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Incorporating of waste from sugar industry and cement industry in concrete

Nirmal Ponnambalam [1*], Chinnaraju K.[2] and Chithra S.[1]
[1]Department of Civil Engineering, Government College of Technology, Coimbatore, 641013, India
[2]Department of Civil Engineering, College of Engineering Guindy, Anna University, Chennai, 600 025, India
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*to whom all correspondence should be addressed: e-mail: pnirmal@gct.ac.in
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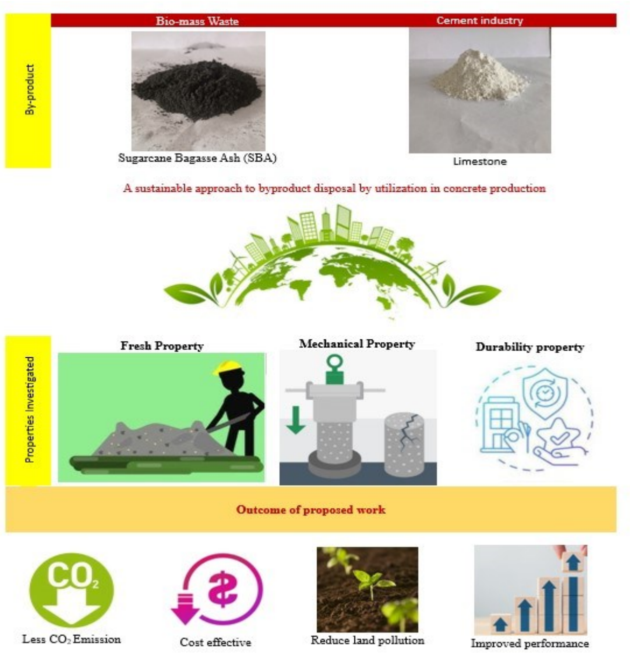
Graphical abstract



Abstract

As the production of biomass waste from agroindustry grows across the world, a large amount of agro-based ashes ends up in polluting land The utilization of Sugarcane Bagasse ash (SBA) as Supplementary cementious materials (SCMs) contributes to a fixing of issues related to CO_2 emissions from cement industry and land pollution in agro-based industry. Individual performance on the utilization of SBA and limestone in concrete reported by many researcher, research on their combined usage in the concrete is limited. As a result, the current work involves the performance evaluation of ternary blended concrete incorporating SBA and limestone. The blended concrete's workability properties, compressive strength, water absorption, Rapid Chloride Penetration Testing (RCPT), Sorptivity, water permeability and electrical resistivity are examined in this paper. It improves the compressive strength and durability properties of ternary blended concrete It was observed that addition of 10-15 % limestone along with 10 % SBA improves the concrete performance. However, exceeding 15 percent had a detrimental impact on concrete properties. The additional alumina contributed by SBA will interact with limestone that enhance the concrete properties. Utilization of SBA and limestone powder reduces cement consumption in cementitious composites and reduce environmental impact due to un-engineered disposal of SBA. Thus, result in improved sustainable production of concrete.

1. Introduction

The industry sector is the major contributor to global CO_2 emissions. Demand reduction, substitution, and carbon management are critical components of CO_2 reduction in industry (Karthik *et al*., 2023; Kathirvel and Murali 2023). The production of construction materials such as steel, cement, and concrete are an extremely energy- and emissions-intensive operation. The manufacturing of cement accounted for 7% of total world CO_2 emissions. Concrete is one of the most widely utilized materials on the planet, with an estimated 14 billion tonnes produced globally in 2020. The IEA CSI Cement Technology Roadmap projects that worldwide cement production is expected to rise by 12-23% by 2050, based on population and development. Furthermore, from 1928 to 2018, the total worldwide CO_2 emissions from cement production were 38.3 ± 2.4 Gt. Awareness about alternative materials to be used as a whole or partial cement replacement material is necessary in order to minimize cement use and CO_2 emission (Cheah *et al*., 2022; Gopika *et al*. 2022; Kathirvel *et al*., 2020).

The ternary blended concrete is a concrete comprising three distinct binders: Ordinary Portland Cement (OPC) and two supplemental cementitious materials (SCMs). Over the years, numerous SCMs derived from waste materials like silica fume, fly ash, Sugarcane bagasse ash, rice husk ash and ground granulated blast furnace slag have been employed to create composite cements (Amran *et al*. 2022). These cements serve the purpose of not only reducing the environmental impact but also improving the durability of concrete while being environmentally friendly. It is important to take into account that when two SCMs are employed, the by-products of these two components may partially compensate each other's disadvantages. As a consequence, ternary concrete may achieve enhanced strength and durability properties.

