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Study on Durability Properties of Ternary Concrete Containing Agriculture Waste and Limestone

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Abstract: This study focuses on exploring the potential of sugarcane bagasse ash (SBA) as a sustainable additive in concrete to enhance its durability properties for construction applications. The research investigated five different concrete mixes, including control, binary, and ternary cementitious systems.

The binary mix incorporated 10% SBA, while the ternary system combined 10% SBA with varying proportions of limestone (10%, 15%, and 20%) as a partial substitute for Ordinary Portland cement (OPC). The durability properties of the concrete mixes, including acid resistance, sulphate resistance, sorptivity, water absorption, water impermeability, and porosity, were thoroughly evaluated.

Based on the experimental results, the optimal mix proportion was identified as 10% SBA + 15% limestone, with the remaining 75% comprising OPC. The findings demonstrated that this specific combination of materials significantly improved the durability of the concrete, indicating the potential of SBA as an eco-friendly and effective solution for sustainable construction practices.

Keywords: Sugarcane Bagasse Ash, Agriculture Waste, Limestone, Ternary concrete, Durability

I. INTRODUCTION

Ordinary Portland Cement is recognized as the most important construction material throughout the world. Due to the amount of CO_2 released during the Portland cement clinkering process, cement production has sparked environmental concerns. There is growing pressure on the construction sector to lessen the environmental impact of cement. The carbon footprints can be reduced by decreasing the clinker volume and this can be achieved by blending the cement with Supplementary Cementitious Materials such as fly ash, sugarcane bagasse ash (SBA). The blended cements are produced either by grinding / intergrinding of Supplementary Cementitious Materials with clinker at the manufacturing plant or by blending SCMs with cement powder after production. These Supplementary Cementitious Materials chemically react with calcium hydroxide to form cementitious compounds and produces pozzolanic reactions.

II. MATERIALS USED

Manufacturing of concrete is done with following materials, Ordinary Portland Cement (OPC), Sugarcane Bagasse Ash, Limestone powder, aggregates.

A. *Ordinary Portland Cement*

Ordinary Portland Cement (OPC) conforming to 53 grade as per IS 269 (Bureau of Indian Standards, 2015) is used here.

B. *Limestone Powder*

The Limestone powder (L) of specific gravity 2.70 is collected from the Tirunelveli district.

C. *Sugarcane Bagasse*

The SBA Sugarcane bagasse ash collected from Subramaniya Siva Co-op sugar mills Ltd. in Dharmapuri, India, was further dried at 105-110ºC for 24 hours to remove the evaporable water content. The dried bagasse ash was further sieved through 300 µm sieve to remove large unburnt fibrous fractions and obtain superior reactive pozzolanic material. The specific gravity of Sugarcane Bagasse is found to be 1.95, tested as per IS 1727-2004. The oxide composition of the sugarcane bagasse found by XRF analysis is shown in table I.

TABLE I. Oxide composition of Sugarcane Bagasse ash

Oxide Composition	Sieved SBA (%)
SiO_2	74.783
Al_2O_3	2.405
Fe_2O_3	3.877
CaO	5.949
MgO	1.05
K_2O	5.818
P_2O_5	4.103
SO_3	1.542
TiO_2	0.191
Loss on ignition (%)	0.282

D. Aggregates

Fine aggregate used is the M-Sand of specific gravity 2.65 and water absorption 1% with grading confirming to zone II as per IS 383-2016. Coarse aggregate used is of size 10 and 20mm as per IS 383-2016 with specific gravity 2.68 and 2.70, water absorption 0.8% and 0.6% respectively.

E. Super Plasticizer

Super Plasticizer used here is ECMAS HP 890. ECMAS HP 890 is a cutting-edge superplasticiser based on properly selected and modified Poly-Carboxylic Ethers to deliver excellent performance.

F. Proportion of Blended Cement

For production of blended cement, ratio of weight of sample to ball 1:4 was used for grinding. Cement mix of various mix proportions produced are as shown in the table II.

TABLE II. Proportion Of Cement Replacement

ID Name	OPC	Sugarcane Bagasse Ash (SBA)	Limestone (L)
OPC 100	100	-	-
SBA 10	90	10	-
SBA 10 L 10	80	10	10
SBA 10 L 15	75	10	15
SBA 10 L 20	70	10	20

III. PRELIMINARY INVESTIGATIONS ON BLENDED CEMENTS

The physical characteristics such as standard consistency, initial and final setting time, fineness, specific gravity and compressive strength of the blended cements are tested as per IS 4031 as shown in fig. 1, compared as shown in fig. 2, 3.

Fig. 1.Standard Consistency Test, Initial setting time Test and Compression Test

The standard consistency increased with increase in the replacement of OPC with Sugarcane bagasse ash (SBA), due to the pozzolanic behaviour of the SBA. Standard consistency decreased for the 10% Limestone replacement and then increased due to the heating effect of Limestone. The initial and final setting time of the cement increased after the addition of Sugarcane Bagasse Ash this is due to low early hydration of SBA. After addition of Limestone the initial setting time is decreased, this is because the Limestone has induced early hydration in the cement. The compressive strength of the 10% SBA is lower than the OPC100.

