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Utilization of Marble Powder, Bagasse Ash, and Wood Waste ash in Sustainable High-Performance Concrete

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Abstract

Concrete is a largely used material for construction in the modern world. The concrete demand is being increased continuously due to rising demand in industrialization and urbanization. Therefore, a bulk number of raw materials is required for concrete production. In this study, Sugarcane Bagasse Ash (SCBA), Wood Waste Ash (WWA), and Marble Powder (MP) are used as supplementary cementitious materials in concrete and their modulus of elasticity, compressive strength, modulus of rupture, tensile strength, drying shrinkage, and water absorption is determined and compared. Consistency of cement, as well as cement plus waste, is calculated to determine the water demand of the wastes. The specific gravity of the waste materials and sieve analysis of fine and coarse aggregate is done and their fineness modulus is determined. Test results show that SCBA shows better results. The water demand of SCBA is the least and it gives maximum compressive strength. The water demand of WWA is highest and it gives minimum compressive strength. By replacing 25% BA in cement concrete the compressive strength reduces up to 40% and with 25% WWA it reduces up to 48%. The Mix Proportioning in the current research was conducted under the guidelines outlined in ACI 211-1. In the first phase, the concrete mixes were prepared by using 100% of cement content as binding material in concrete and were referred to as CC (control mix). In the second phase, 3 different concrete mix proportions were prepared by using 25% of marble powder, bagasse ash, and WWA as partial substitution of cement in concrete and represented by SCBA-25, WWA-25, and MP-25 respectively. Workability was placed constant of 25 mm throughout the study. Then cube (100mm x 100mm x 100mm) specimens were prepared to investigate the average CS of concrete specimens at different ages. The results of the compressive strength test revealed that the bagasse ash and wood waste ash concrete samples exhibited superior performance compared to all other materials, surpassing even the conventional concrete samples at 90 days of age.

Keywords: Sugarcane Bagasse Ash (SCBA), Wood Waste Ash (WWA), Marble Powder, and High-Performance Concrete

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1. Introduction

Cement is the most widely consumed substance in the construction industry because it plays an essential role in the production of concrete. Concrete can resist the impact of all-weather situations. All the developed nations, nowadays, are conducting experimental work to protect their environment by using industrial by-products (Dawouda, Michealb, & Moussac, 2020). Some of the industrial and agricultural waste products have binding properties and can be used as cement substitution materials. A huge amount of Concrete is currently being produced in modern society for different construction projects. Concrete demand is increasing every day with the growth in industrialization and urbanization. Therefore, a huge number of raw materials is required for worldwide concrete production. Meanwhile, a considerable amount of agricultural and industrial waste and other kinds of solid matter disposal are causing crucial environmental problems. Palm oil fuel ash, bagasse ash (BA, rice husk ash (RHA), Wood waste ash (WWA), and bamboo leaf ash) are agricultural wastes, silica fume (SF), GGBFS, marble powder and fly ash (FA) are industrial waste products produced in million tons in every year and are pozzolanic. These are contaminants for nature and using them as cement replacement materials not only reduces pollution as well as concrete costs may also reduce (Mangi, Memon, Khahro, Memon, & Memon, 2020). To reduce the harmful concrete production impact through explosive consumption of raw materials, the usage of industrial wastes as cement substitution materials is an innovative protective solution that helps the environmental sustainability of the construction industry (Aprianti, 2017). Cement is the most expensive material as compared to the filling material. Cement production includes the release of greenhouse gasses like carbon dioxide gas and the utilization of limestone which is taken from natural resources. It is assumed that one ton of CO_2 emits during the production of each ton of cement which is considerably causing global warming (Dhengare, S.P.Raut, N.V.Bandwal, & Khangan, 2015).

The use of industrial waste in mortar and concrete began with a vision to decrease the cost, overcome the negative effects of ordinary Portland cement and use waste materials and industrial by-products activities which were providing a dangerous impact on natural resources and the environment (Matos, et al., 2021). Many latest concrete mixtures are improved with the substitution of mineral admixtures, which improve the fresh properties such as easier compaction and better flow, decrease the heat of evaluation due to hydration, reduce the chloride ion penetration, decrease the alkali silica reaction and sulfate, improve the microstructure, strength, durability, resistance to cracks can be improved as well as minimize the amount of CaO which is produced during the hydration of cement concrete and mortar (Kumar & Prasad, 2019). Mineral admixtures contain high content of silicon dioxide (SO_2). When these admixtures are added as the alternates of cement in concrete, the silicon dioxide present in these admixtures reacts with the calcium hydroxide Ca $(OH)_2$ emitted during the hydration of cement and develops further calcium silicate hydrate (C-S-H), which enhances the durability mechanical and fresh properties of concrete (Mehta, 1983). The FA, SF, and GGBFS use is becoming progressively common in large civil engineering structures.