Biomass ash refers to the solid waste produced when plant biomass is burned for the purpose of generating heat and electricity. As the energy sector transitions from non-renewable fossil fuels to more sustainable biomass fuels, significant amounts of biomass residual ash are generated and disposed off from cogeneration units. Sugarcane Bagasse Ash (SBA), Rice Husk Ash (RHA), palm oil fuel ash (POFA) and so on are commonly generated during the combustion process in agro-industries

Sugarcane is an essential crop in many developing nations. Sugarcane bagasse is a vital byproduct of the sugar industry that is obtained during the manufacturing process of sugarcane juice. Bagasse cogeneration is widely employed in sugar industry to satisfy the energy demands of the industry. In 2019, India produced 405.4 million tonnes of sugarcane, with the capacity to produce 105.4 million tonnes of bagasse and 2.5 million tonnes of SBA (Das *et al*., 2022). Due to the presence of higher percentages of amorphous silica and alumina, it came to light that SBA may be employed as pozzolanic material. The use of SBA could consequently solve the existing problem of bagasse ash disposal in sugar industry.

Globally, the incorporation of SBA in cement and concrete has attracted many researchers over few decades. Most of the research articles published in this regard explore the impact of SBA on the fresh and hardened characteristics of various concretes (Batool *et al*., 2020; Katare *et al*., 2017; Moretti *et al*., 2018). The characteristics of the SBA is one of the primary factors defining its behaviour in cement and concrete. SBA obtained from industry cannot be directly used in concrete because it requires minimal preparation to serve as pozzolanic material. A detailed investigation of the pozzolanic mechanism of SBA employing different ways of processing such as burning, grinding, sieving and combinations of these processes were studied by many researcher (Bahurudeen *et al* 2015; Cordeiro *et al*. 2008). To reduce negative impact on environment, it is necessary to decide on a processing method that enhances pozzolanic activity along with adopting the least amount of processing energy.

Jagadesh *et al*. studied mechanical properties of concrete by substituting cement with different proportion (5-30%) of SBA and observed that the incorporation of 10% bagasse ash in concrete improves its compressive strength by more than 10% (Jagadesh *et al*., 2018). Rajasekar *et al* reported the utilization of processed SBA on ultra-high strength concrete and observed that adding 15-20 wt% processed SBA to the cement reduced chloride penetration and increased compressive strength of the concrete compared to control concrete mix (Rajasekar *et al*., 2018). Zareei *et al* concluded that substitution of 5-10% SBA enhances the durability and impact resistance of concrete (Zareei *et al*., 2018). Based on result of many researchers, the utilization of SBA as a cement alternative in cement composite is advised at lower quantities, i.e., 5-15% by mass of cement (Arenas-Piedrahita *et al*., 2016; Arif *et al*., 2016). Even though addition of SBA to concrete enhances many properties of concrete, it also has adverse impact on concrete. Klathae *et al*. found that incorporating of SBA as replacement in cement leads to significant increase superplasticizer dosage to maintain the desired slump due to porous nature of SBA (Klathae *et al*., 2021) Similar result was observed by Bahurudeen *et al*. that addition of SBA in concrete resulted in decrease in workability because of its high specific surface area (Bahurudeen *et al*., 2014).

Because of its low cost and widespread availability, limestone powder is one of the commonly utilized alternatives as a partial replacement for cement in concrete mixtures. The substitution of limestone in concrete influences the properties of concrete by filler effect, chemical effect and nucleation effect. Ramezanianpour (Ramezanianpour *et al*., 2009) observed 12.5 % increase in slump value with 10% limestone included in concrete and observed reduced compressive strength with addition of limestone on the 90 and 180 day. . Although limestone is typically utilized as a filler material, with the suggested level ranging from 6% to 20% (Meddah *et al* ., 2014). Many researchers have found similar results of compressive strength loss at latter age (Githachuri and Alexander 2013; Meddah *et al*., 2014; Tsivilis *et al*., 2003). The decrease in compressive strength is demonstrated as a result of dilution effect.

2. Research significance

The rise in SBA availability as biomass residue in sugar industry makes it critical to seek out alternatives to reduce the environmental impact. Furthermore, SBA could make up for many of the disadvantages in concrete made of OPC and limestone blended cement. Filler effect of limestone can play a significant part in improving the workability and concrete's early age strength whereas incorporation of SBA enhances latter age compressive strength of concrete. The objective of this study is to utilize SBA and limestone in concrete production as alternatives to cement. The effect of ternary cement on fresh, hardened and durability properties of concrete The blended concrete's workability properties, compressive strength, water absorption, RCPT, Sorptivity, water permeability and electrical resistivity are examined was studied in order to further investigate the potential of SBA and limestone in concrete.

3. Experimental study

3.1. Materials

3.1.1. Cement

OPC 53 grade cement produced by The Ramco cements limited was employed in this investigation complying with the provision of Indian Standard IS 12269:2013. The physical properties and chemical compositions of the cement are reported in Table 1.

