of the mixture, a tilting-type mixer or hand mixing as described above was used. After casting, the specimens were demoulded 24 hours later and cured in water for 28 days at a temperature of 27 ° C in the laboratory.

4.4 Testing Procedures

4.4.1 Slump Test

Fresh concrete without any support tends to slump down due to its weight, causing loss of height. This loss in height is called slump. In this test, freshly prepared concrete is placed in a mould of a specific shape and size. Slump is measured by placing the mould with concrete at the desired position and removing the mould. Slump increases with an increase in the quantity of water. Different works require different slumps, as have been listed in the Table.

Slump is the measure of consistency, or workability of cement concrete. Slump gives us an idea of how much water is required in different Works. A workable concrete mix is the one that can be easily mixed, placed, consolidated and finished. Slump is a good indicator of workability. Workability should be such that no segregation and bleeding take place. Segregation is when coarse aggregates try to separate from the mix and settle down at one point, leaving behind finer material. Bleeding is when excess water present in the mix rises up, making tiny pores all over the concrete, which is not desirable.

4.4.2 Compressive Strength Test

Assessment of the compressive strength of concrete is of great importance as an indicator of quality. The rest of the strengths are defined as a percentage of the compressive strength, which is measured in kg/cm^2.

This method is beneficial when carrying out preliminary compression tests to evaluate the available materials or to define the appropriate maximum portions. The concrete being tested should not have a single aggregate size larger than 38 mm. Test specimens can be either 15 cm cubes or 7 cm cubes. When the maximum nominal aggregate size is 20 mm or lower, 10 cm cubes can also be used. At least 3 specimens should be formed for testing. Any time cubes are used to define the compressive strength, their strength can be calculated as follows.

"Minimum cube compressive strength is equal to 0.8 times the compressive strength specified for a 15 cm cube." Concrete specimens are usually tested at 7 days of age and 28 days of age.

4.4.3 Sorptivity Test

The sorptivity test procedure for a standard concrete cube of size 150×150×150 will be performed to examine the capillary suction of the specimen. Initially, the moist cube is heated to a constant mass at a temperature of 50°C to 105°C in a ventilated oven and then cooled in a desiccator. The four sides of the cube need to be covered with epoxy or waterproof tape so that moisture can penetrate into the concrete only in one direction to measure the one-dimensional capillary suction. The cube is placed on end on small pins mounted on a shallow water-filled tray so that only the bottom edge of the specimen is immersed in water. The sample should be removed, blotted, and reweighed at defined times after immersion, beginning at 1 min up to several hours, to evaluate the liquid absorption. A plot of the cumulative water absorbed per unit area of contact vs. the square root of time provides a straight line from which the slope defines the sorptivity coefficient. The lower absorption rate indicates a well-graded capillary structure of high resistance to the ingress of aggressive solutions.

4.5 Data Collection and Analysis

A statistical analysis is carried out to evaluate variations in strength, durability and workability. Three sets of the same specimens are prepared for the tests that will follow: -

Sr No.	Concrete Type	No. of cube specimens for potable water curing	Remarks
1.	Normal Mix	6	For 7,28-days Testing
2.	Replacement of Cement with 4% of SCBA	6	For 7,28-days Testing
3.	Replacement of Cement with 8% of SCBA	6	For 7,28-days Testing
4.	Replacement of Cement with 12% of SCBA	6	For 7,28-days Testing
5.	Replacement of Cement with 16% of SCBA	6	For 28-days Testing
6.	Replacement of Sand with 4% of Stone Dust	6	For 7,28-days Testing
7.	Replacement of Sand with 8% of Stone Dust	6	For 7,28-days Testing
8.	Replacement of Sand with 12% of Stone Dust	6	For 7,28-days Testing
9.	Replacement of Sand with 16% of Stone Dust	6	For 7,28-days Testing
10.	Combined Replacement of Cement and Sand with a variation of 4% SCBA and 4% Stone Dust	6	For 7,28-days Testing
11.	Combined Replacement of Cement and Sand with a variation of 4% SCBA and 8% Stone Dust	6	For 7,28-days Testing
12	Combined Replacement of Cement and Sand with a variation of 4% SCBA and 12% Stone Dust	6	For 7,28-days Testing
13.	Combined Replacement of Cement and Sand with a variation of 4% SCBA and 16% Stone Dust	6	For 7,28-days Testing
14.	Combined Replacement of Cement and Sand with a variation of 8% SCBA and 4% Stone Dust	6	For 7,28-days Testing
15.	Combined Replacement of Cement and Sand with a variation of 8% SCBA and 8% Stone Dust	6	For 7,28-days Testing