2. Research Methodology

2.1. Methodology

An experimental study will be conducted for the investigation of characteristics of alternative cementitious waste by-product materials in the production of eco-friendly concrete. Various mix proportions utilizing different proportions of these alternative cementitious materials will be prepared and cast. The study will examine several mechanical properties of the concrete specimens under both standard and non-standard curing conditions. The procedure adopted for my research is as under:

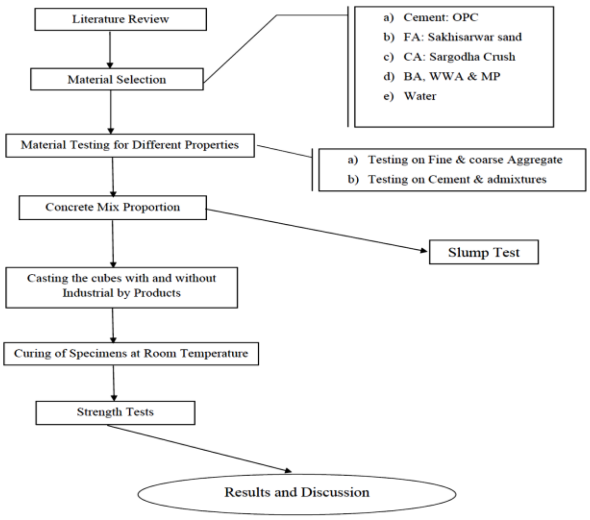

Figure 1: Research Methodology

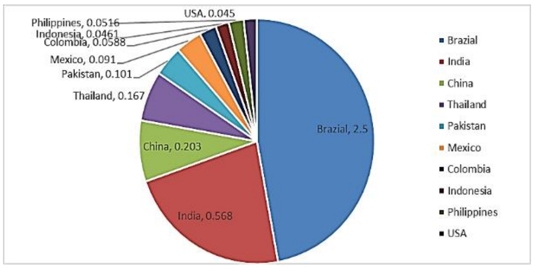

Figure 2: Production of Sugarcane Bagasse Ash in various Countries (Million tons)

2.2. Collection and Preparation of Waste Materials

The alternative waste by-product material that can be used as cementitious waste by-product materials can be found and collected from the locally available industries in Pakistan. To collect the waste by-product materials from agriculture or industry marines etc. for partial replacement as cementitious by-products needed for research. Sieve the waste materials into sizes of required cement.

2.2.1. Marble Powder (MP)

Marble powder, an inactive substance, has been explored for its potential as a mineral additive in concrete production. It has been utilized either as a substitute for cement or as aggregates. Additionally, it has shown successful application in the creation of self-compacting concrete (Vardhan, Goyal, Siddique, & Singh, 2015). The MP is collected from a Marble Factory Multan which is dumped in an open area of the marble factory. It was taken in a bag and carried to the concrete testing laboratory. This marble waste was sieved via ASTM # 100 and 200 standard sieves to study the particle size of the collected sample. The total percentage passed from it is 35% and retained from it is 65%. The sieved waste MP sample is shown in Figure 3.

Figure 3: Marble Powder (MP) prepared Sample

2.2.2. Sugarcane Bagasse Ash (SCBA)

Sugarcane bagasse is composed of approximately 50% cellulose, 25% hemicellulose, and 25% lignin. It is estimated that each ton of sugarcane produces around 26% bagasse (with 50% moisture content) and 0.62% residual ash. The ash resulting from combustion primarily consists of silicon dioxide (SiO2). Despite its slow decomposition and limited nutrient content, ash is commonly utilized as a fertilizer in sugarcane plantations (Srinivasan & Sathiya, 2010).

The SCBA sample is taken from Ashraf Sugar Mills which is located near Ahmadpur East Road in District Bahawalpur. The collected sample is taken in the laboratory and sieved through #100 sieves and then passed through # 200 sieves to check the fineness of the waste sample. It is observed that the percentage retained on # 200 sieves is 45% and through it is 55% of the total sample. It is also observed that the mean particle size of the collected bagasse ash sample is 24 µm. The sieved waste Sugarcane Bagasse Ash sample is shown in

Figure 4.

Figure 4: Bagasse Ash (SCBA) prepared Sample

2.2.3. Wood Waste Ash (WWA)

Currently, more than 70% of wood waste ash (WWA) is disposed of in various forms in the surrounding environment (Campbell, 1990). WWA is generated as a byproduct of burning wood items like chips and bark, and its utilization is limited to controlled applications for optimal crop growth. Globally, WWA is produced through combustion processes in wood-fired power plants, paper factories, sawmills, bakeries, and other wood-burning production facilities (Aprianti, Shafigh, Bahri, & Farahani, 2015).

According to the Food and Agriculture Organization, an estimated annual average of 98.2 million cubic meters of WWA was generated worldwide from 1992 to 2010. Among the top five WWA-producing countries during this period were China (15.3 million cubic meters), Brazil (14 million cubic meters), the USA (13 million cubic meters), the Russian Federation (7.9 million cubic meters), and France (7.7 million cubic meters). These statistics provide valuable insights into WWA production resulting from the combustion of wood fuel and highlight the increased potential for ash production from the burning of wood residues.