3.1.2. Sugarcane bagasse ash

SBA were obtained from Subramaniyan Siva Sugar Cooperative Society and was oven dried for 24 hours and then grounded using a ball mill until they pass through 300 µm sieve as shown in Figure 1a. The physical properties and chemical composition of the SBA is listed in Table 1. The XRD pattern and SEM image of the SBA is shown in Figures 1b and 1c respectively.

Figure 1a. Sugarcane Bagasse Ash (SBA)

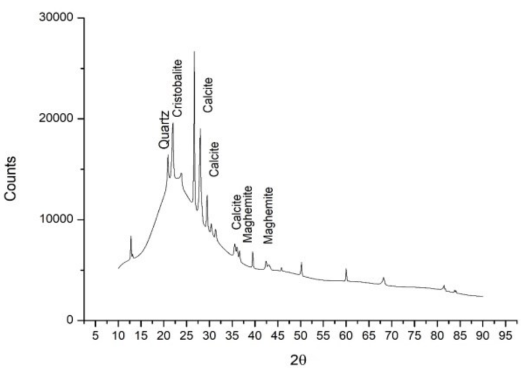


Figure 1b. XRD pattern of SBA

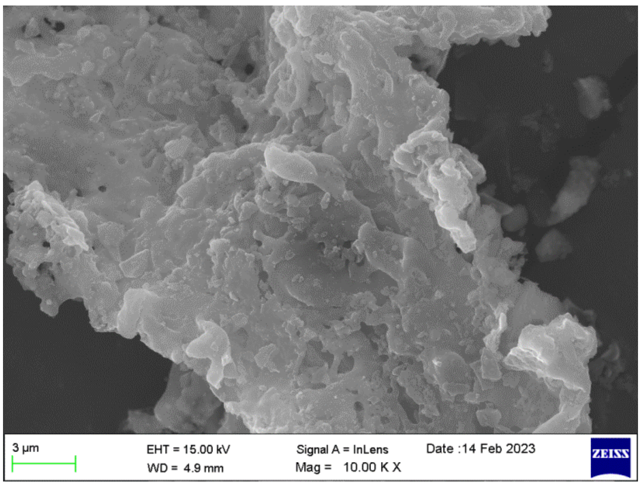


Figure 1c. SEM Image of SBA

3.1.3. Limestone

Commercially available limestone powder was employed in this study as shown in Figure 2a. The physical properties and chemical composition of the SBA is also listed in Table 1. The XRD pattern and SEM image of the limestone is shown in Figures 2b and 2c respectively.

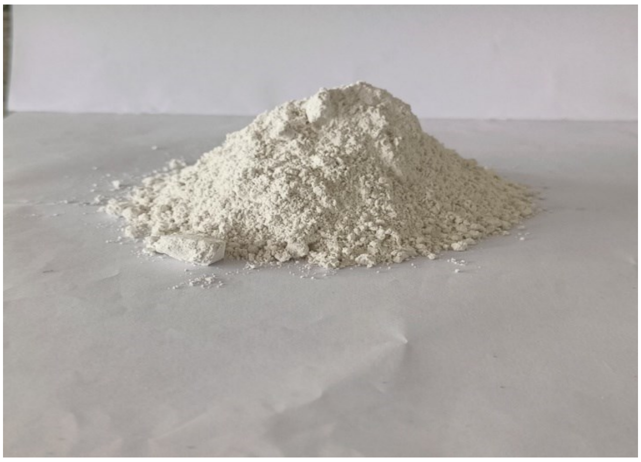


Figure 2a. Limestone

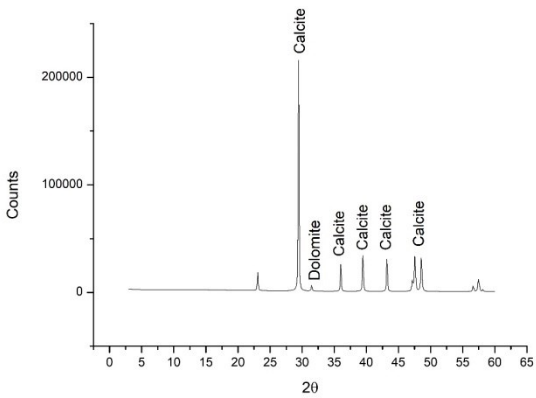


Figure 2b. XRD pattern of limestone

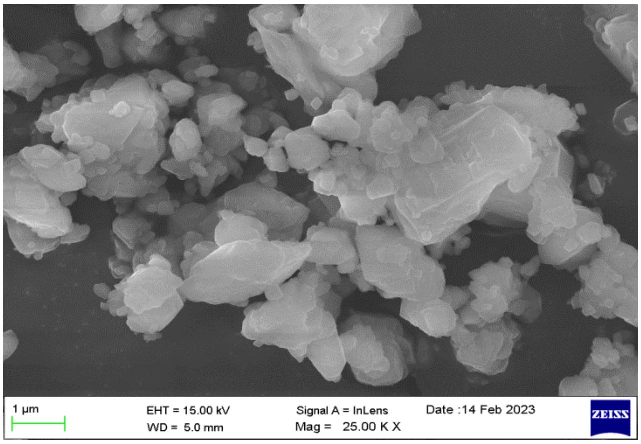


Figure 2c. SEM Image of limestone

3.1.4. Aggregate

The fine aggregate employed in this study was crushed granite rock of size less than 4.75mm, while the coarse aggregate used was a combination of 10mm and 20mm crushed granite. The physical properties of aggregate are listed in Table 2. Before mixing, aggregates were saturated surface dried.