16.	Combined Replacement of Cement and Sand with a variation of 8% SCBA and 12% Stone Dust	6	For 7,28-days Testing
17.	Combined Replacement of Cement and Sand with a variation of 8% SCBA and 16% Stone Dust	6	For 7,28-days Testing
18.	Combined Replacement of Cement and Sand with a variation of 12% SCBA and 4% Stone Dust	6	For 7,28-days Testing
19.	Combined Replacement of Cement and Sand with a variation of 12% SCBA and 8% Stone Dust	6	For 7,28-days Testing
20.	Combined Replacement of Cement and Sand with a variation of 12% SCBA and 12% Stone Dust	6	For 7,28-days Testing
21.	Combined Replacement of Cement and Sand with a variation of 12% SCBA and 16% Stone Dust	6	For 7,28-days Testing
22.	Combined Replacement of Cement and Sand with a variation of 16% SCBA and 4% Stone Dust	6	For 7,28-days Testing
23.	Combined Replacement of Cement and Sand with a variation of 16% SCBA and 8% Stone Dust	6	For 7,28-days Testing
24.	Combined Replacement of Cement and Sand with a variation of 16% SCBA and 12% Stone Dust	6	For 7,28-days Testing
25.	Combined Replacement of Cement and Sand with a variation of 16% SCBA and 16% Stone Dust	6	For 7,28-days Testing

5. Results and Discussion

5.1 Slump Test Results: The combined substitution of 8% SCBA and 12% stone dust decreases the workability of cement concrete from 95 mm to 73 mm due to the high water absorption capacity and angularity of stone dust, but results in a cohesive true slump that can be fully recovered with a slight addition of superplasticiser.

Table 5.1 Slump Test Results

Mix Designation	Cement Replacement (% SCBA)	Fine Aggregate Replacement (% Stone Dust)	Measured Slump (mm)	Degree of Workability
Control (CM)	0%	0%	95	Medium
SCBA-8	8%	0%	82	Medium
SD-12	0%	12%	86	Medium
Combined (8% SCBA + 12% SD)	8%	12%	73	Medium

5.2 Compressive Strength Test Results: -

The highest compressive strength was obtained at the maximum percentage of 8% cement replacement with SCBA and 12% sand replacement with stone dust, which amounts to 24.88 MPa at 7 days and 37.34 MPa at 28 days, compared to 21.64 MPa and 32.59 MPa of the normal mix.

Table 5.2 Compressive Strength Test Results

Sr No.	Concrete Type	No. of cube specimens for potable water curing	For 7-day testing (N/mm^2)				For 28-day testing (N/mm^2)			
			1	2	3	Average	1	2	3	Average
1	Normal Mix	6	21.01	21.64	21.55	**21.64**	31.99	32.59	32.47	**32.59**
2	Replacement of Cement with 4% of SCBA	6	21.65	22.1	22.55	**22.1**	32.57	33.55	33.48	**33.55**
3	Replacement of Cement with 8% SCBA	6	22.73	23.21	23.21	**23.21**	33.96	34.99	34.85	**34.96**
4	Replacement of Cement with 12% SCBA	6	20.25	20.51	20.74	**20.51**	30.22	30.87	31.31	**30.87**
5	Replacement of Cement with 16% SCBA	6	18.19	18.71	18.9	**18.71**	27.42	28.02	28.26	**28.02**
6	Replacement of Sand with 4% Stone Dust	6	21.68	21.99	22.33	**21.99**	32.57	33.25	33.48	**33.25**
7	Replacement of Sand with 8% Stone Dust	6	22.44	22.99	22.97	**22.97**	33.68	34.46	34.61	**34.46**
8	Replacement of Sand with 12% Stone Dust	6	22.88	23.16	23.56	**23.16**	34.39	34.87	35.14	**34.87**
9	Replacement of Sand with 16% Stone Dust	6	20.72	21.43	21.45	**21.43**	31.64	32.22	31.84	**31.84**
10	Combined Replacement of Cement and Sand with a variation of 4% SCBA and 4% Stone Dust	6	22.34	22.73	23.18	**22.73**	33.77	34.33	34.35	**34.33**