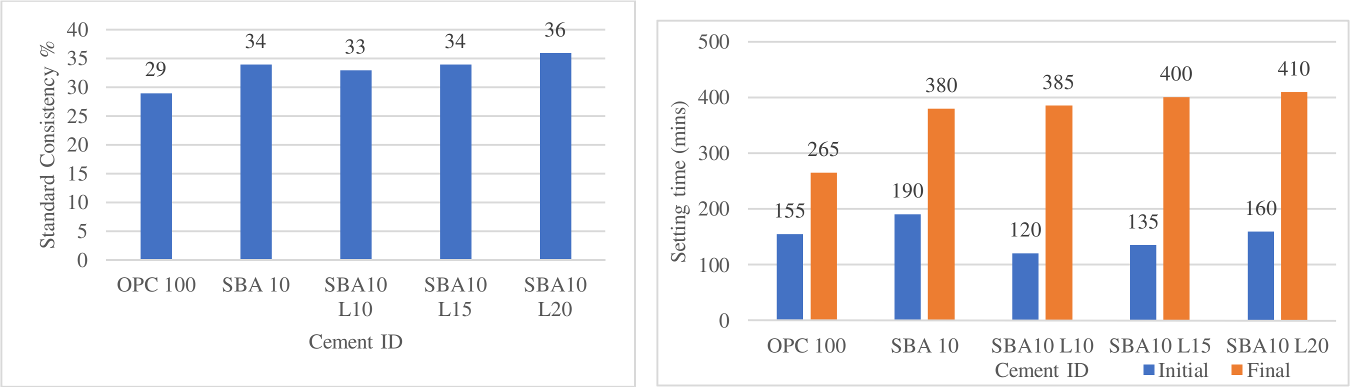

Fig. 2.Standard Consistency, Initial and final setting time of cement

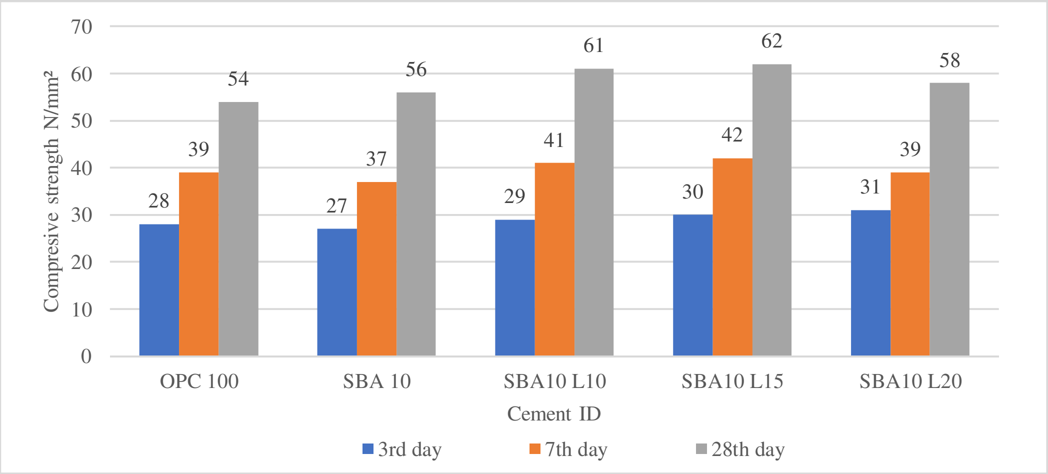

Fig. 3.Compressive strength

This shows that the early hydration of the cement with the partial replacement of sugarcane bagasse is low. The other ternary mixes, SBA10 L10 and SBA10 L15, show good early strength. This shows that the Limestone addition has helped in the early hydration of the blended cement. SBA10 L20 shows a decrease in the later compressive strength; this is due to the dilution effect of the Limestone.

IV. MIX PROPORTIONS

The concrete mix design was prepared in accordance with IS 10262:2019. The mix proportions are shown in table III.

TABLE III. Mix proportion of materials for 1 m³ concrete mix

	OPC 100	**SBA 10**	**SBA 10 L 10**	**SBA 10 L 15**	**SBA 10 L 20**
Concrete Grade	M30	M30	M30	M30	M30
OPC	370 kg	333 kg	296 kg	277.5 kg	259 kg
SBA	-	37 kg	37 kg	37 kg	37 kg
L	-	-	37 kg	55.5 kg	74 kg
(M-Sand/ Zone 2)	690.70 kg	686.50 kg	688.50 kg	692.10 kg	693.20 kg
CA 10mm	481.80 kg	478.90 kg	480.30 kg	482.80 kg	483.60 kg
CA 20mm	728.10 kg	723.80 kg	725.80 kg	729.70 kg	730.80 kg
Water	161.00 L	161.00 L	161.00 L	161.00 L	161.00 L
Super Plasticizer	1.00 litres	1.35 litres	1.25 litres	1.10 litres	1.10 litres

V. EXPERIMENTAL INVESTIGATION

A. Water Absorption

The water absorption test, as per ASTM C642, plays a vital role in assessing the porosity and permeability of hardened concrete in the thesis investigation. By subjecting cubical concrete specimens to vacuum saturation, the test measures the ability of the Concrete to absorb water. The procedure involves precise weighing of the specimens before and after saturation, calculating the water absorption percentage. Accurate specimen preparation and meticulous vacuum saturation are essential to obtain reliable results. The outcome of this test will provide crucial data on the durability of ternary concrete containing 10% Sugarcane Bagasse Ash at 28 days and 56 days. The Fig. 4 shows the water absorption test done for the concretes.