Table 1 Physical and chemical composition of raw materials

Description	OPC	SBA	Limestone
Physical Characteristics			
Blaine surface [m^2/kg]	310	530	345
Specific gravity	3.11	1.96	2.60
Chemical Composition			
SiO_2	20.4%	72.5%	2.55%
Al_2O_3	3.1%	6.5%	0.65%
CaO	64.0%	3.8%	53.5%
Fe_2O_3	2.3%	3.8%	0.4%
MgO	1.2%	-	0.35%
SO_3	0.23%	1.5%	<0.01%
P_2O_5	-	3.1%	-
K_2O	0.13%	4.8%	-
LOI	1.2	8.26	44.5

Table 2. Physical properties of aggregates

S.No.	Physical Properties	Fine Aggregate	Coarse aggregate
1.	Specific gravity	2.65	2.75
2.	Bulk density (kg/m^3)	1580	1620
3.	Grading	Zone - II	Well graded
4.	Fineness modulus	2.54	6.11

Table 3. Proportions of concrete mixtures

Mix ID	Water Binder ratio	Cement (kg/m^3)	SBA (kg/m^3)	LS (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)		SP (%)
						20mm	10mm	
C	0.45	370	-	-	690	730	480	0.9
B-10	0.45	333	37		690	730	480	2.1
T-20	0.45	296	37	37	690	730	480	2.0
T-25	0.45	277.5	37	55.5	690	730	480	1.8
T-30	0.45	259	37	74	690	730	480	1.5

3.1.5. Superplasticizer

Sulphonated naphthalene polymers-based superplasticizer was used to achieve the slump value of 80-100mm.

3.2. Mix proportion and sample preparation

Five types of concrete mixes with fixed 0.45 water-cement ratio were examined and are shown in Table 3. All concrete mixes were prepared using pan mixer with a capacity of 50l. Aggregates and binder were dry mixed initially and then gradually water was added along with superplasticizer until the mixture was visually uniform. The total mixing time was restricted to 3 minutes. For each mix, twenty-one 150 mm cubes were cast for compressive strength, water absorption and water permeability tests. Four 150 mm x 300 mm cylinders were for determining the sorptivity and rapid chloride penetration test. All specimens were kept in the casting yard for 24 hours after casting. The specimens were then demolded and placed in a water bath to cure until the day of testing.

3.3. Test procedures

3.3.1. Workability

The slump flow test was conducted on fresh concrete as per IS 1199-1959 (1199 1959) to evaluate the workability of concrete and no segregation occurred in any mixes.

3.3.2. Compressive strength

According to IS 516-2021, the compressive strength of concrete cubes was determined using 3000kN CTM at 7, 28 and 90 days of curing. Three concrete specimens were tested for each mix to determine the average compressive strength.

3.3.3. Water absorption

The percentage of water absorption in hardened concrete is determined from the amount of pore volume filled by water in fully saturated condition. Water absorption of concrete specimens were tested in concordance with ASTM C642(American Society for Testing and Materials 1997) after 28 and 90 days of curing and calculated using the formula

$$Water\,absorption = \frac{B-A}{A} x\,100\% \quad (1)$$

Where A is mass of oven-dry sample and B is mass of saturated sample after immersion.

3.3.4. Rapid chloride penetration resistance

After 28 and 90 days, 150mm x 300mm cylinder is taken out of curing and 100mm diameter and 50mm thick slice concrete specimen are cut from it and examined for RCPT in accordance with ASTM C 1202(ASTM C1202 2012). The specimen was vacuumed for 3 hours and soaked in water for 18 hours in the vacuum saturation equipment. The specimens were then covered with epoxy sealant all over the cylindrical surface except for the sliced area as shown in Figure 3. A potential difference of 60 V dc is kept constant between two ends of specimen, one is immersed in 3% NaCl solution and other in 0.3 M NaOH solution. For a total of 6 hours, current was monitored every 30 minutes. The total charge (coulombs) transmitted through the specimen was calculated using following formula.

$$Q=(I_0+2I_{30}+2I_{60}+\ldots+2I_{330}+I_{360}) \quad (2)$$

where Q is the total charge transmitted; I_0 is the current measured instantly after voltage is applied; I_t is the current measured at time 't' after voltage is applied.