Several studies have examined the physical properties of WWA, such as specific gravity and compacted bulk density, which are approximately 2.13 and 760 kg/m3, respectively. However, slight variations in the data for compacted bulk density have been observed (Okeyinka & Oladejo, 2014). The chemical composition of WWA can vary depending on its production source and the combustion process involved. The primary oxides present in industrial WWA are mixed oxides (SiO_2 + Al_2O_3 + Fe_2O_3; 49.90%), SiO_2 (46.90%), and CaO (21.60%), with a loss on ignition (LOI) value of 24.50%. Other oxides, such as Na_2O, Al_2O_3, Fe_2O_3, MgO, and K_2O, are present in smaller amounts in industrial WWA (Tamanna, Raman, Jamil, & Hamid, 2020).

For this research purpose, the wood waste ash was collected from the rural areas by burning the wood in coal. Then burnt wood coal is ground to get wood waste ash. The prepared sample is then passed through # 100 sieves. The average particle size of WWA is 16 µm. The coal's heap after the fire and the prepared sample of wood waste ash after passing through # 100 sieves are shown in Figure 5 (a) and (b).

Figure 5: Wood Waste Ash (WWA) Dumped

2.3. Mix Concrete Design:

Table 1: Design Mix Proportions

Mix designation	Add. Binders (%)	w/c ratio	Water (kg/m³)	Cement (kg/m³)	Add. Binder (kg/m³)	Sand (kg/m³)	Coarse aggregate (kg/m³)	Superplasticizer Admixtures (%)
CC	0	0.37	182	490	-	545.0	1145	0.7
MP-25	25	0.37	182	367.5	122.5	545.0	1145	0.7
BA-25	25	0.37	182	367.5	122.5	545.0	1145	0.7
WWA-25	25	0.37	182	367.5	122.5	545.0	1145	0.7

3. Results And Discussions

3.1.Consistency of Concrete Mixes

Table 2: Comparison of consistency of cement and Pastes

Sr. No	Mix Name	Ingredients	Cement (gm)	Waste (gm)	Water (gm)	Reading of plunger from the bottom (mm)	Consistency %
1	CC	Cement 100% (CC)	500	-	165	5	33
2	BA-25	Cement 75%, BA 25%	450	50	180	5	36
3	MP-25	Cement 75%, MP 25%	450	50	195	6	39
4	WWA-25	Cement 75%, WWA 25%	450	50	200	5.5	40

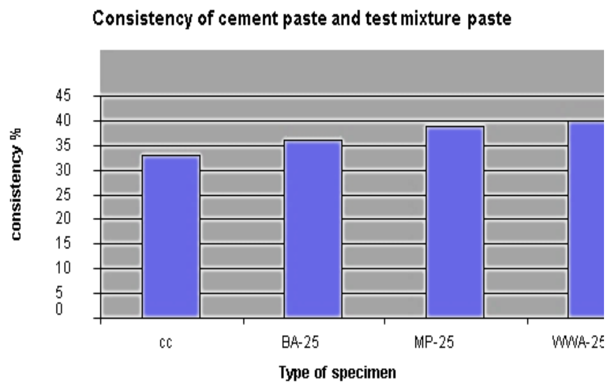

Figure 6: Consistency of Pastes

3.2.Initial and Final Setting Time of Blended Pastes

It was noticed that the setting time increases with the addition of fractional supplanting of SCBA with concrete. As the SCBA content is expanded from 0 to 15%, the underlying setting time was seen to increment from 105 to 142 min and the last setting time expanded from 230 to 340 min, as appeared in Figure 7.

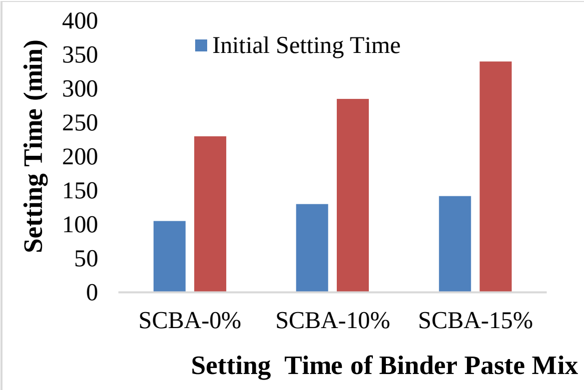

Figure 7: Initial and Final Setting Time of SCBA

The incorporation of WWA as a fractional replacement of cementitious material in WWA/OPC mixed concrete caused in the pastes is shown in Figure 8. The mix WWA-10 showed that the initial setting time was up to 160 minutes whereas the final setting time of about 270 minutes. Whereas, the mixture WWA-15 showed the highest values for initial as well as final setting times which were about 195 and 290 minutes, respectively.

