OPEN ACCESS

Kashf Journal of Multidisciplinary Research
Vol: 02 - Issue 07 (2025)
P-ISSN: 3007-1992 E-ISSN: 3007-200X
https://kjmr.com.pk

DURABILITY AND MECHANICAL CHARACTERISTICS OF BINARY BLEND CONCRETE: IMPLICATIONS FOR RESOURCE CONSERVATION

[1]Waqas Aziz, [2]Muhammad Shoaib Ashraf, [3]Khawaja Adeel Tariq, [4]Hafiz Muhammad Faisal, [5]Hafiz Muhammad Saud*

[1,2]Department of Civil Engineering, The University of Faisalabad, 38000 Faisalabad, Pakistan

[3] Department of Civil Engineering, University of Engineering and Technology Lahore, 54890 Lahore Pakistan

[4]Department of Civil Engineering, University of Southern Punjab , Multan, Pakistan

[5]Department of Civil Engineering, Bahaudin Zakariya University, Multan, Pakistan

*[*]**Corresponding author:*** waqasaziz30@gmail.com

Article Info

Abstract

The cement industry is the major source of carbon dioxide emission and consumption of natural resources which is causing irreparable damage to the environment. Therefore, finding alternative materials to reduce emission and consumption of natural materials becomes a great concern. There are materials that are produced as by product such as Fly Ash, Rice husk Ash and Bagasse Ash etc can be used in concrete for conservation and the circular economy. Utilization of these resources minimize waste diverting from landfills and significantly lowering the carbon footprint. This innovative approach enhances the mechanical and durability of concrete leading towards long lasting structures. Fly Ash and Bagasse Ash are selected to make sustainable concrete blends. twelve mixes of binary concrete were formed incorporating Fly Ash and Bagasse Ash. In the first phase optimization of Fly Ash and Bagasse Ash replacement was done at different replacement levels including control mix. After finalizimg the mixes, testing was done to investigate the fresh, Mechanical and durability properties. In the optimization of concrete the binary concrete mix C70F30 and mix C80B20 showed good results and can be used for sustainable development in civil engineering.

Keywords:
Binary Blend Concrete, Sustainable Concrete, Fly Ash Concrete, Bagasse Ash Concrete, Durability Properties.

1. Introduction

The greenhouse effect is the most serious issue nowadays to maintain the sustainability of the environment. The concentration of CO2 develops 85% of greenhouse gasses and should decrease from its historical value of 390 parts per million. [1, 2]. Greenhouse gases consist of carbon dioxide, methane, nitrous oxide and other fluorinated gases. The primary source of CO2 emissions is human activity through burning of fossil fuels such as coal, natural gas and oil for energy and transportation. 50–65% of total metahe (CH4) emission is because of energy, industry, agriculture, land usage and waste management. Similarly, 40% of nitrous oxide (N2O) emissions comes from agriculture, transportation, industry and other activities. Ozone depletion, industry and the transmission and distribution of power are the main sources of emissions of fluorinated gases [3]. There are many other sources that contribute toward the CO2 emission including the production of cement. The construction sector is one of the biggest sectors of producing concrete and cementing materials as the production of 1 ton of binder releases a similar amount of CO2 that is 5-7% of the overall emission. The CO2 emission is linked with the cement industry as modern cement contains 84% of cement clinker. The cement clinker productions emit a large quantity of CO2. Cement production reached up to 85.4 million tons globally in 2018 with an increasing rate of 12% since 2013[4, 5]. In 2022, the production was reported as 4.1 billion metric tons and it is expected to increase with a growth rate of 5.3%. The cement Production capacity of Pakistan is around 83 million tons and that is expected to increase by 99 million tons till 2024 and Pakistan has produced 57 million tons of cement in 2021 [6]. The CO2 emission from concrete production also includes the extraction process of raw material, manufacturing, installation, transportation and decomposition [7, 8].

The housing and advanced infrastructure development, the demand of materials and advanced techniques is increasing day by day [9]. In this scenario researchers are working on less valuable and waste materials that have pozzolanic properties [10]. Blend concrete using supplementary cementitious materials (SCMs) having good response in performance and economy compared to normal concrete [11]. These SCMs materials including ground granulated blast furnace slag (GGBS), lime sludge, silica fumes and Fly Ash (FA) are using to increase mechanical properties [12, 13]. The use of industrial and agro- waste can solve the problem of disposal and pollution caused by these materials and also reduce the emission of greenhouse gases [14]. The benefits of using SCMs in concrete are mainly to enhance the concrete properties, less economy and ecological concrete [12, 15]. The selection of FA and BA is based on their abundant local availability to use in sustainable blend concrete that is suitable for low-cost housing and affordable construction. Utilization of these materials reduces environmental impact and helps in resource conservation and potential cost savings in construction materials. However, they also present challenges related to variability in quality and require careful handling.

2. Materials and Methodology

There are various variety of materials are available and an opportunity of selecting the finest conceivable material with minimum manufacturing costs could be a major challenge. The selected materials for this study are OPC Type-I cement conforming to standard specification ASTM [16, 17], Coarse Aggregates (Sargodha crush) conforming to standard specifications ASTM [18],Fine Aggregates (Chenab sand) meeting the requirement ASTM [18], Fly Ash fulfilling the standard ASTM [19] and Natural pozzolanic material ASTM [19] from district of southern Punjab of Pakistan. The additional pozzolanic materials used in this study is Fly ash and Sugarcane Bagasse Ash. Sugarcane bagasse ash is produced as a residue by the process of obtaining sugar and alcohol [20]. Fly Ash is the fine residue of coal burning in the coal-based power generation plants [21]. The portable drinking water is used for the mixing of concrete.

2.1 Origion of Fly Ash and Sugacane Bagasse Ash

Fly Ash is produced by the combustion of coal in coal power plants and steam generators. As per the economic survey of Pakistan 2021-2022, coal power plants are producing 5280MW of electricity in which 1320MW is produced through Thar Power Plant. A total of 160 million tons of coal fly ash is produced annually in Pakistan [22]. However, Bagasse Ash is being produced by the combustion of sugarcane waste. Pakistan is the fifth largest sugarcane producer in the world. The cultivated area of sugarcane in Pakistan is 1270000 hectors with a production of 83.15 million tons [23]. Pakistan is the world's fifth-largest sugarcane producer and the eighth-largest consumer of cane sugar. Sugarcane is grown in an area of 1.2 million hectares and gives raw material to 90 mills in Pakistan. Punjab is the most sugarcane producing province of Pakistan with 66% contribution of total sugarcane production.

2.2 Fly Ash

Firstly, searches have been made and it was found that that FA is being produced in coal plants in Muzaffargarh and coal-fired boilers in Lahore. A visit has been arranged to a steam boiler located at Multan Road Lahore and tried to understand the procedure of Fly Ash production. It was also observed that how the Fly Ash is being treated to make it useable for agriculture or any other purposes.