Fig. 4.Durablity tests conducted on the ternary concrete – Water absorption test, Porosity test, Sorptivity test

B. Porosity test

The porosity test is vital in assessing the microstructural behaviour and durability of ternary concrete with 10% SBA and limestone. It determines void content, influencing mechanical strength, permeability, and environmental resistance, offering valuable insights for long-term performance assessment.

The porosity test in this project was conducted on concrete specimens based on the ASTM C642 procedure. The specimens were first dried in an oven at 100 to 110°C for a minimum of 24 hours, followed by cooling to 20 to 25°C, and weighing to obtain the oven-dry mass 'A'. Subsequently, the specimens were immersed in water at approximately 21°C for at least 48 hours, and the surface-dry mass 'B' was determined. The specimens were then boiled for 5 hours, allowed to cool, surface-dried, and their mass 'C' was recorded. Finally, the immersed apparent mass 'D' was measured in water. And the porosity is calculated from the formula (C – A) / (C – D) x100. Fig. 4 shows the immersed apparent mass suspended in water.

C. Sorptivity test

In this project, the sorptivity test (ASTM C1585-20) was performed on concrete specimens following the specified sample conditioning and procedure. The specimens were placed in an environmental chamber at a temperature of 50 ± 2°C and relative humidity (RH) of 80 ± 3% for 3 days to ensure uniform conditioning. Alternatively, a desiccator with a saturated solution of potassium bromide was used to maintain the RH at 80 ± 3%, while keeping the temperature at 50 ± 2°C. After the conditioning period, each specimen was placed in a sealable container to equilibrate at 23 ± 2°C for a minimum of 15 days before starting the absorption procedure. The test procedure involved recording the mass of the conditioned specimen before sealing its side surfaces. The sealed specimen was then exposed to water absorption at 23 ± 2°C with tap water at the same temperature by placing it on the support with water level maintained between 1 mm to 3 mm. Mass was recorded at intervals from 60 s to 7 days, with the first measurement at 60 ± 2 s and the second at 5 min ± 10 s. Subsequent measurements were within 2 min of 10 min, 20 min, 30 min, and 60 min, and every hour ± 5 min up to 6 hours. After the initial 6 hours, measurements were taken once a day up to 3 days, followed by 3 measurements at least 24 hours apart during days 4 to 7. A final measurement was taken at least 24 hours after the measurement at 7 days, resulting in seven data points for contact time during days 2 through 8. After conducting the sorptivity test, water absorption (I) was calculated as the change in mass (m_t) divided by the product of the exposed area (a) and water density (d) (I= m_t / a*d). Subsequently, the initial and secondary rates of water absorption ($mm/s^{1/2}$) were determined by performing linear regression analysis of absorption (I) plotted against the square root of time (t) for specific time intervals. Fig. 4 shows the sorptivity test setup. The sorptivity of the concrete was experimented on the 28th and 56th days.

D. Water Impermeability Test

In this project, the water impermeability test, according to BS EN 12390-8:2019, was employed to determine the depth of water penetration under a constant pressure of 5 ± 0.5 bars in hardened concrete specimens as shown in fig. 5. The test evaluates the concrete's resistance to water ingress and its overall durability properties. Cylindrical specimens were conditioned, immersed in pressurized water for 72 hours, and subsequently measured for the depth of water penetration. These results provide vital insights into the concrete's microstructural behaviour and its long-term durability, enhancing our understanding of its performance in practical applications. The water penetration depth of the concrete on the 28th and 56th days calculated for this test.

Fig. 5.Durablity tests conducted on the ternary concrete – Water impermeability test

E. Acid resistance test

The acid resistance test, conducted in this study in accordance with ASTM C 1898-20, is a critical evaluation to assess the effects of acid attack on hardened concrete. In this study we have evaluated the effect of Hydrochloric acid (HCL) and Sulphuric acid (H_2SO_4) on concrete separately. For this purpose, after a curingperiod of 28 days, the specimens were allowed to dry for 24

Fig. 6. Durablity tests conducted on the ternary concrete – Acid resistance test

Hours to determine their initial weight. For the test, separate solutions of 5% hydrochloric acid (HCl) for HCl acid resistance test and 5% Sulphuric acid (H_2SO_4) solution for H_2SO_4 acid resistance test were prepared and adjusted to a pH of approximately 2. The concrete cubes were immersed in the acid solutions for durations of 28 and 56 days (as depicted in Fig. 6). Regular verification of the acid concentration ensured its consistency throughout the test duration. Following the immersion periods, the cubes were removed from the acid solution (as shown in Figure 6) and meticulously cleaned to eliminate any unstable particles leached by the acid. Subsequently, their final weight was recorded, and they were subjected to compression testing to ascertain their compressive strength. By utilizing the initial weight, final weight, and compressive strength data, the percentage loss in weight and strength was calculated, providing crucial insights into the concrete's susceptibility to acid attack. The compressive strength, reduction in the percentage of compressive strength and reduction in the percentage of mass of the concrete on the 28th and 56th days, are calculated.