Figure 3. Sample examined for RCPT

3.3.5. Sorptivity test

The Sorptivity was measured on a 100 mm diameter and 50 mm thick slice covered with epoxy sealant, specimen cut from 150mm x 300 mm cylinder at 28 and 90 days. Specimens were positioned on wedges and the tray was filled with $Ca(OH)_2$ solution to 2 mm above the specimens' bottom surface as seen in Figure 4. Specimens were withdrawn for mass measurement at regular intervals, and the exposed face was softly cleaned with a cloth to create a saturated surface dry condition.

Figure 4. Test setup for sorptivity

3.3.6. Water permeability test

Three 150mm Cube were examined for water permeability test. In the water permeability apparatus, specimen is seated between neoprene gasket of cover plate. To prevent water leakage during testing, silica sealant was coated at the contact between the rubber gasket and the specimen. A water pressure of 0.5N/mm^2 was kept constant on the surface of specimen for 72 hours. The specimens were quickly removed from the permeability cell when the pressure was released and were split. The depth of water penetrated in the specimen is measured as the water penetration of concrete.

3.3.7. Electrical resistivity

The electrical resistivity test was also performed on saturated cylinder sample of height 200mm and 100mm diameter at 28 and 90 days of curing using a Proceq Resipod with four-point wenner probe with 38mm spacing.

4. Results and Discussion

4.1. Mineralogical investigation of SBA and limestone

Mineralogical investigation of SBA was examined by XRD technique. The XRD graph of SBA showed quartz, calcite, maghemite and cristobalite peaks with a major spike between 15^o and 30^o, which signifies the detection of amorphous silica in SBA. Furthermore, the current observations are consistent with past studies (Athira and Bahurudeen 2022). SBA, with a high amorphous silica concentration, proves to be an essential contribution to concrete. Figures 1b and 2b show SEM images of SBA and limestone. The SBA seemed to have irregularly shaped particles with a porous structure which has negative impact on the workability of concrete. The XRD pattern of limestone shows major calcite peaks along with weak dolomite peak. Limestone has angular and crystalline particles with smooth texture. Similar outcomes have been noticed by other researchers (Sua-Iam and Makul 2013; Thongsanitgarn *et al*., 2014).

4.2. Workability

Percentage of superplasticizer used for attaining target slump is showed in Table 3. The target slump value of 95mm was reached with 0.9% of superplasticizer in control concrete mix but with substitution of 10% SBA in B-10 mix fail to achieve it. Additional superplasticizer dosage of 1.3 time than control mix was required to achieve the targeted slump. Due to SBA's irregular morphology, excessively porous structure, and absorbent nature, mix containing SBA requires more superplasticizer to reach the targeted slump compared to control mix (Bheel *et al*., 2021). Addition of limestone to SBA incorporated concrete reduce plasticizer dosage. Increase in limestone content in concrete reduces the superplasticizer dosage to attain targeted slump because of the smooth round shape of limestone, which resulted in less friction force between particles thus improving the workability. About 30% reduction in superplasticizer dosage was observed for T-30 mix compared to B-10 mix.

4.3. Compressive strength

Figure 5 illustrates the compressive strength of all mixes. Compressive strength of all mixes increases with curing time, as anticipated. The compressive strength of control mix were 31.2, 39.5 and 45.6 MPa at 7, 28 and 90 days of curing respectively. At all testing ages, maximum compressive strength was observed for B-10 mix. At 28- and 90-days B-10 had a 5% and 10.7% increase in compressive strength compared to the control mix. This finding could be clearly demonstrated that increase in strength occur because of pozzolanic action of SBA. Furthermore, the increase in strength in presence of SBA also indicated that pozzolanic hydration of SBA occur gradually over time. Rerkpiboon (Rerkpiboon *et al*., 2015) observed similar result when 20 % SBA replacement in concrete improved the compressive strength by 12-13% than control mix at latter days.

The highest compressive strength for ternary concrete at 28 days and 90 days was observed for T-25 mix. At 90 days, the highest compressive strength in concrete specimens was 46.5 MPa for the T-25 mix, while the minimum compressive strength was 37.6 MPa for the T-30 mix. T-30 mix have lowest compressive strength at all testing ages; and reduction in the strength can be accounted for reduced cement content in concrete mix. T-25 mix exhibits enhanced compressive strength at 28 days and 90 days which may be due to i) The concrete containing SBA reacts faster in the presence of limestone because finer limestone provides additional sites for hydration and improves the reactivity of SBA. ii) The filler effect of the limestone powder, which improves the packing density of the concrete mix. Jiangtal discovered a similar trend of strength increase induced by limestone replacement in cement with 10% limestone and 20% flyash substitution (Jiang *et al*. 2020). This agrees with finding of DeWeerdt *et al*. who reported increased compressive strength when fly ash was blended with limestone and it appears that the presence of limestone in ternary cement can improve the compressive strength (De Weerdt *et al*. 2011).