2.3 Sugarcane Bagasse Ash

Sugarcane is being produced majorly in southern areas of Punjab, Sindh and Khyber Pakhtunkhwa. Visit was made to sugar mill in south Punjab (Kot Addu) to understand the production process of BA and collected from there in crude form. Sugarcane Bagasse Ash was collected from the sugar mill in crude form having moisture content. So, it was dried for a few days to remove the moisture and then sieved thoroughly to attain a proper particle size for better performance in the concrete mix.

2.4 Mix Design Proportion

The mix design method is the standard criteria for selecting the material so that a designed strength can be achieved by using the proportions of cement, aggregate and water. The mix design was conducted by the standard method of practice used for the selection and proportion of material ACI PRC-211.1-09 [24] that includes a proper proportion of materials for normal weight, heavy weight and mass concrete.

2.5 Mixing of Concrete

Concrete mixes are made according to the mix proportion by weight batching. For mixing of concrete, coarse aggregate and sand are mixed thoroughly in the concrete mixer, after mixing of coarse and fine aggregate cement was added to the concrete mixer for the proper dry mixing of material. After dry mixing water as per w/c ratio is added to the mix and mixing is done until a consistent color and paste appear in the mix.

2.6 Casting and Curing

After the mixing of concrete, the casting and curing process was started as per ASTM C192/ C192M[25], the steel molds were oiled properly and tightened up for proper shape of concrete samples. Concrete was poured into the mold in three layers with 30 blows on each layer then placed on a vibrating table to remove air bubbles from the concrete mold. The surface of the mixes was trimed and placed for the hardening of concrete samplesas shown in (Figure 11).

Figure 1 Casting of Concrete Specimen

Minimum three mixes were casted for the testing of hardened and durability properties of concrete. After 24 hours, the demolding process was started and placed the sample in the curing tank. All the concrete samples were cured in continuous moist curing till the age of testing with the water temperature of about 26 ± 3 °C except the samples used for accelerated curing technique.

2.7 Specimen's Testing

2.7.1 Workability of Concrete

Slump cone test is used to check the ease of transportation and placement of concrete during the construction process. This procedure includes a slump cone, tamping rod, mixing tray and measuring scale as per ASTM C143/ C143M [26]. For measurement of slump value mixing of concrete was done using the mix design ratio and the amount of cement, sand, aggregate and water were mixed thoroughly and filled the material in the slump cone apparatus in three layers with 35 blows on each layer. After this, the slump cone was lifted (Figure 22) asked the concrete to settle on his weight and measured the height of the drop with the help of a scale.

Figure 2 Slump Cone Test

2.7.2 Density

After mixing of concrete the concrete mold of known volume was filled in three layers with 20 strokes on each layer and divided the weight with the volume given the density of concrete as per ASTM C1688/ C1688M [27].

2.7.3 Compressive strength

After demolding of the concrete specimen, compression test was performed at the age of 7, 14, 28, 56 and 90 days as per ASTM C39/ C39M [28]. The compressive strength includes a compression testing machine of 1000kN capacity to measure the strength as shown in (Figure 33) . The concrete specimen's capping was done with the help of plaster of Paris to level the top surface and placed in the testing machine. The loading was applied with a constant rate of loading without any shock with 0.2MPa/s (0.15-0.35MPa/s). At the point of failure, the amount of failure load and divided it with surface area to have compressive strength of concrete.

Figure 3 Compressive strength of Concrete

2.7.4 Splitting tensile strength

ASTM C496 / C496M[29] was followed to measure the splitting tensile strength of concrete. The apparatus involves testing machine, bearing bar and bearing plates. First of all, measured the length (L) and diameter (d) of the concrete specimen and placed the sample in lateral position and placed the bearing rod on the concrete cylinder. The loading rate was kept constant without shock on the cylinder until the sample split in two halves and recorded the load (P) as shown in (Figure 44).

$$\textbf{Spliting Tensile Strength} = \frac{2P}{\pi \mathrm{Ld}} \quad \text{.......................} \quad \textbf{(1)}$$

Figure 4 Splitting tensile strength of Concrete

2.7.5 Flexural Strength

istest is used to measure the flexural strength of concrete as per ASTM C78/ C78M [30]. This test includes testing the machine and assembly of loading for flexural strength of the concrete specimen. The prism 100mm*100mm*500mm was placed in a loading assembly and the load was applied with the constant loading rate of 1MPa/min (0.86-1.21MPa/min) on the concrete prism as shown in (Figure 55). The crack appeared so the flexural strength was calculated by the formulation as given under where “L” is length, “b” is width and “d” is the depth of the prism.

$$\textbf{Flexural Strength} = \frac{PL}{bd^2} \quad \text{(2)}$$

Figure 5 Flexural Strength of Concrete

2.7.6 Water Absorption

Water absorption is the measure of strength and durability of concrete. More water absorption indicates a larger number of voids in the concrete and hence lesser strength and durability of concrete. The water absorption is measured by ASTM standard ASTMC642 [31]. The concrete sample is dried in an oven for 24 hours at 100°C- 110°C and weighed it as A. The sample was immersed in water for 24 hours for saturated condition and then kept outside the water for saturated surface dry condition and weighed it as B. The water absorption was calculated using the given formulation.

$$\textbf{\textit{Water Absortion}} = \frac{(B - A)}{A} * 100 \quad \text{(3)}$$

2.7.7 Sorptivity

This property of concrete gives clear indication of performance of concrete in an aggressive environment, surface of concrete and permeability of concrete. The procedure to measure water absorption includes support assembly, timing device, weighing machine and caliper as per ASTM C1585-20 [32]. The specimen’s weight was taken and sealed from the side and placed in the pan with 2mm gap between surface of pan and poured water up to 3mm in the pan (Figure 66).

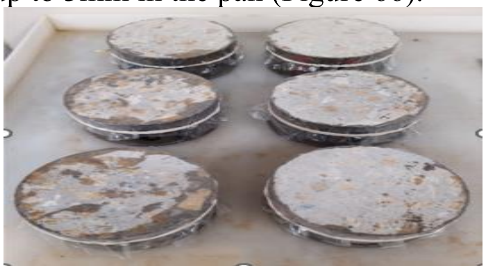

Figure 6 Sorptivity setup for concrete Specimen

The weight of sample was recorded on regular interval after clearing the surface of the concrete so that no extra water remains in contact. In the given formulation of water absorption "I" is the absorption, "m" is the change in mass in gram, "d" is the density in gram per cubic millimeter and "a" is the contact area in square millimeter. The rate of water absorption was calculated using the given formulation.

$$\textbf{Water Absorption (I)} = \frac{m_t}{\text{ad}} \quad\quad \textbf{(4)}$$

After Calculating the values of (I), a graph was drawn between "I" and square root of time. After few values a trend line was drawn and a value of Sorptivity is selected on desired duration from the graph.