F. Sulphate resistance test

The determination of sulphate attack on concrete cube specimens was conducted following the prescribed guidelines of ASTM C1012-04 [26]. After curing for 28 days, the cubes were weighed to establish their original weight. Subsequently, the specimens were fully immersed in a water solution containing Sodium sulphate (Na_2SO_4) for 28 and 56 days at a controlled temperature of 23 ± 2 °C (as depicted in Figure 6.15). Following the immersion periods, the specimens were taken out of the solution and subjected to surface drying before recording their final weight. Throughout the procedure, a noticeable white-colored deposit was observed on the concrete's surface. Finally, the cube specimens were subjected to a compression test, and the results were compared with those of normal water-cured concrete, providing essential insights into the concrete's susceptibility to sulphate attack. These findings contribute valuable data to the thesis, enhancing the understanding of concrete's durability properties and performance under sulphate exposure conditions. The compressive strength, reduction in the percentage of compressive strength and reduction in the percentage of mass of the concrete on the 28th and 56th days, are calculated.

VI. RESULTS AND DISCUSSIONS

A. Water Absorption

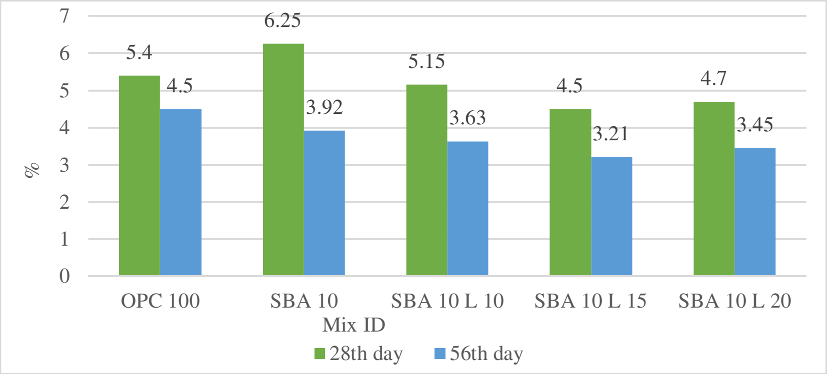

Fig. 7. Comparison on Water absorption values of the ternary concrete

The results of the water absorption tests at 28th and 56th day are compared as shown in the Fig. 7. From the comparison, it could be understood that the water absorption of the concrete at 28 days decreased with the increase in the replacement of OPC with Limestone (L). But for SBA10 mix the water absorption at 28 days is greater than the conventional due to the hygroscopic nature of SBA. But at 56 days the water absorption in SBA10 has decreased compared to conventional concrete. This is due to the pozzolanic reaction that converted the excess portlandite to CSH gel. This CSH gel has reduced the pores in the concrete resulting in the less water absorption upto 15% increase in Limestone content (L), after the 15% due to dilution effect the CSH gel formation is reduced resulting in increase in the water absorption in SBA10 L20 mix. So 15% could be considered the optimal replacement percent in water absorption.

B. Porosity test

The results of the porosity tests at 28th and 56th day are compared as shown in the Fig. 8. From the chart, it could be understood that the trend for water absorption of the concrete and porosity are similar to each other. This is due to the pozzolanic reaction that converted the excess portlandite to CSH gel. This CSH gel has reduced the pores in the concrete upto 15% increase in Limestone content (L), after the 15% due to dilution effect the CSH gel formation is reduced resulting in increase in the porosity of SBA10 L20 mix. So 15% could be considered the optimal replacement percent in porosity.

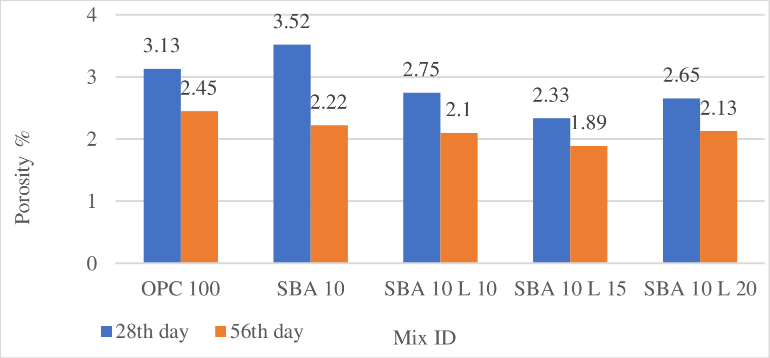

Fig. 8.Porosity of the ternary concrete at 28th and 56th days

C. Sorptivity Test

On comparing the results of the sorptivity tests at 28th and 56th day of the concrete as shown in the Fig. 9, it is concluded that the sorptivity of the concrete at 28 days decreases with increasing replacement of OPC with limestone (L). Furthermore, at 56 days, the sorptivity remains lower than at 28 days. This decrease in sorptivity over time could be attributed to the lower portlandite content, which gradually reduces due to consumption through pozzolanic reactions, leading to the formation of C-S-H gel. The presence of well-formed and dense C-S-H gel significantly reduces the interconnected porosity in the concrete, resulting in lower sorptivity values, particularly up to a 15% increase in limestone content (L). However, beyond 15% limestone content, the dilution effect reduces C-S-H gel formation, leading to increased sorptivity in the SBA10 L20 mix. Therefore, a limestone content of 15% could be considered the optimal replacement percentage for achieving lower sorptivity.