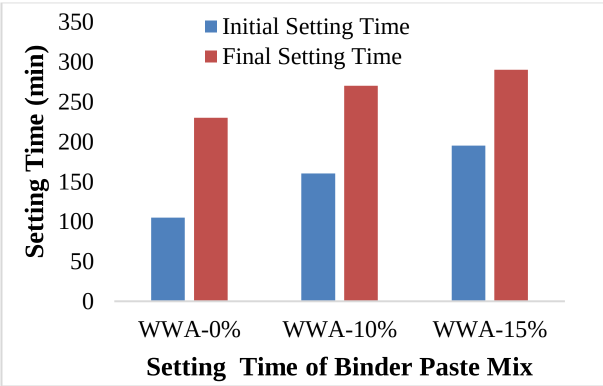

Figure 8: Initial and Final Setting Time of WWA

The performance of the initial as well as final setting time of OPC-MP is shown in Figure 9. The concrete glue tests containing 10 &15% MP have higher introductory setting times for example 160 min and 195 min, separately, when contrasted with control concrete glue with 0% MP, last setting time for concrete glue blends containing 10 & 15% MP saw to be 270 min and 290 min, individually.

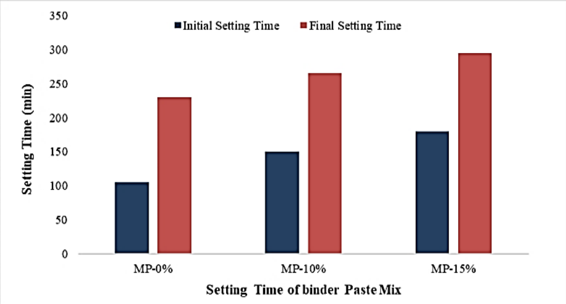

Figure 9: Initial and Final Setting Time of MP

3.3.Effect of WWA, BA & MP on Workability of Concrete

The superplasticizer was incorporated into concrete for ensuring the desired workability at a lower w/c ratio, by adding 0.7% superplasticizer of the total cement weight into the total gauging water. For conventional concrete, the workability was highest i.e., about 40 mm, however, as the substitution level of additional binders was considered in the control mixture, the slump values were reduced.

Based on slump test results it is concluded that the workability of the concrete is decreased if the percentage substitutions of MP, BA, and WWA are increased. The inclusion of these admixtures resulted in a larger amount of water in the concrete mixture compared to the referral mix.

To maintain the required amount of slump, the super plasticizing admixture may be required according to the marble powder, bagasse, ash, and wood waste ash percentages.

The mix MP-25 showed a slump value of about 37 mm and was almost closer to the control concrete having an average difference of up to 8% as shown in Table 3. Lower slump values were shown by the Mix BA-25 which was about 12% compared to the control mixture. However, a significantly higher reduction was observed for mixture WWA-25 which was about 25%.

Table 3: Slump values of prepared Mixes

Mix designation	Waste %age	Superplasticizer (%)	Slump (mm)
CC	0	0.7	40
MP-25	25	0.7	37
BA-25	25	0.7	35
WWA-25	25	0.7	30

In a study conducted by (Ganesan, Rajagopal, & Thangavel, 2007) the impact of bottom ash (BA) on concrete workability was evaluated. The authors noted that the inclusion of BA in concrete resulted in reduced workability, with the extent of reduction dependent on the BA content. They further explained that this decrease in workability is attributed to water absorption by the admixture particles. Similarly, (Paya, Monzo, Borrachero, Pinzon, & Ordonez, 2002) found that the slump value decreased by approximately 56% when 25% of the cement was substituted with marble powder, as compared to the control sample.

(Hernandez, Rodriguez, & Middendorf, 2001) have examined the effect of marble powder as cement replacement. The marble powder was replaced by cement at the rate of 2.5, 5, 7.5, 10, 12.5, and 15% (by weight). They concluded that the workability decreased as the PM amount increased. Furthermore, the use of a polycarboxylate ether-based superplasticizer was found to be needed for maintaining the workability at the lower ratios of W/C. (Mehta P., 1992) determined that the concrete's slump values slightly decreased by increasing the marble powder content. (Etiegni, 1990) investigated the effect of different substitution levels of marble powder as pozzolanic material on the fresh properties of concrete at three various water binder ratios 0.45, 0.40, and 0.35. The authors revealed that the workability decreases with a percentage increase in marble slurry content, due to the high percentage of marble slurry fines present in it which tends to increase the water demand or high range superplasticizers of the concrete mixture for keeping it same workability.