3. Results and Discussion

3.1 Tests on Cement

The values obtained from different tests performed according to the ASTM procedure are given in (Table 1). So, the selected cement has suitable properties for the development of sustainable concrete.

Table 1 Properties of Ordinary Portland Cement

Sr. No.	Properties of Cement	Obtained Values
1.	Consistency	32%
2.	Initial Setting Time	42min
3.	Final Setting Time	8hr
4.	Fineness of Cement	7%
5.	Soundness (Expansion) of Cement	2mm
6.	Specific gravity of Cement	3.12

3.2 Tests on Coarse Aggregate

Coarse aggregates are those material that retained on sieve No. 4. The coarse aggregates are natural crush stone. Sargodha crush is used as coarse aggregate in this research. The value obtained from different tests are given in (Table 2).

Table 2 Properties of Coarse Aggregate

Sr. No.	Properties of Coarse aggregate	Obtained Values
1	Rodded Bulk Density	1662kg/m3
2	Specific Gravity	2.59
3	Water Absorption	0.6%
4	Fineness Modulus	6.73

3.3 Tests on Fine Aggregate

The material passing through sieve No. 4 fall in the category of fine aggregate. The fine aggregates used are natural sand particles. Chenab sand is used as a fine aggregate in this study. The value obtained from different tests are given in (Table 3).

Table 3 Properties of Fine Aggregate

Sr. No.	Properties of Fine Aggregate	Obtained Values
1	Rodded Bulk Density	1571.13kg/m3
2	Specific Gravity	2.505
3	Water Absorption	1.24%
4	Fineness Modulus	1.81

3.4 Mix Proportion

Mix proportioning was done using the material properties that were calculated to study the behavior of materials used for the concrete. ACI 211.1-09 is used for the material proportioning of concrete. The mix design was conducted for design strength of 21MPa for the control mix as the minimum strength criteria for the structural concrete according to ACI318. The w/c ratio is 0.59 and the aggregate to binder ratio is 5.65. The mix code explains the substitution level of SCMs in the particular mix as Control mix containing 100% cement. The mixes from mix 2 to 12 depicts the binary blend concrete having the replacement of single SCM such as Mix 2 to mix 7 describes the replacement of Fly Ash with cement as C65F35 mix contains 65% of cement and reaming 35% of Fly Ash. Similarly, mix 8 to 12 designates the replacement of Bagasse Ash as C85B15 contains 85% of cement and 15% of Bagasse Ash. The selected quantities of constituent materials of various concrete mixes are described in (Table 4).The mixes of binary and TBC were repeated randomly to check and validate the performance.

Table 4 Mix Proportions of Concrete Mixes

Sr No.	Mix Code	Materials (kg/m^3)					
		Cement	FA	BA	Sand	Aggregate	Water
1.	Control Mix	314	-	-	712	1065	200.22
2.	C90F10	282.6	31.4	-	712	1065	200.22
3.	C85F15	266.9	47.1	-	712	1065	200.22
4.	C80F20	251.2	62.8	-	712	1065	200.22
5.	C75F25	235.5	78.5	-	712	1065	200.22
6.	C70F30	219.8	94.2	-	712	1065	200.22
7.	C65F35	204.1	109.9	-	712	1065	200.22
8.	C95B5	298.3	-	15.7	712	1065	200.22
9.	C90B10	282.6	-	31.4	712	1065	200.22
10.	C85B15	266.9	-	47.1	712	1065	200.22
11.	C80B20	251.2	-	62.8	712	1065	200.22
12.	C75B25	235.5	-	78.5	712	1065	200.22

3.5 Workability of Concrete

The workability of concrete is measured by slump cone and comes in the range of 60- 77mm from the top surface of the concrete. It can be observed that the addition of SCMs causes increase in slump value. The increase of Fly Ash substitution from 0 to 35% caused an increase in slump from 60mm to 77mm. The increase in slump is about 3% at 10% addition and around 23% increase at 35% dosage of Fly Ash. Similarly, the increased substitution of Bagasse Ash increases the slump from 60mm to 72mm as the slump increase was observed from 3% to 16% at the substitution level from 5% to 25%. The detailed values of slump of various mixes can be seen in (Figure 67). It can be seen that the workability increases as the addition of Fly Ash increases up to 35% and the same trend is followed by the Bagasse Ash up to 25%. The increase in slump was because of the spherical shape of Fly Ash and the fineness and glassy texture of Bagasse Ash particles.

Figure 6 Workability of concrete mixes

The same property has been investigated by the researcher and it is concluded that Fly Ash addition enhances the workability of concrete. The increase in a slump of concrete is because of the spherical shape of Fly Ash that reduces friction between the binder and coarse aggregate. It also reduces the surface to volume ratio that decreases water demand as well [33]. The addition of Bagasse Ash also increases the slump value of concrete because of finer particle size than cement and the glassy texture [34].

3.6 Density of Concrete

The density of concrete indicates the weight of the overall structure and it affects some of the properties of concrete. The density of concrete is measured by concrete mixes. It can be seen that the density of the control mix is 2393kg/m3. The density of all the mixes falls in the range of 2345-2389kg/m3 which means all the concrete mixes are of normal weight concrete. The density keeps on decreasing as the cement is replaced by FA and BA. The decrease in density with Fly Ash replacement was up to 1.37% and 2.21% decrease with the replacement of BA compared to control mix as shown in (Figure 8).

The reduction in density was due to the reduction in the amount of cement that leads to lesser amount of hydrates at early stages. However, after prolonged age the density was increased because of the pozzolanic reaction of SCMs and hydration of cement present in the mix. It has been investigated that the density of concrete containing SCMs reduces at an early age because of the lesser volume of hydrate in the microstructure of concrete due to the lesser amount of cement in the concrete [35]. The density of concrete containing SCMs increases with age because of continuous hydration and pozzolanic reaction within the concrete that results in denser microstructure of concrete [36, 37].