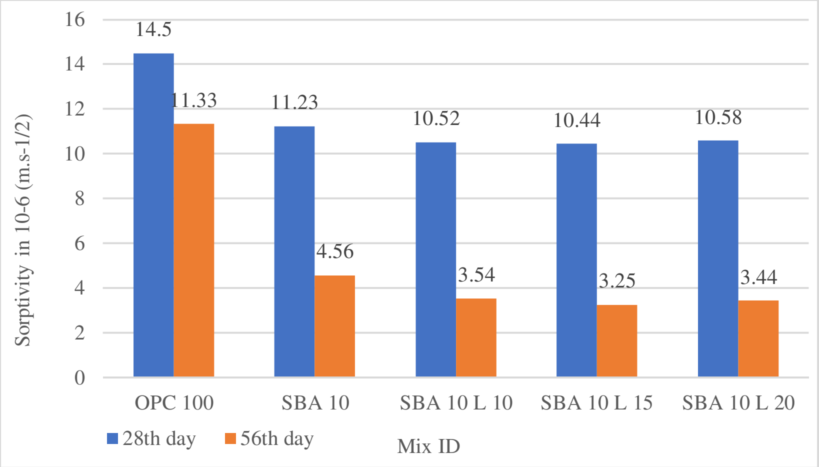

Fig. 9.Sorptivity values of the ternary concrete at 28th and 56th days

D. Water impermeability test

The water penetration depth results were measure and compared as shown in Fig. 10. This figure exhibits a trend in sorptivity similar to both the 28th day and 56th day results, confirming the formation of C-S-H gel during the curing period, which leads to a reduction in pores and, consequently, decreased water penetration. Based on the graph, it is evident that the optimal content for achieving water impermeability is SBA10 L15.

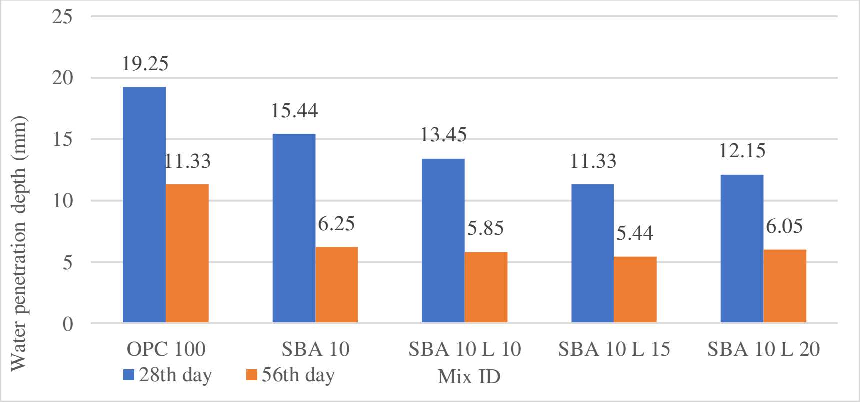

Fig. 10. Water penetration depth of ternary concrete at 28th and 56th days

E. Acid Resistance Test

Based on the graph analysis from the fig.11, 12 it can be inferred that the reduction in strength and mass of the concrete due to H_2SO_4 and HCl decreases with an increase in limestone content up to 15% limestone replacement. This phenomenon can be explained by the formations of portlandite and CSH gel. Specifically, portlandite reacts with sulfuric acid to form calcium sulphate ($CaSO_4$) and water, known as sulphate attack, which can lead to concrete degradation over time, causing expansion, cracking, and weakening. Similarly, in the presence of hydrochloric acid, calcium chloride ($CaCl_2$) and water are formed, leading to concrete deterioration. However, as the portlandite content decreases with an increase in limestone content, the susceptibility to deterioration is reduced. Furthermore, the presence of CSH gel provides increased resistance to sulfuric acid and hydrochloric acid, leading to a decrease in strength and mass loss. The higher formation of CSH gel contributes to this protective effect. Although CSH gel formation increases with time, it is noteworthy that the % strength and mass loss is more significant on the 56th day compared to the 28th day. This can be attributed to the extended exposure of the concrete to the acid over a longer period, which intensifies the detrimental effects on the material. In conclusion, the incorporation of limestone in the concrete mixture up to 15% replacement leads to decreased vulnerability to acid-induced strength and mass loss due to the reduction in portlandite content and the increased formation of CSH gel. Nonetheless, prolonged exposure to acid can still cause substantial damage, as evident in the higher deterioration observed on the 56th day compared to the 28th day.