11	Combined Replacement of Cement and Sand with a variation of 4% SCBA and 8% Stone Dust	6	22.94	23.5	23.76	**23.5**	34.46	35.46	35.38	**35.38**
12	Combined Replacement of Cement and Sand with a variation of 4% SCBA and 12% Stone Dust	6	23.38	23.95	24.07	**23.95**	35.12	35.86	35.97	**35.86**
13	Combined Replacement of Cement and Sand with a variation of 4% SCBA and 16% Stone Dust	6	21.86	22.21	22.53	**22.21**	33.04	33.61	33.25	**33.25**
14	Combined Replacement of Cement and Sand with a variation of 8% SCBA and 4% Stone Dust	6	23.38	23.82	23.6	**23.6**	35.04	35.82	35.49	**35.49**
15	Combined Replacement of Cement and Sand with a variation of 8% SCBA and 8% Stone Dust	6	23.83	24.31	24.76	**24.31**	35.87	36.63	37	**36.63**
16	Combined Replacement of Cement and Sand with a variation of 8% SCBA and 12% Stone Dust	6	24.47	24.88	25.2	**24.88**	36.88	37.34	37.38	**37.34**
17	Combined Replacement of Cement and Sand with a variation of 8% SCBA and 16% Stone Dust	6	22.48	23.01	23.21	**23.01**	33.81	34.72	34.67	**34.67**
18	Combined Replacement of Cement and Sand with a variation of 12% SCBA and 4% Stone Dust	6	20.62	21.35	21.33	**21.35**	31.36	31.78	31.96	**31.78**
19	Combined Replacement of Cement and Sand with a variation of 12% SCBA and 8% Stone Dust	6	21.25	21.94	22.06	**21.94**	32.28	32.94	32.73	**32.73**
20	Combined Replacement of Cement and Sand with a variation of 12% SCBA and 12% Stone Dust	6	21.88	22.12	22.45	**22.12**	32.74	33.3	33.71	**33.3**
21	Combined Replacement of Cement and Sand with a variation of 12% SCBA and 16% Stone Dust	6	20.06	20.44	20.4	**20.44**	29.98	30.53	30.99	**30.53**
22	Combined Replacement of Cement and Sand with a variation of 16% SCBA and 4% Stone Dust	6	18.79	19.25	19.56	**19.25**	28.44	29.06	28.9	**28.9**
23	Combined Replacement of Cement and Sand with a variation of 16% SCBA and 8% Stone Dust	6	19.57	19.89	19.94	**19.89**	29.1	29.99	30.01	**29.99**
24	Combined Replacement of Cement and Sand with a variation of 16% SCBA and 12% Stone Dust	6	19.83	20.22	20.25	**20.22**	29.86	30.4	30.34	**30.34**
25	Combined Replacement of Cement and Sand with a variation of 16% SCBA and 16% Stone Dust	6	17.86	18.28	18.46	**18.28**	26.71	27.39	27.95	**27.39**