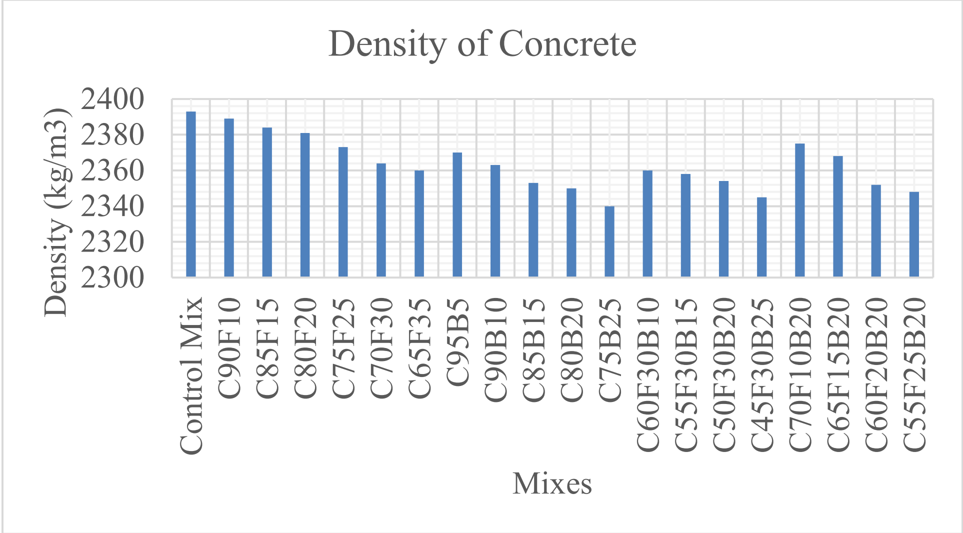

Figure 7 Density of Different Concrete Mixes

3.7 Compressive Strength

The compressive strength of concrete indicates the suitability of concrete for structural members and it is an important parameter for quality assessment of concrete. The mix design ratio was used as 1:2.26:3.4 with w/c ratio of 0.59. The mix proportioning of concrete is done for achieving a concrete having a strength of 21MPa. It was found that at 28 days strength of control mix was 23.45MPa that is above designed strength. Although, the concrete strength obtained with replacement of Fly Ash comes in the range of 23.08-26.91MPa. As the FA content increases the strength of concrete increase up to a replacement of 30% while it reduces at 35% fly ash replacement. The strength of concrete increase from 23.45 to 26.91MPa that is 15% higher strength than control concrete with a replacement of 30% fly ash. Similarly, the concrete strength with Bagasse Ash falls in the range of 22.73-26.8MPa. However, the replacement of Bagasse Ash with cement also increases the strength of concrete from 23.45MPa to 26.8MPa that is 14.2% higher strength than Control concrete at a 20% replacement of Bagasse Ash. The strength reduces if the replacement of Bagasse Ash is more than 20%. It can be seen that for binary blend concrete the concrete offers maximum strength at a 30% replacement for Fly Ash and at 20% replacement for Bagasse Ash. The strength of concrete with replacement of both FA and BA gives the strength in the range 21.3-27.42MPa that is also used as structural concrete in the slab.

The increase in strength is because the particles of FA and BA are finer than cement that fills the empty spaces present in concrete mix to give a good packing density and the pozzolanic reaction of silica, alumina with the portlandite that results in the filled pores with the C-S-H gel and hence increase in mechanical properties. It has been investigated that the increase in mechanical strength is because of the filler effect of fine particles and the pozzolanic activity of Bagasse Ash [38, 39]. It is also reported that a reduction in strength is noticed for more than 30% replacement of Fly Ash [40] while a reduction in strength for 20% of Bagasse ash [41]. The reduction in strength is due to the lack of Portlandite in the concrete mix for that much content of SCM [42].

It can also be seen from the (Figure 8) that all the mixes showed 28 days compressive strength more than 21MPa which means any concrete mix can be used as a structural concrete [43]. The minimum strength is shown by C55F25B20 which is also 21.3MPa while C45F30B25 showed a strength of 21.56MPa that can also be used as structural concrete. For both the above-mentioned mixes cement content is 55% and 45% respectively. For sustainable development both mixes can be utilized in place of Control mix because it has 100% cement content. The more the cement content the more hazardous to the sustainability of the environment due to the more carbon emission from the manufacturing of the cement. The gradually increasing need for cement due to population growth leads to the reduction of non-renewable resources also causing dust pollution along with CO2 emission [44].

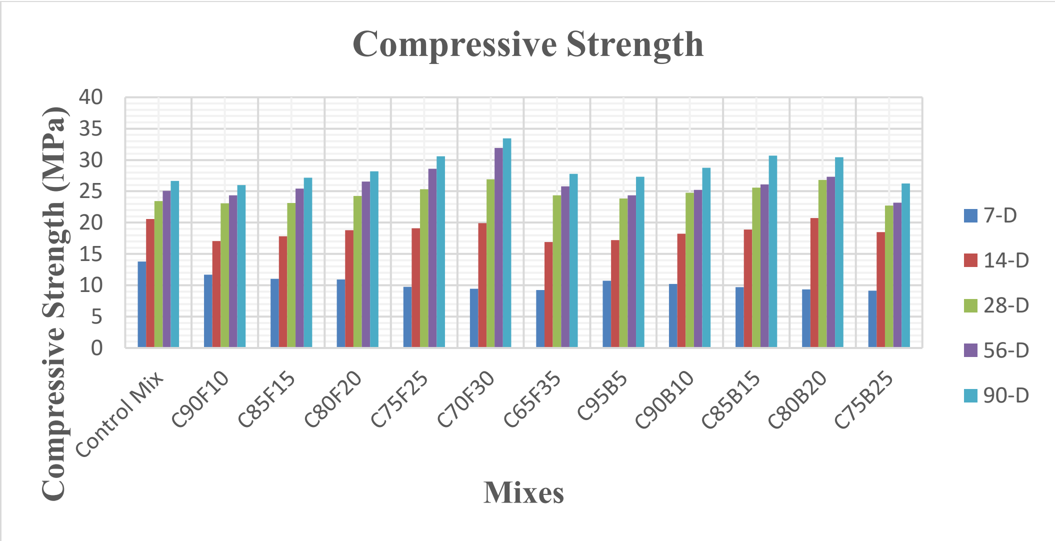

Figure 8 Compressive strength of concrete

Keeping in mind the lesser amount of CO2 emission and lesser destruction of natural resources, the use of binary and ternary blend concrete is beneficial for the environmental suitability point of view. On the other hand, FA and BA have issue in the rate of gain of strength at early ages. The rate of reaction of FA is slow compared to OPC (Ordinary Portland Cement) at the early age of 1 and 7 days but after this it gains the strength at a faster rate and at the age of 28 days it offer more strength than normal concrete. The slow rate of reaction was due to the slow rate of reaction of binary and TBC due to the presence of Pozzolans that prolong the setting time of cement. It has been studied that the inclusion of Pozzolans prolongs the setting time because of cement dilution, latent hydraulics and pozzolanic properties that lead to reduction in mechanical and durable properties at the early age [45] but the extended setting time is favorable for hot weather concreting [46].