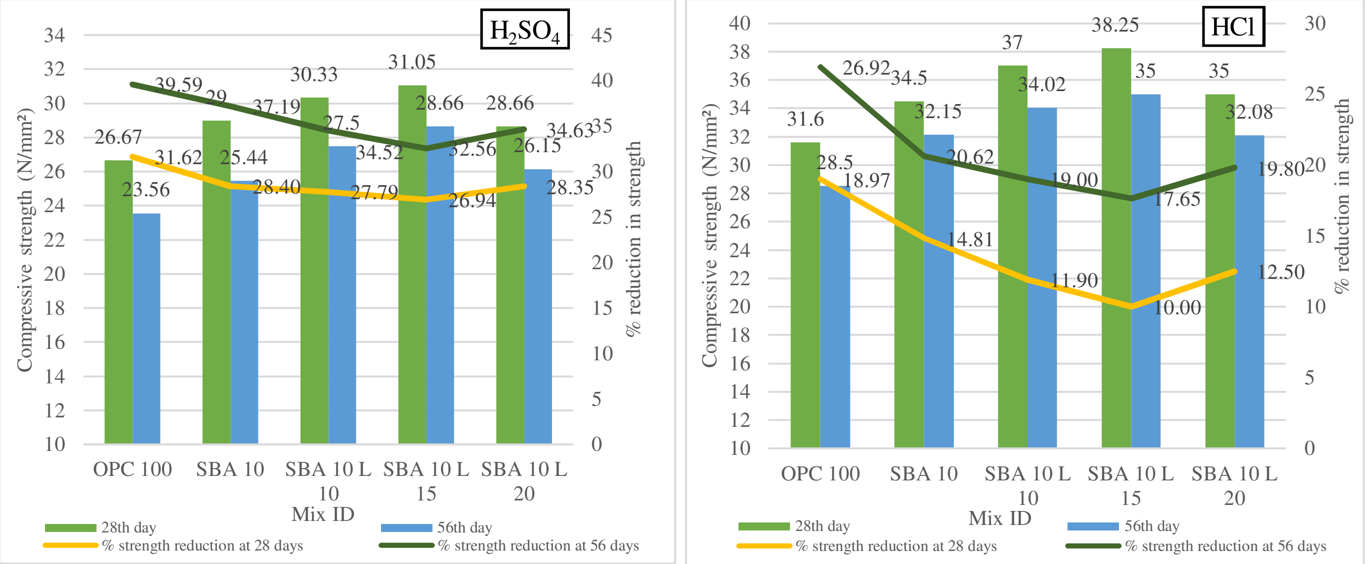

Fig. 11. The compression strength and percentage of strength loss at the 28th and 56th days for H_2SO_4, HCl curing

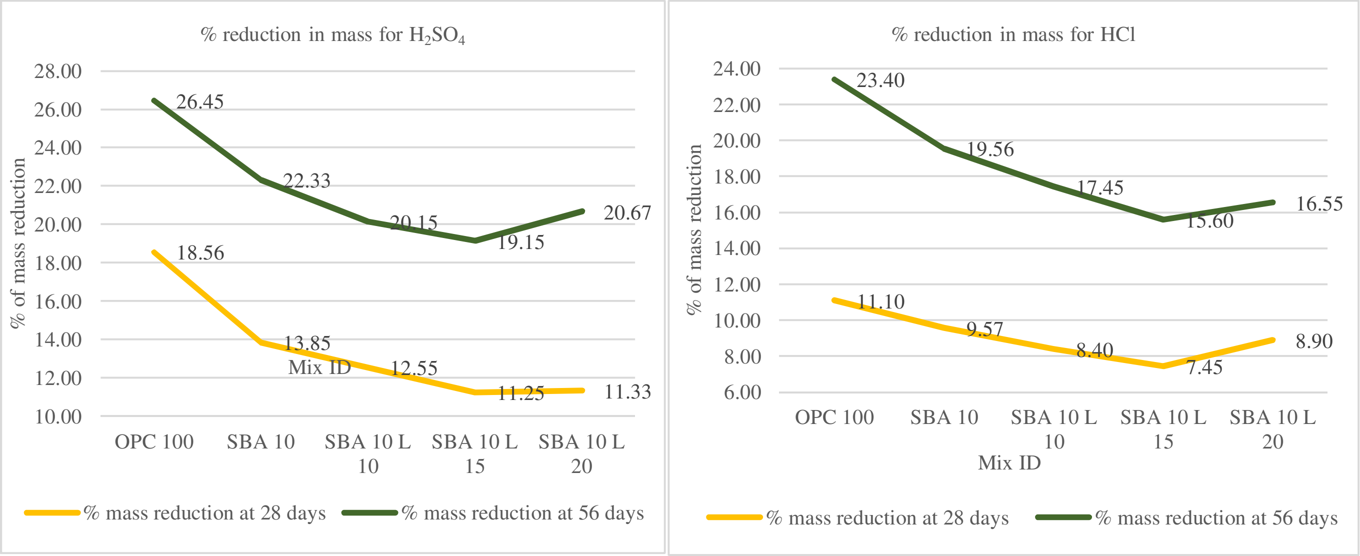

Fig. 12. The percentage of mass loss at the 28th and 56th days for H_2SO_4 and HCl curing