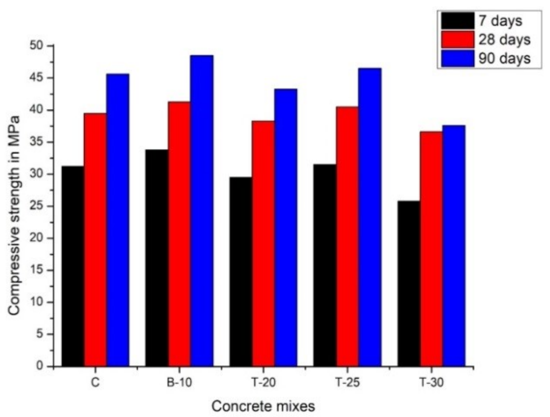


Figure 5. Compressive strength of concrete mixes at 7, 28 and 90 days of curing

4.4. Water absorption

Figure 6 shows the water absorption of all the concrete mixtures investigated at 28 and 90 days of curing, with values ranging from 2.85% to 6.12% by dry mass. It should be observed that 28 days cured specimens absorbed the more amount of water than 90 days cured specimen. As anticipated for all concrete, the absorption capacity declined consistently with increase in curing time due to pore volume reduction caused by filling up of additional hydration products formed during hydration. The water absorption observed on 90 days samples were reduced by 48.69%, 43.7%, and 45.1% in average comparing to those on 28 days ones for mix group B-10, T-20, and T-25 mixes respectively. B-10 mix shows higher water absorption percentage than control mix at 28 days, owing to presence of porous structure in SBA which absorb and retain more water in it. Whereas scenario is reversed at 90 days, water absorption is less compared to control due to formation of additional hydration product due to pozzolanic reaction of SBA which reduce pore volume. Ganesan *et al*. observed that water absorption rises with SBA concentration in concrete cured for 28 days because of hygroscopic nature of SBA which observe more water but as curing time increases, water absorption values decreased significantly (Ganesan *et al*., 2007).

Incorporation of limestone reduces the water absorption in SBA blended concrete. Reduction in water absorption with limestone addition in concrete was not significantly high when compared to B-10 mix upto 15% replacement. This was most likely due to the filler effect of limestone, which influences the microstructure of the concrete by enhancing packing density. Beyond 25% replacement, increase in water absorption is observed due to dilution effect.

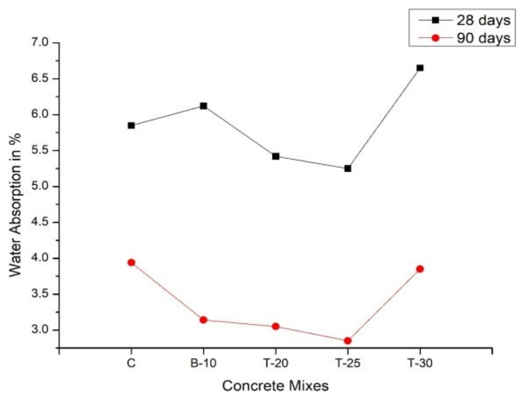


Figure 6. Water absorption at 28 and 90 days of curing

4.5. Water impermeability test

The water penetration depth was determined at 28 and 90 days as per DIN 1048-5 are displayed in Figure 7. Average water penetration depth for all mixes varies from 6.9mm to 18.5mm. At 28 days of curing, B-10 mix showed a significant reduction (25.41%) when compared to control concrete. After 90 days, B-10 mix penetration depth was decreased to 46.2% than control specimens. The test outcomes show that utilizing SBA in concrete greatly enhances the resistance of concrete to oppose water penetration. At 28 and 90 days, T25 showed least water penetration depth among other mix. Bahurudeen *et al* reported significant reduction in water penetration of SBA incorporated concrete under pressure and observed increase in resistance to water penetration with increase in SBA (Bahurudeen *et al*., 2015). Addition of limestone proves to be useful in improving resistance against water penetration. As a result of enhanced nucleation sites, a denser microstructure was formed with the incorporation of limestone and reduces the water penetration depth in concrete.