3.8 Tensile Strength

The tensile strength of concrete is significant regarding the durability and serviceability of concrete structures. It can be seen that the tensile strength of the control mix is 2.53MPa at the age of 28 days as shown in (Figure 10). However, the strength of concrete with the replacement of Fly Ash also increases with the increase in FA content similar to compressive strength up to replacement of 30% and it was found to be in the range of 2.55-2.91MPa. The maximum strength is offered by the C70F30 mix containing 30% of FA. The 28 days tensile strength of Fly Ash concrete is 0.7-15% higher than the control mix. However, the strength decreases with a further increase in FA content. Similarly, the BA concrete shows an increasing trend of strength as the replacement of BA increases up to 20% and it is from 2.63-2.95MPa which is 3.9-16% higher strength than the control mix. The maximum strength is shown by C80F20 which is 2.95MPa. However, it decreases with 25% replacement of BA and was 2.5MPa. The increase in strength is beacused of the pozzolanic behavior of FA and BA and after a certain limit it keeps on decreasing because of higher amount of Pozzolans than the liberated lime. It has been investigated that the gain in strength is due to the pozzolanic properties of BA and FA [47, 48].

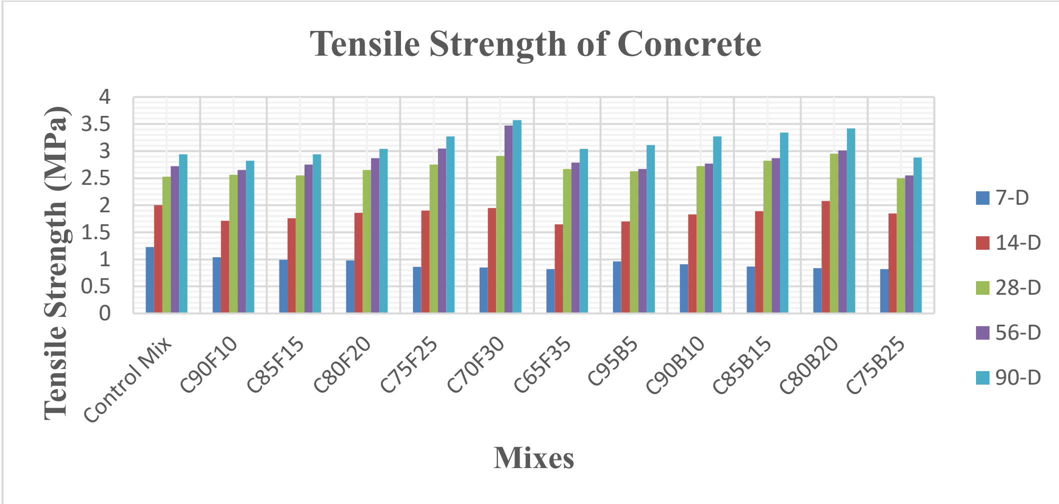

Figure 9 Tensile strength of concrete mix

The cement will be more environment friendly if the cement content is less in the concrete. This has been investigated by researchers that cement can be reduced by using alternative materials for environmental sustainability [49]. The improvement in strength at early ages is similar to the compressive strength of concrete mixes. At an early age due to the presence of FA and BA, the rate of gain of strength was slow but improved after the age of 7 days. The decrease in strength is due to the slow hydration of FA and BA while the increase in strength is due to the reaction of silica and alumina reaction with Calcium hydroxide. It has been reported that the decrease in strength at an early age is due to the slow hydration of Pozzolans [47] and the increase in strength is because silica present in Pozzolans reacts with alumina and $Ca(OH)2$ and increases the strength [50].

3.9 Flexural Strength

The flexural strength of concrete is the indirect measure of the tensile strength of concrete. The flexural strength of all the mixes is measured and found satisfactory results for all the mixes. It can be noticed that the flexural strength of the control mix at the age of 28 days is found to be 3.38MPa. It followed the same trend of increasing strength at various ages and replacement levels as of compressive and tensile strength as shown in (Figure 11). As the percentage replacement of FA increases the flexural strength of all the mixes increases and the strength falls in the range of 3.37 to 3.62MPa at different substitutions. The increasing trend goes well up to 30% of FA and after that it decreases. The increase in flexural strength up to 30% is from 0-7% compared to control concrete and at 35% replacement it decreases. The maximum strength is at 30% replacement and is found to be 3.62MPa. Similarly, the Bagasse Ash replacement increased the flexural strength of concrete at different percentages up to 20% and decreased at 25% afterward. The strength of BA replacement comes to be 3.34-3.62MPa which is 1-7% higher than the control mix except for the mix C75B25 in which the strength decreases than the control mix. The maximum strength is offered by the mix C80B20 which is 3.62MPa which is 7% higher than the control mix.

The decrease in strength at increasing percentages may be due to the lesser amount of cement that produces less Ca (OH)2 than the required for the content of BA and FA to react with. It has been investigated that the strength decreases with a higher percentage due to the lack of $Ca(OH)2$ and Cement [51]. All the mixes show good flexural strength which means all of these mixes can be used as structural concrete. It is reported that with a growing population and infrastructure disposal is also a big issue [52] that can be resolved using these materials. The pozzolanic reaction of Fly Ash and Bagasse Ash with the portlandite also increases the mechanical properties of binary and ternary blend mixes. The lesser rate of gain of strength is due to the lesser amount of portlandite present in the concrete matrix at initial days of concrete mixing. It has been investigated that the strength increases with the increase in fly Ash content [53, 54].

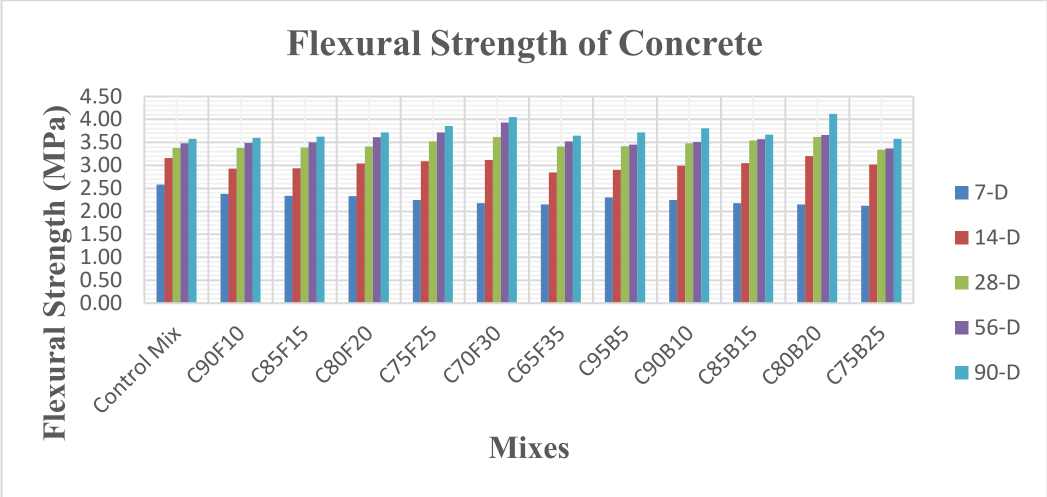

Figure 10 Flexural strength of Concrete mixes

3.10 Water Absorption

Water absorption is the measure of %age of water absorbed in the concrete mix because of the availability of the number of pores and size of pores in the concrete. It can be seen that the absorption of water was found 4% for the control mix at 28 days. The absorption of FA concrete was in the range of 3.46-3.75% which is 6-13% less than that of the control mix at the same age. The absorption for BA concrete was 3.2-3.9% which is 2-20% less than that of the control mix.