3.4.Mechanical Properties

3.4.1. Compressive Strength

Table 4 presents the results of the comprehensive strength of all mixes, with three samples tested at each stage. A total of 72 samples were analyzed and their respective strength values are documented in the table. The observed results of referral mix that were tested at the age of 1 day, 3-days, 7-days, 28-days, 56-days and 90-days of curing showed a compressive strength of 22.16 MPa, 31.53 MPa, 35.39 MPa, 42.36 MPa, 43.77 MPa, and 44.56 MPa, respectively. The compressive strength results for various mixes with substitutions of 25% SCBA, 25% MP, and 25% WWA with cement were obtained at different curing periods. These tests were conducted at the concrete laboratory of DHA Multan. For the mix with 25% SCBA substitution, the compressive strength values increased progressively with curing time. At 1 day, 3-days, 7-days, 28-days, 56-days, and 90 days of curing, the compressive strengths were measured at 16.4 MPa, 22.7 MPa, 30.56 MPa, 37.53 MPa, 42.96 MPa, and 47.03 MPa, respectively. Similarly, for the mix with 25% MP substitution, the compressive strengths also showed an upward trend as the curing period increased. The values recorded at 1, 3, 7, 28, 56, and 90 days of curing were 11.93 MPa, 16.8 MPa, 20.16 MPa, 25.36 MPa, 30.5 MPa, and 32.6 MPa, respectively.

In the case of the mix with 25% WWA substitution, the compressive strength results exhibited a similar pattern, with increasing values over time. The compressive strengths measured at 1 day, 3-days, 7-days, 28-days, 56-days, and 90 days of curing were 16 MPa, 23.8 MPa, 32.8 MPa, 37 MPa, 44.23 MPa, and 46.23 MPa, respectively.

These findings indicate that the mixes containing bagasse ash (SCBA), marble powder (MP), and wood waste ash (WWA) as partial cement replacements demonstrate promising compressive strength characteristics. The concrete laboratory of DHA Multan played a vital role in conducting these tests and determining the mechanical properties of the concrete samples.

Table 4: Compressive Strength of Prepared Concretes cube Specimens

Cube No	Concrete Type	Compressive Strength					
		1-day	3-days	7-days	28-days	56-days	90-Days
1	CC	22.4	33.4	36.1	42.4	44.5	45.2
2		23.1	32.8	35.3	43.3	44.2	44.7
3		21.9	28.4	36.4	41.4	42.6	43.8
4	BA-25	16.5	21.9	33.6	38.5	42.5	46.6
5		17.1	22.8	32.7	36.6	43.8	47.7
6		15.6	23.4	25.4	37.5	41.4	46.8
7	MP-25	12.3	16.5	21.3	26.6	31.2	31.8
8		11.7	17.2	22.4	25.0	30.8	32.6
9		11.8	16.7	16.8	24.5	29.8	33.4
10	WWA-25	15.7	22.9	32.6	37.4	44.5	45.6
11		16.4	23.4	32.7	37.1	43.8	44.7
12		15.9	24.1	33.1	36.5	44.4	48.4

The compressive strength development for the prepared mixes at various ages is shown in Figure 10. From the figure, at the age of 1 day, the rate of compressive strength development of 25-BA, 25-MP, and 25-WWA added concrete was 74%, 53%, and 72%, respectively. The compressive strength of the reference mix served as the baseline, representing 100% strength. To assess the impact of substitutions, the mixes with 25% BA, MP, and WWA replacements were evaluated at a 3-day curing period. The rate of gain of compressive strength, relative to the reference mix, was determined for each substitution. The mix with 25% BA substitution exhibited a 72% rate of gain of compressive strength compared to the reference mix. This indicates a significant compressive strength improvement during the 3-day curing period.

Similarly, the mix with 25% MP substitution showed a rate of compressive strength gain of 53% relative to the reference mix. Although slightly lower than the BA substitution, it still demonstrated a notable increase in compressive strength.

On the other hand, the mix with 25% WWA substitution displayed the highest rate of compressive strength gain among the three substitutions, measuring at 74% compared to the reference mix. This indicates a substantial enhancement in compressive strength within the 3-day curing period. These results emphasize the effectiveness of the substitutions in enhancing the concrete mixes' early-age compressive strength. The varying percentages highlight the differences in strength gain achieved by each substitution in comparison to the reference mix.