F. Sulphate Resistance Test

The analysis of the graph in fig 13, 14 indicates that the susceptibility of concrete to sulphate attack is influenced by the content of portlandite and the formation of ettringite and CSH gel. Increasing limestone content up to 15% in the concrete mix reduces strength and mass loss caused by sulphate attack. Sulphate ions in the environment react with portlandite and calcium aluminate phases, forming calcium sulphate compounds like ettringite, leading to concrete degradation. With higher limestone content, less portlandite is available for sulphate attack, and increased CSH gel formation acts as a protective barrier, limiting sulphate ion ingress. While limestone replacement improves resistance, concrete may not be entirely immune to sulphate-induced deterioration, as environmental conditions and exposure time also play crucial roles, this is the reason why % loss of mass and strength is greater at 56th day when compared to 28th day. In conclusion, incorporating up to 15% limestone in the SBA10% blended cement concrete enhances its sulphate attack resistance by reducing portlandite content and promoting CSH gel formation.

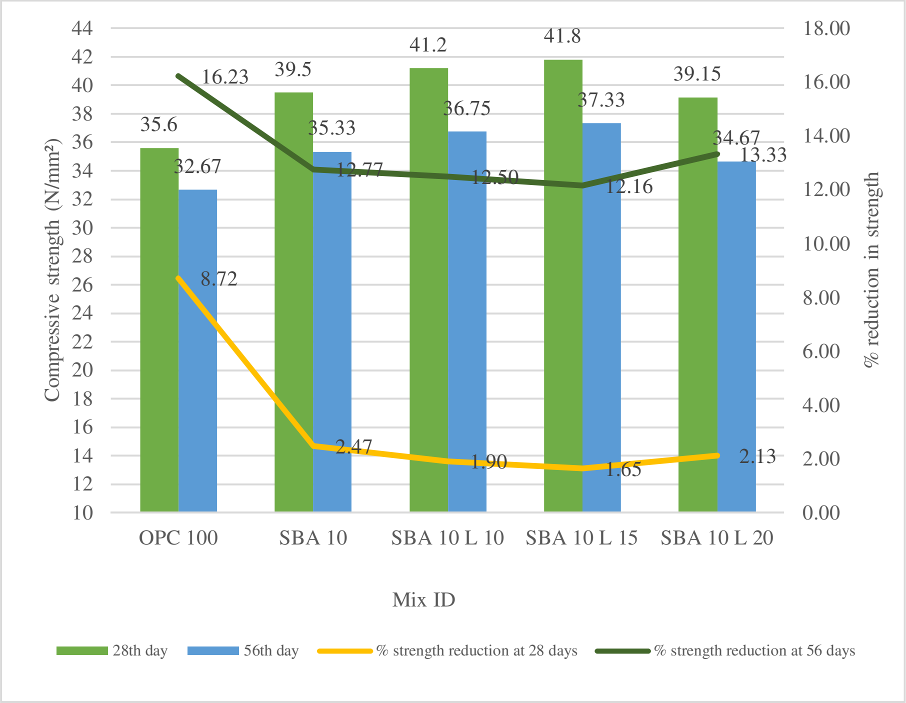

Fig. 13. The compression strength and percentage of strength loss at the 28th and 56th days of Na_2SO_4 curing

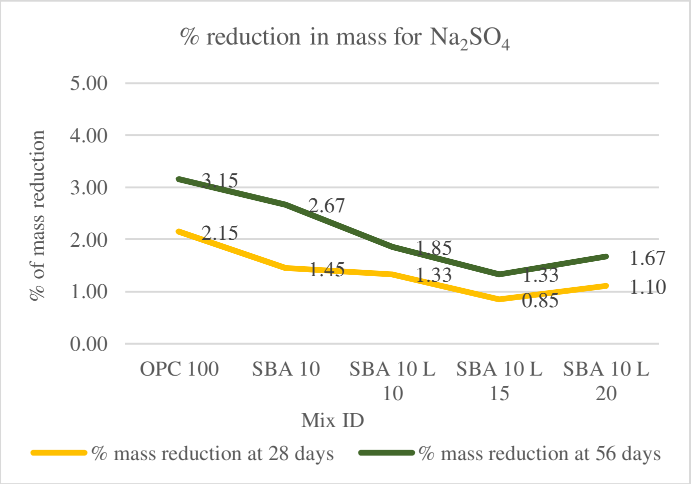

Fig. 14. The percentage of mass loss at the 28th and 56th days for Na_2SO_4 curing

VII. CONCLUSION

The conclusions of this investigation summarized as a whole are listed here.