However, At the age of 90-day the water absorption further decreases as the absorption of the control mix is 3.1% while the absorption of FA concrete is 2.28-2.48% which is 20-26% lesser than the control mix and the absorption of BA concrete is 2.43- 2.9% that is 6-21% lesser than control mix. The effect of replacement of FA and BA can be seen in (Figure 111) which elaborates that the increase in %age of FA and BA decreases the absorption of concrete up to 30% and 20% replacement respectively. The minimum absorption obtained for a mix of FA and BA are C70F30 and C80B20. The reduction in water absorption is due to the denser concrete matrix due to ashes, lesser number of pores, less pore size and high packing density of the mix. It has been authenticated by researchers that absorption decreases due to lesser porosity, denser concrete, delayed formation of C-S-H gel and packing of concrete [55, 56]. Lesser absorption gives compact microstructure and durable concrete for construction [57].

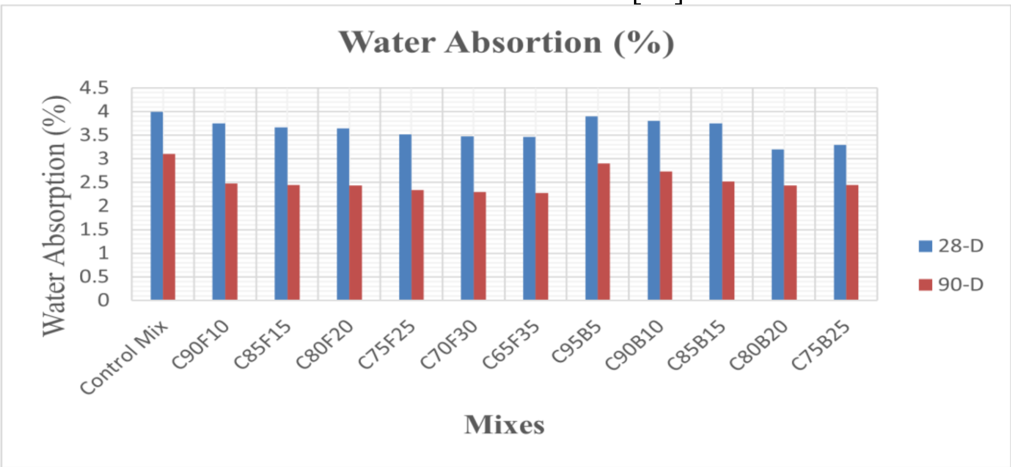

Figure 111 Water Absorption of Different Concrete Mixes

3.11 Sorptivity

Sorptivity is one of the important parameters to assess the durability of concrete. It can be noticed that the sorptivity of the control mix was found to be 0.13mm/min1/2 at the age of 28 days. The sorptivity of FA and BA Concrete was in the range of 0.1-0.12 mm/min1/2 and 0.096-0.114 mm/min1/2 which is about 7-23% and 12-26% lower than the control mix at various replacement levels respectively. A similar trend is followed by the concrete at the age of 90 days as the sorptivity further decreases corresponding to the control mix. The sorptivity was found at the age of 90 days in the range of 0.083-0.097 mm/min1/2 for FA and 0.083-0.1 mm/min1/2 for BA concrete which is anyhow 3- 17% and 0-16% lesser than the control mix at different replacement of FA and BA content. Sorptivity of concrete mixes follows a similar trend as of water absorption in the previous section of all the mixes as shown in (Figure 12). It can be seen that with an increase in the replacement percentage of FA and BA the sorption decreases. This phenomenon is observed in up to 30% and 20% substitution of FA and BA in the concrete same as water absorption does with the concrete mixes. The Sorptivity increase at 35% replacement of FA and 25% replacement of BA is because of higher water absorption due to the greater surface area of Pozzolans corresponding to other filler material present in the concrete matrix.

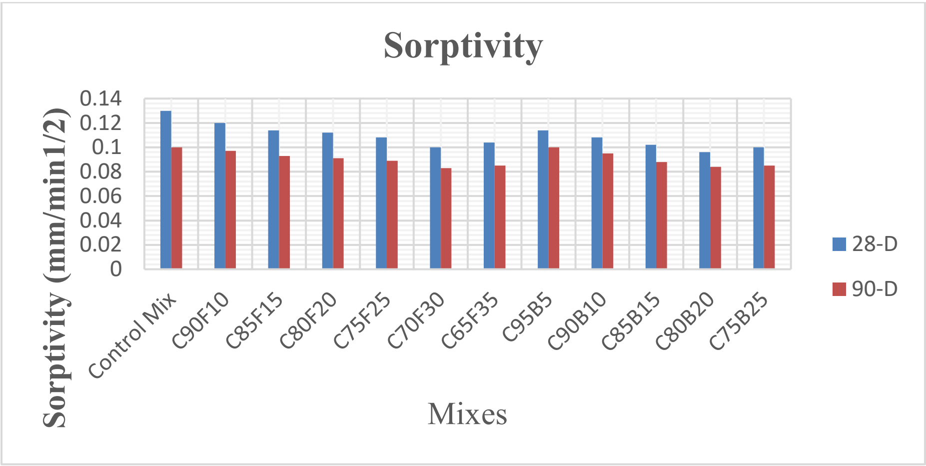

Figure 12 Sorptivity of concrete mixes

The decrease in sorption at higher replacement is because of lesser water absorption, pozzolanic reaction, filling ability of FA and BA. It has been investigated that lower sorption leads to higher compressive strength and a denser matrix [58] and shows a similar behavior to water absorption because both depends on microstructure and porosity of concrete [59]. The sorptivity is because of pore geometry that may not be linked with connectivity of pores [39]. It is also investigated that the sorptivity decreases because of fineness of filler [60] and increasing %age of FA in the concrete mix [61].

4. Conclusions

1. The aim was to optimize the use of FA and BA in the concrete to have good sustainable concrete and it was found out that concrete having 30% FA and 20% BA in binary blend that is environment friendly and economical compared to control concrete.

2. All the concrete mixes showed improvement in workability after replacement of Pozzolans compared to control concrete. The slump value was obtained ranging from 62-77mm. The maximum slump is offered by C65F35 mix containing 65% cement and 35% FA that is 28% higher than Control mix.