(Aslam & Jumaat, 2016) performed the mechanical properties of concretes containing 20-50% OPBC in OPS concrete and compressive strength was improved significantly. They reported that the mixes C-0 and C-10 showed about 90-95% of the 28-day compressive strength at the age of 7 days, whereas, this ratio was between 81 to 90% for mixes containing 20-50% OPBC aggregate. For artificial LWA concrete, this ratio was found in the range of 76-87% (Wilson & Malhotra). Furthermore, the ratio for 3-day to 28-day compressive strength of OPS-OPBC concrete was found in the range of 71-83%. While the 7 days of curing BA-25, MP-25, and WWA-25 concrete samples showed a compressive strength of 86%, 57%, and 92%, respectively. At 28 days, the Mix that was prepared by the substitution of 25%, BA, MP, and WWA with cement showed a rate of strength gain of 89%, 60%, and 87%, respectively. Similarly, at 56 days the rate of strength gain in comparison to the referral mix was 98%, 70%, and 101%, for the mix that contained 25% BA, MP, and WWA, respectively. Alike, at the age of 90 days, the rate of strength gain in comparison to the referral mix was 105%, 73%, and 104%, for the mix that contained 25% BA, MP, and WWA, respectively. It is noticeable that with the use of BA, the 28-day compressive strength is 11% lower than the referral mix, beyond the 28-day age the strength improved significantly as observed. However, at 90 days of curing the CS of BAC is 5% higher than the referral mix. It is observed that the exchange of MP with cement decreases the CS of concrete. However, with the use of WWA, the 28-day compressive strength is 13% lower than the referral mix, beyond 28 days, the strength improved significantly as observed. Furthermore, at the age of 90 days, the CS of WWAC is about 4% higher than the referral mix. It is concluded that the inclusion of BA and WWA in concrete reduces the hydration rate thus low compressive strength is noted at an early age (Udoeyo, Inyang, Young, & Oparadu, 2006).

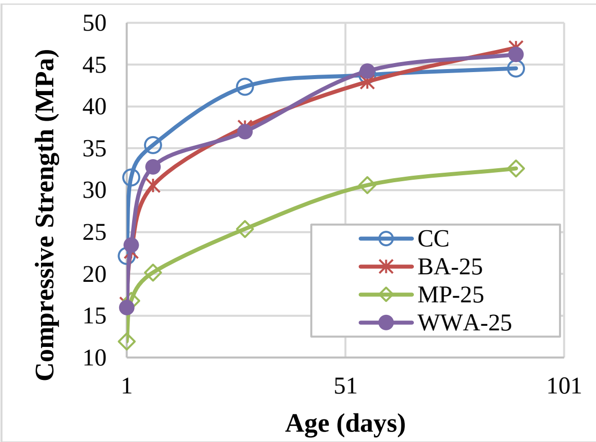

Figure 10: Development of Cube Compressive Strength for Mixes at Different Ages

3.4.2. Modulus of Elasticity

The modulus of elasticity was analytically estimated using prescribed equations derived from established standards. These equations took into account the 28-day compressive strength, with a constant slump value. (Tasnimi, 2004) introduced Equation (1) specifically for cylindrical compressive strengths falling within the range of 15 to 55 MPa.

$$E = 2.1684 f_y^{0.535} \tag{1}$$

In Table 5, the results of applying Equation (1) for predicting the modulus of elasticity (E) for the concrete samples are presented. It was observed that the predicted values using Equation (1) were considerably lower compared to the actual modulus of elasticity. Considering this disparity, the mixes BA-25 and WWA-25 exhibited relatively close results to the modulus of elasticity of the control mixture, with an average difference of approximately 6%. On the other hand, the MP-25 mix showed significantly lower values for the modulus of elasticity, with a deviation of about 24% below the control mixture. Consequently, it can be concluded that BA and WWA present themselves as viable alternative materials for use in the construction industry of Pakistan.

Table 5: Predicted Results for Modulus of Elasticity

Mix Designation	28-day Compressive strength	Predictions for E-Values (GPa)
CC	42.0	16.0
BA-25	37.5	15.0
MP-25	25.0	12.13
WWA-25	37.0	14.96

3.4.3. Splitting Tensile Strength

Similar to the modulus of elasticity, the results for splitting tensile strength were also predicted using the suggested analytical models with 28-day compressive strength. Three equations were selected, equation (2) was proposed by ACI 318-05 (2005) for conventional concrete with a strength range from 21 to 83 MPa. Equation (3) was suggested by (Gesoglu, Ozturan, & Guneyisi, 2004) the equation (4) was proposed by (Cheah & Mahyuddin, 2012).

$$f_t = 0.59(f_y)^{0.5} \tag{2}$$

$$f_t = 0.27\sqrt[3]{f_{cu}^2} \tag{3}$$

$$f_t = 0.301(f_{ancy})^{0.67} \tag{4}$$

Where, f_t represents splitting tensile strength, whereas compressive strengths after 28 days are shown b $_y$. Table 6 displays the predicted results using equations (2) to (4) for splitting the tensile strength of the concrete samples. Interestingly, all of these equations provided more accurate predictions compared to equation (1) as observed. For all mixes, the predicted splitting tensile strength values exceeded the minimum recommended value of 2.0 MPa as stipulated by the standards.

Furthermore, the values predicted for mixes containing BA and WWA closely aligned with the control concrete's splitting tensile strength. This indicates that both BA and WWA can serve as effective replacement materials without compromising the splitting tensile strength performance.

Based on these findings, it can be concluded that both BA and WWA demonstrate favorable characteristics as alternative cementitious materials for the construction industry.

They exhibit higher predicted splitting tensile strength values and perform well when compared to the control concrete, making them suitable candidates for consideration in construction applications.