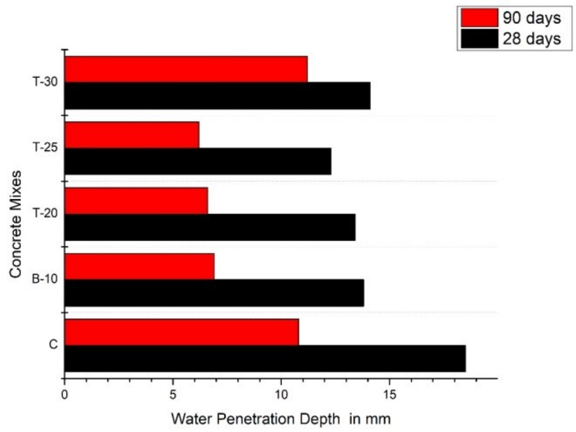


Figure 7. Water penetration depth of concrete mixes after 28 and 90 days of curing

4.6. RCPT

Figure 8 shows the results of RCPT. The charge transmitted through the control mix at 28 and 90 days of curing was 3210 and 2660 coulombs, respectively. The resistance of control mix from result obtained with respect to chloride ion penetration was classified as 'moderate' by ASTM 1202-12. Results show that the total current passed diminishes with age as the link between pores in the cementitious matrix reduces due to hydration processes. For all mixes, the accumulated charge passing values range from 3210 to 1130 coulombs at 28 days and 2660 to 745 coulombs at 90 days. In accordance with test results observed, substituting OPC with SBA and limestone resulted in a considerable drop in the charge passed. Incorporation of 10% SBA in concrete at 28 and 90 days reduces charge passed in concrete by 42% and 41.32% compared to control concrete. The discontinuous pores and pore refinement in B-10 mix as a result of pozzolanic performance cause the reduction in total charge passed. Guidelines categorize B-10 mix at 28 and 90 days as 'low' permeability. Praveenkumar *et al* concluded that SCBA lowers chloride penetration in HPC mixtures by up to 10% replacement. The path for ions shrinks as a result of pore structure refinement caused by the pozzolanic reaction and the micro filler impact of bagasse ash (Praveenkumar *et al*., 2021). Similar result were reported by many authors (Arenas-Piedrahita *et al*., 2016; Bahurudeen *et al*., 2015; Bayapureddy *et al*., 2020). Furthermore, ternary blended concrete mixes are superior to B-10 mix in terms of resistance against chloride penetration because of its fine composition. Chloride permeability reduced as the amount of limestone increased. T-20 and T-25 mix are classified as 'very low' as per specification in by ASTM 1202-12. Dave *et al*. observed considerable reduction in total charge passed in quaternary blend than binary and control blends, which is attributable to an increase in the volume of pozzalans in the mortar mix (Dave *et al*., 2016). Gesogˇlu *et al*. shown that substitution of limestone filler (5-10%) generally enhance the chloride penetration resistance of the ternary blended concretes (Gesoğlu *et al*., 2012).

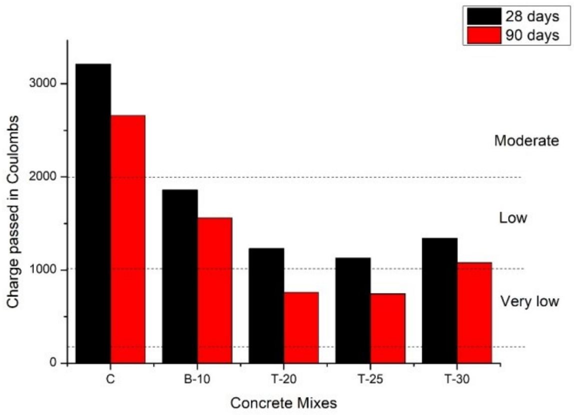


Figure 8. Total charge passed at 28 and 90 days

4.7. Sorptivity

Figure 9 illustrates sorptivity values for all concrete specimens tested at 28 and 90 days. Comparing the 28 and 90 days Sorptivity values for the control mix, no significant variation in Sorptivity value was noticed whereas in binary and ternary blended concrete marked reduction in sorptivity values at 90days was observed. For instance, after 90 days, the sorptivity for the T-25 mix was 2.33 times as small as that for the T-25 mix at 28 days whereas for the control mix was only 1.12 times as small as that for the same at 28 days. Water sorptivity of B-10 mix was reduced upto 27.81% and 61.81% compared to control mix at 28 and 90 days. This indicates that the inclusion of SBA proves helpful in improving resistance to unidirectional sorption Rajasekar *et al*. reported that regardless of curing days, a reduction in sorptivity was seen when cement substitution with treated bagasse ash increases and concluded that addition of fine elements in concrete reduces sorptivity. Amin *et al*. observed reduction in sorptivty with increasing the SBA and nano eggshell powder ratios in HPC mixes as result of C-S-H structure formed by pozzolanic reaction of SCBA (Amin *et al*., 2022).

Inclusion of limestone in concrete reduces the sorptivity value but not notably. Maximum reduction of 13.5% and 20.8% was observed for T-25 mix at 28 and 90 days compared to B-10 mix. Ghrici *et al*. revealed that incorporation of 15% limestone with cement in concrete for the w/b ratio of 0.6. at 28 and 90 days of age decreases the sorptivity of concrete by 2% and 9%, respectively (Ghrici *et al*., 2007). Similar result were observed by Tsivilis *et al*. , while replacing 15% of concrete with limestone at w/b = 0.7 had an negligible influence on concrete (Tsivilis *et al*., 2003).