3. The fresh density of concrete mixes was kept on decreasing compared to control mix on adding the FA and BA content in the concrete. The density of concrete mixes was ranging from 2345-2389kg/m^3 while the density of control mix was 2393kg/m^3.

4. The compressive strength of concrete mixes having FA and BA increases with increase in Pozzolans as the strength of FA was maximum at 30% which is 15% higher than control mix and 14.2% higher for BA replacement of 20%.

5. Concrete mixes showed good splitting tensile strength at 28 days as all the mixes showed strength more than 2MPa at the age of 28 days which means these mixes are suitable for structural concrete construction as the minimum tensile strength should be 2MPa.

6. Similarly, flexural behavior of concrete mixes was better as well compared to control concrete and the maximum strength was 7% more than Control mix.

7. The rate of gain of strength in compression, tensile and Flexure was slow at early ages of all the mixes containing pozzolans but after 7 days it speeds up and even better response in strength development at the age of 28, 56 and 90 days than the control concrete because of slow pozzolanic reaction at early ages.

8. Water absorption of concrete mixes decrease with increase in FA and BA content in binary mixes up to a certain extent compared to control concrete.

9. Sorptivity of concrete mixes decrease up to 30% of FA and 20% of BA content as the sorptivity of control concrete is 0.13 mm/$min^{1/2}$ and 0.1 mm/$min^{1/2}$.

Reference

[1] P. K. Mehta, "Global Concrete Industry Sustainability," Concrete International, vol. 31, no. 2, 2/1/2009.

[2] P. K. Mehta, "Global concrete industry sustainability," Concrete international, vol. 31, no. 2, pp. 45-48, 2009.

[3] U. S. E. P. Agency, "EPA (2024). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2022," 2024.

[4] S. J. Brandenberg et al., "Preliminary report on engineering and geological effects of the July 2019 Ridgecrest earthquake sequence," Report 2019, Available: http://pubs.er.usgs.gov/publication/70204401.

[5] M. A. Megat Johari, J. J. Brooks, S. Kabir, and P. Rivard, "Influence of supplementary cementitious materials on engineering properties of high strength concrete," Construction and Building Materials, vol. 25, no. 5, pp. 2639-2648, 2011/05/01/ 2011.

[6] V. C. R. C. Limited, "Cement Sector Report," PakistanSeptember 2023.

[7] Hermawan, P. F. Marzuki, M. Abduh, and R. Driejana, "Identification of Source Factors of Carbon Dioxide (CO2) Emissions in Concreting of Reinforced Concrete," Procedia Engineering, vol. 125, pp. 692-698, 2015/01/01/ 2015.

[8] G. Syngros, C. A. Balaras, and D. G. Koubogiannis, "Embodied CO2 Emissions in Building Construction Materials of Hellenic Dwellings," Procedia Environmental Sciences, vol. 38, pp. 500-508, 2017/01/01/ 2017.

[9] M. Schneider, M. Romer, M. Tschudin, and H. Bolio, "Sustainable cement production—present and future," Cement and Concrete Research, vol. 41, no. 7, pp. 642-650, 2011/07/01/ 2011.

[10] E. Aprianti, P. Shafigh, S. Bahri, and J. N. Farahani, "Supplementary cementitious materials origin from agricultural wastes – A review," Construction and Building Materials, vol. 74, pp. 176-187, 2015/01/15/ 2015.

[11] M. S. Imbabi, C. Carrigan, and S. McKenna, "Trends and developments in green cement and concrete technology," International Journal of Sustainable Built Environment, vol. 1, no. 2, pp. 194-216, 2012/12/01/ 2012.

[12] M. Khan and M. Ali, "Improvement in concrete behavior with fly ash, silica-fume and coconut fibres," Construction and Building Materials, vol. 203, pp. 174-187, 2019/04/10/ 2019.

[13] R. Palod, S. Deo, and G. D. Ramtekkar, "Effect on mechanical performance, early age shrinkage and electrical resistivity of ternary blended concrete containing blast furnace slag and steel slag," Materials Today: Proceedings, vol. 32, 05/01 2020.

[14] A. B. Padavala, M. Potharaju, and V. R. Kode, "Mechanical properties of ternary blended mix concrete of fly ash and silica fume," Materials Today: Proceedings, vol. 43, pp. 2198-2202, 2021/01/01/ 2021.

[15] K. E. Hassan, J. G. Cabrera, and R. S. Maliehe, "The effect of mineral admixtures on the properties of high-performance concrete," Cement and Concrete Composites, vol. 22, no. 4, pp. 267-271, 2000/01/01/ 2000.

[16] A. Al-Sibahy, "Behaviour of Reinforced Concrete Columns Strengthened with Ferrocement under Compression Conditions: Experimental Approach," World Journal of Engineering and Technology, vol. 4, no. 4, 2016.

[17] Standard Specification for Portland Cement, 2012.

[18] Standard Specifications for concrete aggregate, 2018.

[19] Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete, 2022.

[20] M. M. N. S. de Soares, D. C. S. Garcia, R. B. Figueiredo, M. T. P. Aguilar, and P. R. Cetlin, "Comparing the pozzolanic behavior of sugar cane bagasse ash to amorphous and crystalline SiO2," Cement and Concrete Composites, vol. 71, pp. 20-25, 2016/08/01/ 2016.

[21] A. Yousuf, S. O. Manzoor, M. Youssouf, Z. A. Malik, and K. S. J. J. M. E. S. Khawaja, "Fly ash: production and utilization in India-an overview," vol. 11, no. 6, pp. 911-921, 2020.

[22] W. Abbass, S. U. Mahmood, A. Ahmed, F. Aslam, and A. Mohamed, "Comparative analysis of enriched flyash based cement-sand compressed bricks under various curing regimes," Heliyon, vol. 10, no. 5, p. e26945, 2024/03/15/ 2024.

[23] L. A. Rehman S, " Sugar Annual," Pakistan22/04/2021.

[24] Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete (Reapproved 2009), 2009.

[25] Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory, 2019.

[26] Standard Test Method for Slump of Hydraulic-Cement Concrete, 2020.

[27] Standard Test Method for Density and Void Content of Freshly Mixed Pervious Concrete (Withdrawn 2023), 2014.

[28] Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens, 2021.

[29] Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens, 2017.

[30] Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading), 2022.

[31] Standard Test Method for Density, Absorption, and Voids in Hardened Concrete, 2022.

[32] Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes, 2020.

[33] S. Sathawane, V. Vairagade, and K. Kene, "Combine Effect of Rice Husk Ash and Fly Ash on Concrete by 30% Cement Replacement," Procedia Engineering, vol. 51, pp. 35–44, 12/31 2013.

[34] N. Shafiq, A. Hussein, M. Nuruddin, and H. Al-Mattarneh, "Effects of sugarcane bagasse ash on the properties of concrete," Proceedings of the Institution of Civil Engineers - Engineering Sustainability, vol. 171, 04/05 2016.