1) Up to 15% limestone replacement reduced water absorption at 28 and 56 days. SBA10 mix showed higher absorption at 28 days due to SBA's hygroscopic nature. At 56 days, SBA10 absorption decreased due to pozzolanic reaction converting portlandite to CSH gel, reducing pores.
2) Water absorption and porosity showed similar trends. CSH gel formation reduced porosity up to 15% limestone content. Beyond 15%, dilution effect increased porosity in SBA10 L20 mix.
3) Sorptivity at 28 days decreased with higher limestone replacement. Over time, lower portlandite content and CSH gel formation reduced sorptivity, especially up to 15% limestone content. Beyond 15%, dilution effect increased sorptivity.
4) SBA10 L15 mix achieved water impermeability due to CSH gel formation, reducing pores and water penetration.
5) Up to 15% limestone content reduced strength and mass loss from H_2SO_4 and HCl attacks due to CSH gel formation. Prolonged exposure to acid still caused damage, more pronounced at 56 days.
6) Up to 15% limestone reduced strength and mass loss from sulphate attack. CSH gel acted as a protective barrier. Beyond 15%, susceptibility to sulphate attack increased. Incorporating SBA and limestone up to 15% enhances concrete durability.

In conclusion, incorporating up to 15% limestone in the ternary concrete mixture with 10% sugarcane bagasse ash (SBA) enhanced its durability and resistance to water absorption, porosity, sorptivity, acid attacks, and sulphate attack. These findings highlight the potential of using sustainable materials like SBA and limestone in concrete, contributing to a more eco-friendly and durable construction approach.

VIII. ACKNOWLEDGMENT

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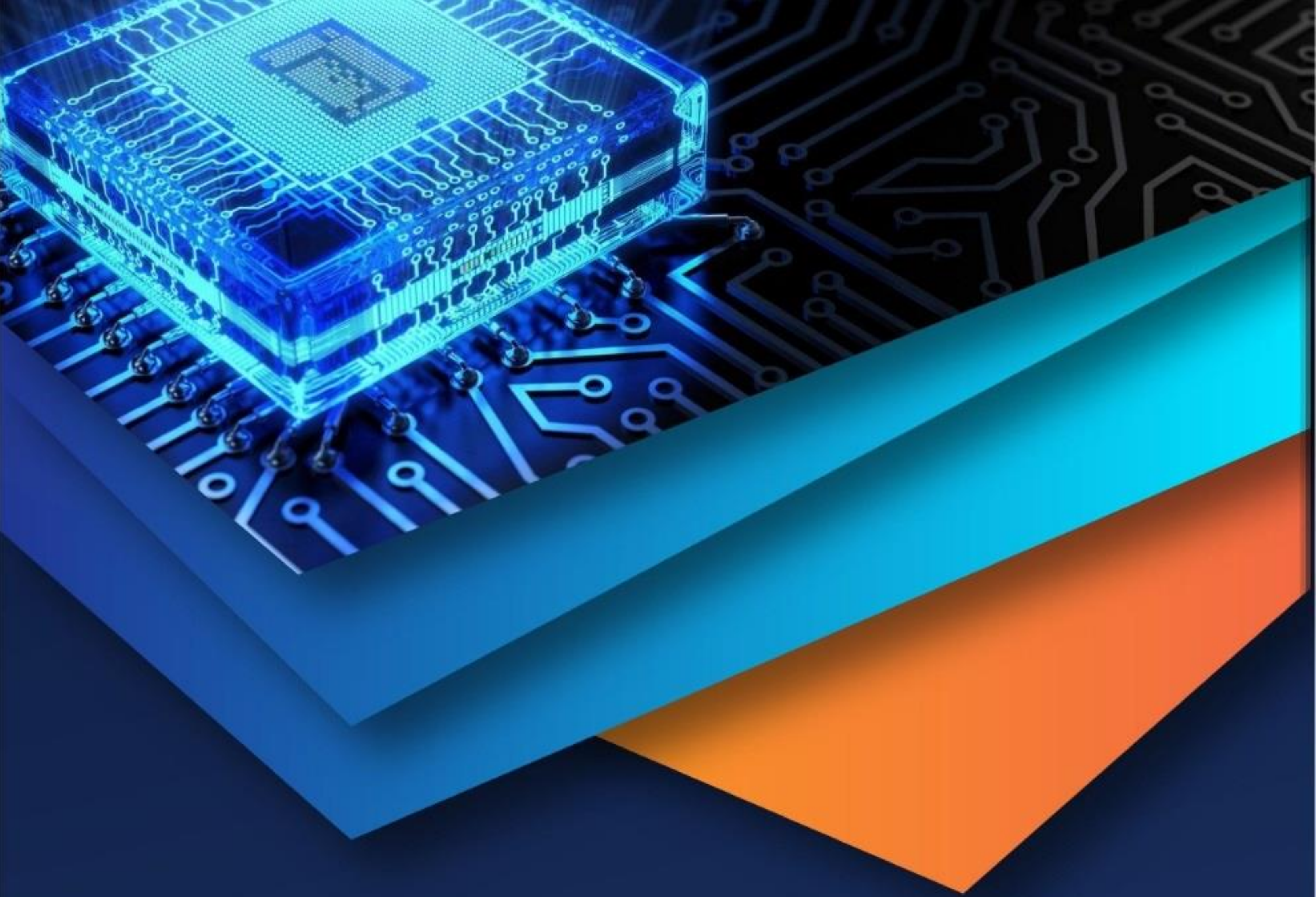

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