Table 6: Predicted Results for Splitting Tensile Strength

Mix Designation	28-day Compressive strength	Predictions for Splitting Tensile Strength (MPa)		
		Eq. (2)	Eq. (3)	Eq. (4)
CC	42.0	3.82	3.26	3.68
BA-25	37.5	3.61	3.02	3.41
MP-25	25.0	2.95	2.30	2.60
WWA-25	37.0	3.58	2.99	3.38

3.4.4. Flexural Strength

Similar to the E-value and splitting tensile, the flexural strength of the prepared mixes was also predicted using the suggested analytical models with 28-day compressive strength.

Three equations were selected, equation (5) was proposed by (Shafigh, Jumaat, Mahmud, & Norjidah, 2012.)for CS range between 35 to 53 MPa, proposed equation (6) with cubical strength ranging between 20 to 60 MPa. (Zhang & Gjvorv, 1991) proposed Equation (7) for flexural strength prediction from CS.

$$f_r = 0.12(f_{cu})^{1.03} \quad (5)$$

$$f_r = 0.46\sqrt[3]{f_{cu}^2} \quad (6)$$

$$f_t = 0.73\sqrt{f_{cu}} \quad (7)$$

Where, f_r represents the flexural strength, and the 28-day CS is shown as bf_{cy}. The predicted results are shown in Table 7, from the equations (5-7), it was found that BA-25 and WWA-25 showed better results for the flexural strength compared to the control mixture, however, the results for MP-25 were significantly lower than the referral mix CC.

Again, from the flexural results, the BA and WWA were found better in performance and can be utilized in the construction industry as an alternative material.

Table 7: Predicted Results for Flexural Strength

Mix Designation	28-day Compressive strength	Predictions for Flexural Strength (MPa)		
		Eq. (5)	Eq. (6)	Eq. (7)
CC	42.0	5.63	5.55	4.73
BA-25	37.5	5.01	5.15	4.47
MP-25	25.0	3.30	3.93	3.65
WWA-25	37.0	4.95	5.10	4.44

3.4.5. Drying Shrinkage

For drying shrinkage, only the first 4 mixes including the control mixture and BA-25, MP-25, and WWA-25 with a 15% substitution of various waste materials were prepared. The waste materials' substitution level of up to 25% drastically reduced the mechanical properties, that's why for shrinkage purposes, only four mixes have been selected. Figure 11 illustrates the strain progression for drying shrinkage for all mixes over 90 days.

The values of drying shrinkage values in 90 days were analyzed for the different mixes. The control conventional concrete exhibited a drying shrinkage value of approximately 301 micro strains, falling within the shrinkage range for good quality concretes.

In the early days, similar drying shrinkage results were demonstrated by the BA-25 mixture as that of control concrete. However, as the drying period progressed, the shrinkage strain increased steadily. Nevertheless, at 90 days, the shrinkage results were quite close to those of the control concrete, differing only by approximately 4.5%. Additionally, starting from around 77 days, the BA-25 mixture displayed a similar trend to the control concrete, indicating a consistent and stable shrinkage gain.

On the other hand, the MP-25 mix exhibited the highest drying shrinkage value, measuring about 348 micro strains, which is approximately 14% higher than the control concrete. A notable drawback is that the MP-25 mix continued to show an increasing trend in shrinkage even after 90 days. A similar increasing trend in shrinkage was also observed for the WWA-25 mixture.

Based on the drying shrinkage strain results, it can be concluded that the BA-25 mix emerges as the best alternative material for use in the construction industry of Pakistan. It exhibits drying shrinkage values that are comparable to the control concrete, demonstrating its suitability as a reliable replacement material.