[35] K. Rahla, R. Mateus, and L. Bragança, "Comparative sustainability assessment of binary blended concretes using Supplementary Cementitious Materials (SCMs) and Ordinary Portland Cement (OPC)," Journal of Cleaner Production, vol. 220, 02/01 2019.

[36] C. Cheah, K. Chung, M. Ramli, and G. Lim, "The engineering properties and microstructure development of cement mortar containing high volume of inter-grinded GGBS and PFA cured at ambient temperature," Construction and Building Materials, vol. 122, pp. 683-693, 09/01 2016.

[37] M. Safiuddin and M. F. M. zain, "Supplementary cementing materials for high performance concrete," BRAC University Journal, vol. 3, pp. 47-57, 01/01 2006.

[38] K. Ali, N. Amin, and M. Shah, "Chemical study of limestone and clay for cement manufacturing in Darukhula, Nizampur District, Nowshera, North West Frontier Province (N.W.F.P.), Pakistan," Chinese Journal of Geochemistry, vol. 27, pp. 242-248, 09/01 2008.

[39] A. Bahurudeen, D. Kanraj, V. Gokul Dev, and M. Santhanam, "Performance evaluation of sugarcane bagasse ash blended cement in concrete," Cement and Concrete Composites, vol. 59, pp. 77-88, 2015/05/01/ 2015.

[40] N. Shanahan, V. Tran, A. Williams, and A. Zayed, "Effect of SCM combinations on paste rheology and its relationship to particle characteristics of the mixture," Construction and Building Materials, vol. 123, pp. 745-753, 07/22 2016.

[41] N. Chusilp, C. Jaturapitakkul, and K. Kiattikomol, "Effects of LOI of ground bagasse ash on the compressive strength and sulfate resistance of mortars," Construction and Building Materials, vol. 23, pp. 3523-3531, 12/01 2009.

[42] P. Chindaprasirt, W. Kroehong, N. Damrongwiriyanupap, W. Suriyo, and C. Jaturapitakkul, "Mechanical properties, chloride resistance and microstructure of Portland fly ash cement concrete containing high volume bagasse ash," Journal of Building Engineering, vol. 31, p. 101415, 2020/09/01/ 2020.

[43] ACI CODE-318-19(22): Building Code Requirements, 2022.

[44] N. Mohamad, K. Muthusamy, R. Embong, A. Kusbiantoro, and M. Hashim, "Environmental impact of cement production and Solutions: A review," Materials Today: Proceedings, vol. 48, 03/01 2021.

[45] A. Oner and S. Akyuz, "An experimental study on optimum usage of GGBS for the compressive strength of concrete," Cement and Concrete Composites, vol. 29, no. 6, pp. 505-514, 2007/07/01/ 2007.

[46] N. Dave, A. K. Misra, A. Srivastava, and S. K. Kaushik, "Setting time and standard consistency of quaternary binders: The influence of cementitious material addition and mixing," International Journal of Sustainable Built Environment, vol. 6, no. 1, pp. 30-36, 2017/06/01/ 2017.

[47] K. Ramakrishnan, V. Ganesh, G. Vignesh, M. Vignesh, V. Shriram, and R. Suryaprakash, "Mechanical and durability properties of concrete with partial replacement of fine aggregate by sugarcane bagasse ash (SCBA)," Materials Today: Proceedings, vol. 42, pp. 1070-1076, 2021/01/01/ 2021.

[48] R. Srinivasan and K. Sathiya, "Experimental study on bagasse ash in concrete," International Journal of Service Learning in Engineering, vol. 5, 10/19 2010.

[49] W. Zjup, J. O. Ighalo, and A. Adeniyi, "A perspective on environmental sustainability in the cement industry," vol. 2, pp. 161-164, 07/14 2020.

[50] K. Montakarntiwong, N. Chusilp, W. Tangchirapat, and C. Jaturapitakkul, "Strength and heat evolution of concretes containing bagasse ash from thermal power plants in sugar industry," Materials & Design, vol. 49, pp. 414–420, 08/01 2013.

[51] R. Somna, C. Jaturapitakkul, and A. Amde, "Effect of ground fly ash and ground bagasse ash on the durability of recycled aggregate concrete," Cement and Concrete Composites, vol. 34, pp. 848–854, 08/01 2012.

[52] W. Aziz et al., "Mechanical properties, drying shrinkage and structural performance of coconut shell lightweight concrete," Structures, vol. 35, pp. 26-35, 01/01 2022.

[53] H. K. Sugandhini, G. Nayak, K. K. Shetty, and L. P. Kudva, "The Durability of High-Volume Fly Ash-Based Cement Composites with Synthetic Fibers in a Corrosive Environment: A Long-Term Study," Sustainability, vol. 15, no. 15. doi: 10.3390/su151511481

[54] R. Babalu, A. Anil, K. Sudarshan, and P. Amol, "Compressive strength, flexural strength, and durability of high-volume fly ash concrete," Innovative Infrastructure Solutions, vol. 8, no. 5, p. 154, 2023/04/24 2023.

[55] J. Wang, Z. Che, K. Zhang, Y. Fan, D. Niu, and X. Guan, "Performance of recycled aggregate concrete with supplementary cementitious materials (fly ash, GBFS, silica fume, and metakaolin): Mechanical properties, pore structure, and water absorption," Construction and Building Materials, vol. 368, p. 130455, 2023/03/03/ 2023.

[56] G. L. Golewski, "The Effect of the Addition of Coal Fly Ash (CFA) on the Control of Water Movement within the Structure of the Concrete," Materials, vol. 16, no. 15. doi: 10.3390/ma16155218

[57] A. Joshaghani and A. Moeini, "Evaluating the Effects of Sugarcane-Bagasse Ash and Rice-Husk Ash on the Mechanical and Durability Properties of Mortar," Journal of Materials in Civil Engineering, vol. 30, 07/01 2018.

[58] V. Kunkulagunta, P. P. Sai, and M. Thiruvadi, "Investigation on the behaviour of ternary blended concrete with scba and sf," IOP Conference Series: Materials Science and Engineering, vol. 263, p. 032012, 11/01 2017.

[59] S. Rehman et al., "The Influence of Thermo-Mechanical Activation of Bentonite on the Mechanical and Durability Performance of Concrete," Applied Sciences, vol. 9, 12/17 2019.

[**60]** G. Cordeiro, L. Tavares, and R. Toledo Filho, "Improved pozzolanic activity of sugar cane bagasse ash by selective grinding and classification," Cement and Concrete Research, vol. 89, 11/30 2016.

[61] P. Nath and P. Sarker, "Effect of Fly Ash on the Durability Properties of High Strength Concrete," Procedia Engineering, vol. 14, pp. 1149-1156, 12/31 2011.