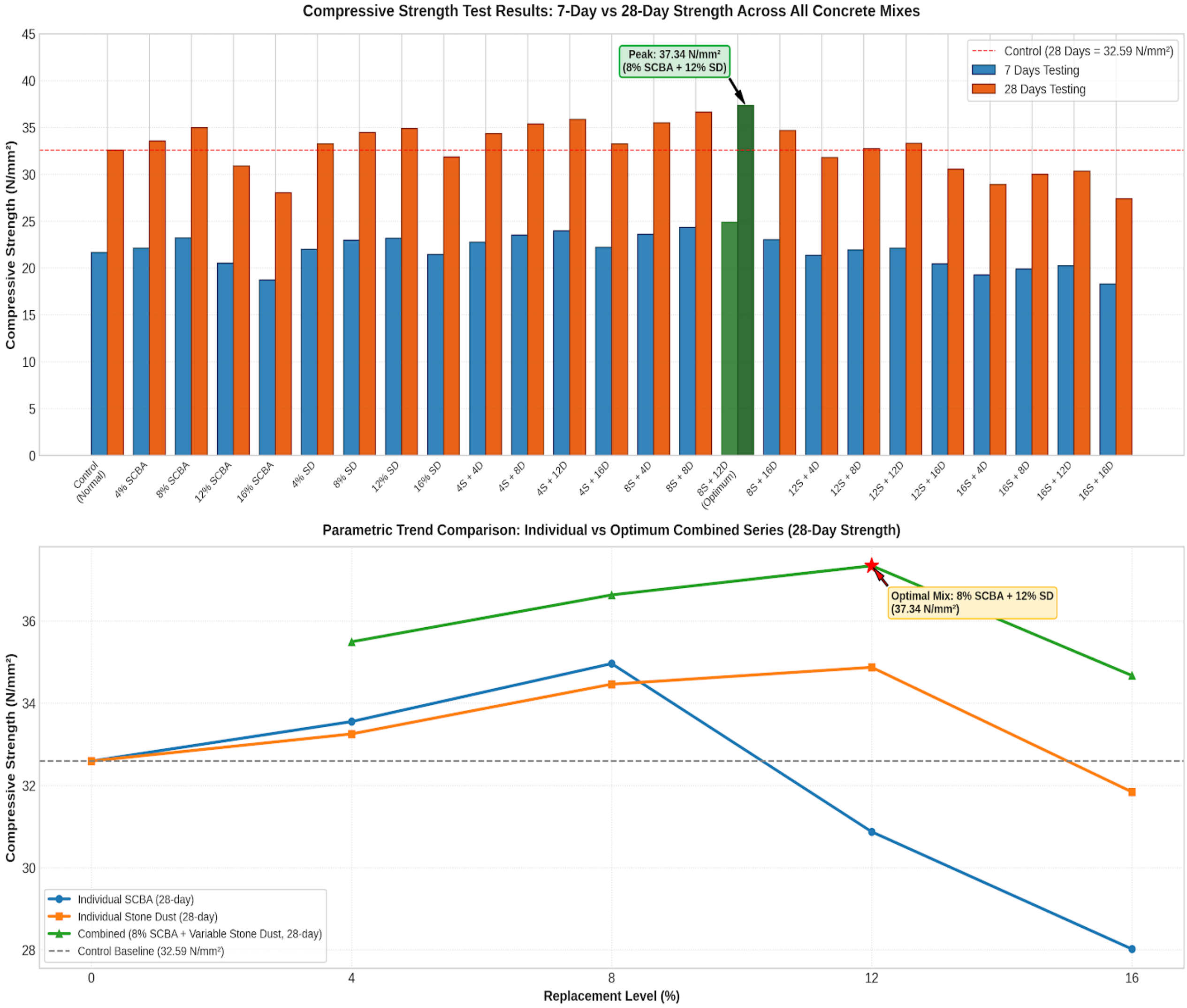

Fig.5.2 Compressive Strength Test

5.3 Sorptivity Test Results: -

5.3 a) Initial Sorptivity (S_i): Determined from absorption within the first 2 hours (dominated by large capillary pores).

Table 5.3(a) Cumulative Water Ingress

Time t (min)	Control Mix (CM) I (mm)	SCBA-8% + SD-12% I (mm)
1	0.048	0.031
5	0.104	0.067
10	0.145	0.093
20	0.203	0.129
30	0.247	0.156
60	0.344	0.217
120	0.479	0.301

5.3 b) Secondary Sorptivity (S_s): Determined from 1 day to 9 days (governed by slower filling of gel and micro-capillary pores).

Table 5.3(b) Day-wise Mass Gain (Δm) & Cumulative Ingress (I)

(Days)	Control Mix (CM)		SCBA-8 + SD-12	
	Δm (g)	I (mm)	Δm (g)	I (mm)
Day 1	27.2	1.209	16.7	0.742
Day 3	42.1	1.871	24.8	1.102
Day 6	55.4	2.462	31.7	1.409
Day 9	64.8	2.88	36.2	1.609

6. Conclusion

This study demonstrates the viability of using Sugarcane Bagasse Ash (SCBA) as a partial cement replacement and Stone Dust as a natural sand replacement in M25 grade concrete. It was found that optimum compressive strengths were achieved with 8% SCBA and 12% Stone Dust as individual replacements. A ternary composite of concrete with 8% SCBA and 12% Stone Dust as a replacement recorded the maximum compressive strength of 37.34 N/mm² at 28 days, which was higher than that of the control concrete. The slump value reduced from 95 mm to 73 mm due to an increase in fineness and water demand, but it can still be observed that medium workability was maintained. The SCBA-8 + SD-12 mix has a finer pore structure that lowers total water penetration by approximately 44% on Day 9 compared to the control mix and is more resistant to secondary capillary action.

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