4.8. Electrical resistivity

Figure 10 shows the electrical resistivity test results of concrete mixes at 28 and 90 days. For all mixes, the results indicate a considerable rise in electrical resistivity with age. Electrical resistivity of control mixes at 90 days increases by 2.4 times than electrical resistivity at 28 days. 10% SBA replacement levels improved electrical resistivity considerably and displayed increasing trends. The addition of SBA, which react with portlandite to generate more C-S-H, causes an increase in the electrical resistivity. This reaction has a direct impact on the microstructure of the concrete because the formation of additional new hydration products improves the cement matrix and reduces porosity along with pore interconnectivity. Furthermore, as a result of the continual cement's hydration, there is a pore system discontinuity that causes blockage, hinders ionic transport in the pore, and reduces the ionic concentration of the solution. Joshaghani *et al*. reported that addition of SBA in cement concrete improve the electrical resistivity concrete at 28 and 98 days (Joshaghani *et al*., 2017).

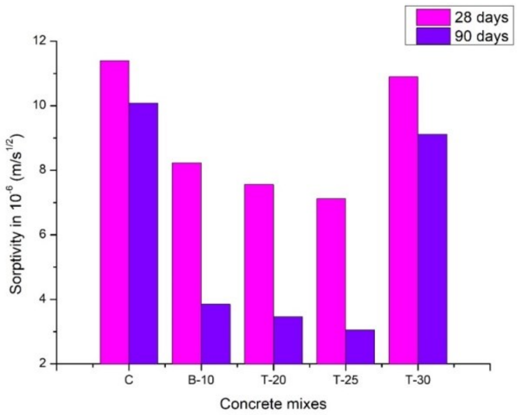


Figure 9. Sorptivity value at 28 and 90 days

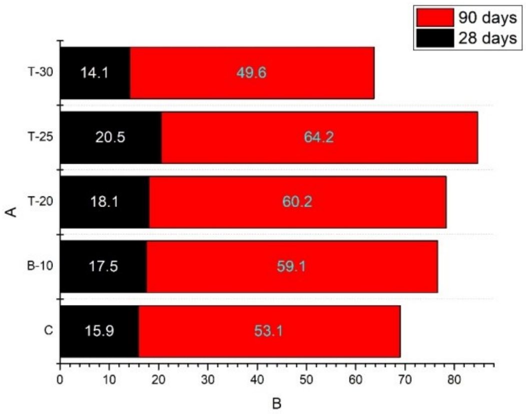


Figure 10. Electrical resistivity at 28 and 90 days

At 28 days, electrical resistivity of ternary blended concrete T-20, T-25 and T-30 mix were 18.1 kΩ cm, 20.5 kΩ cm and 14.1 kΩ cm. After 90 days, the T-25 mix had the maximum electrical resistivity of 64.2 kΩ cm and T-30 mix have the lowest electrical resistivity of 49.6 kΩ cm. Incorporation of limestone improve the electrical resistivity of ternary blended concrete. Similar result were observed (Gesoğlu *et al*., 2012).

5. Conclusions

The following observations were drawn from the investigations:

1. Substitution of cement with SBA increases the superplasticizer dosage because of the porous structure of SBA but incorporation of limestone in ternary blended concrete reduces the superplasticizer dosage. The superplasticizer dosage of B-10 concrete reduce from 2.1 to 1.5% with addition of 20% of limestone in T-30 mix
2. For all days, the compressive strength of B-10 mix was higher than the other mixes, which is 5% and 6% higher than control mix at 28 and 90 days. Maximum compressive strength for ternary blended concrete was observed for 10% SBA and 15% limestone at 28 and 90 days.
3. Water absorption for B-10 mix was higher than control mix at 28 days because of hygroscopic nature of SBA and subsequently reduced at 90days. Ternary blended concrete T-25 mix showed 27.77% less water absorption than control mix at 90 days.
4. The utilization of SBA and limestone in concrete reduces the permeability of concrete, improves the resistance to water and chloride penetration in concrete. The incorporation of limestone up to 15% in ternary blended concrete decreases its permeability. For T-25 mix, a significant reduction in permeability of 33.5 % was observed at 28 days.
5. The use of limestone and SBA in concrete contributes to its densification, resulting in pore structure refinement caused by pozzolanic activity, which improves durability properties of concrete.
6. It proved that a presence of limestone powder was adequate to improve the performance of concrete, beyond 25 % of replacement adversely affect the concrete properties.
7. Overall, the use of limestone powder can lower cement consumption, and sustainability of concrete production. It enhances compressive strength and durability properties to a greater extent for ternary blended concrete.

Recommendation on future research

1. The effect of ternary blended cement with regard to other durability properties like steel corrosion, chloride induced corrosion and carbonation can also be studied.
2. The life-cycle assessment (LCA) of the ternary blended concrete can be studied

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