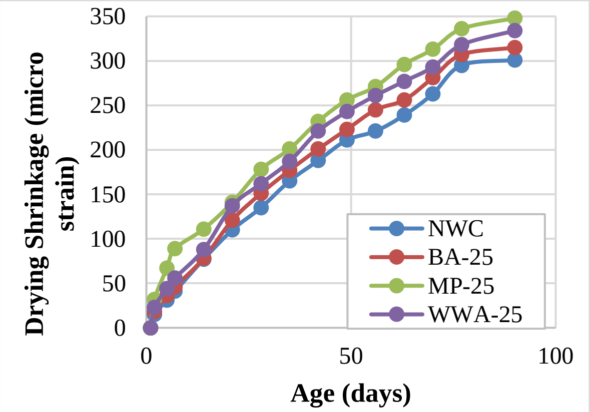

Figure 11: Drying Shrinkage Development for Four Mixes

4. Conclusions

- The analysis results of BA, MP, and WWA show that the wastes have a little amount of amorphous silica in them. The CS concrete samples result also presents that with cement substitution, there is a decrease in the compressive strength. So, it is concluded that raw wastes have little pozzolanic activity.
- Chemical composition shows that BA, MP, and WWA have more silica content. It is observed that the content of silica in the wastes is about 6-7 times higher in comparison to OPC. The BA has 3.69% CaO, 2.67% Al_2O_3, and 3.69% CaO, whereas the other two wastes contain 0.013 and 0.71 Al_2O_3. However, WWA contains 09.52% CaO, and MP contains 42.56% CaO. Furthermore, the silica (SiO_2) content in BA is 55.91%, while in WWA it is 83.00% and in MP 12.10%.
- Mix BA-25 gave the compressive strengths at 1 day, 3-days, 7-days, 28-days, 56-days and 90-days of curing of about 16.4 MPa, 22.7 MPa, 30.56 MPa, 37.53 MPa, 42.96 MPa, and 47.03 MPa, respectively. Mix MP-25 shows the values for strength at the age of 1 day, 3-days, 7-days, 14-days, 28-days, 56-days, and 90-days were about 11.93 MPa, 16.8 MPa, 20.16 MPa, 25.36 MPa, 30.5 MPa, and 32.6 MPa, respectively. Whereas the Mix WWA-25 also showed better results at various ages at 1 day, 3-days, 7-days, 28-days, 56-days and 90-days of curing showed the compressive of 16 MPa, 23.8 MPa, 32.8 MPa, 37 MPa, 44.23 MPa, and 46.23 MPa, respectively.
- At the 28-day age, the Mix that was prepared by the substitution of 25%, BA, MP, and WWA with cement showed a rate of strength gain of 89%, 60%, and 87%, respectively. The investigation performed by Dhengare et al., (2015), and Srinivasan and Sathiya, (2010) on M35 and M20 concrete by substitution of BA as cement replacement. It was revealed that, at 28 days of age, the strength gain rate in comparison to the referral mix was 92% and 82% for the mix containing 25% BA respectively.

Similarly, the research performed by Patricija Kara et al., (2013) on M20 concrete with the substitution of WWA by cement. The authors demonstrated that at the 28-day age, the strength gain rate in comparison to the referral mix was 83% for the mix containing 25% WWA. Udoeyo et al., (2006) revealed that at 28 days of age, the rate of gain in strength compared to the referral mix was 82% and 72% for the mix containing 20% and 25% WWA respectively.

- Among all the materials tested, including conventional concrete, the bagasse ash and wood waste ash concrete samples showed the highest compressive strength results, even surpassing the performance of conventional concrete at the 90-day mark. The reason BA and WWA give better results as CRM is due to their good chemical composition and as well as its minimum water requirement.
- Chemical composition shows that BA, MP, and WWA have more silica content. It is observed that the silica in wastes is about 6-7 times higher than OPC. BA contains 3.69% CaO and 2.67% Al_2O_3, whereas the other two wastes contain 0.013 and 0.71 Al_2O_3. However, WWA contains 09.52% CaO, and MP contains 42.56% CaO. The silica content in BA is 55.91%, while in WWA it is 83.00%, and in MP 12.10%.
- The CS results of the BA concrete samples show that BA is the best of all the three Wastes used in this research. It gives maximum compressive strength. The reason BA gives better results than CRM is due to its minimum water demand as well as its good chemical composition.
- The BA-25 and WWA-25 mixes demonstrated comparable modulus of elasticity results to the control mixture, with an average difference of almost 6%. In contrast, the MP-25 mix exhibited significantly lower values for the modulus of elasticity, measuring approximately 24% lower than the control mixture. Based on these findings, it can be concluded that both BA and WWA are viable alternative materials that can be recommended for use in the construction industry of Pakistan. They exhibit a similar modulus of elasticity to the control mixture, making them suitable replacements for conventional materials.
- Equations (2) to (4) consistently yielded improved predictions for all the mixes, with all values for splitting tensile strength surpassing the minimum recommended value of 2.0 MPa as set by the standards. Notably, the predicted values for mixes containing BA and WWA closely aligned with those of the control concrete. This indicates that both BA and WWA are effective alternative replacement materials, exhibiting satisfactory performance in terms of splitting tensile strength. Therefore, these materials can be considered viable options for use in the construction industry as replacements for conventional materials.
- From the equations (5-7), it was found that BA-25 and WWA-25 showed better results for the flexural strength compared to the control mixture, however, the results for MP-25 were significantly lower than that of the control mix CC. Again, from the flexural results, the BA and WWA were found better in performance and can be utilized in the construction industry as an alternative material.

- Initially, during the first week, the BA-25 mixture exhibited comparable results to the control concrete in terms of shrinkage strain. However, as the drying period progressed, the shrinkage strain continued to increase steadily. By the 90 days age, the shrinkage results for the BA-25 mixture were relatively close to those of the control concrete, with only a difference of approximately 4.5%. Moreover, starting from around 77 days, the BA-25 mixture displayed a similar trend to the control concrete, indicating a consistent and stable pattern of shrinkage gain. This suggests that the BA-25 mixture's shrinkage behavior closely resembles that of the control concrete, with a diminishing rate of shrinkage over time, indicating a more stabilized state similar to the control mixture.

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