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Research Article

Experimental Investigation of Concrete Characteristics Strength with Partial Replacement of Cement by Hybrid Coffee Husk and Sugarcane Bagasse Ash

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Concrete is the most extensively utilized construction material globally and is increasingly used due to industrialization and urbanization. Currently, most scientists worldwide are concentrating their attention on effective strategies to adopt materials from large amounts of waste resources as a partial substitute for cement in concrete production due to scarcity of resources and continuous environmental pollution. In this study, an experimental investigation was conducted on the properties of concrete made from the partial replacement of cement by hybrid coffee husk ash (CHA) and sugarcane bagasse ash (SCBA). The study considered different percentages (0%, 5%, 10%, and 15%) of hybrid ash to assess the engineering properties of fresh and hardened concrete of C-20/25. A slump and compaction factor test was conducted to study the workability of fresh concrete. The study showed that, as the percentage of replacement increased from 0% to 15%, the workability of the concrete decreased up to 15.15%. In addition, compression, split tensile, and flexural tests were done on the 7th, 14th, and 28th days to investigate the properties of hardened concrete. Based on the test result, 10% of hybrid ash was the maximum percentage of replacement that showed a compressive and tensile strength greater than the target strength. Therefore, the study concludes that up to 10% replacement of cement by hybrid ash may be employed in concrete production, which in turn is used to minimize the cost of construction and environmental pollution by recycling waste coffee husk and sugarcane bagasse.

1. Introduction

Concrete is one of the most widely implemented materials in the construction area worldwide, which is mainly composed of cement, coarse aggregate, and fine aggregate mixed with water. The production of concrete ingredients like cement demands a large number of natural resources. In another way, the consumption of natural resources is increasing because of the rapid development of urbanization and industrialization, which may lead to a significant effect on environmental sustainability. From the total greenhouse gases production (CO2), 8% is emitted from the cement industrial sector [1, 2], which is increasing at an enormous rate due to population growth and urbanization. At the current time, the attention and focus of most industrialists and researchers are to reduce the exhaustion of usual resources and environmental pollution by considering waste materials in concrete production [3, 4]. In a general sense, the generation of wastes from industrial and agricultural sectors is unavoidable. However, effectively utilizing and reusing them must be the solution to reducing environmental impact. Many inventions are emerging over the world to control and regulate byproducts, industrial wastes, and residuals. This allows the preservation of the environment from pollution and sustainability of the resources. In this regard, some researchers [5, 6] have proposed the utilization and viability of numerous industrial and agricultural wastes as construction material without negotiating the required quality and strength. Numerous researches have been reported and affirmed [7, 8] the substitution of cement by waste product is not only a matter of waste disposal but also possible to produce concrete with enhanced robustness properties.

So far, many construction industries are commonly practicing the importance of diverse waste materials that replace cement in concrete production. Several studies have been conducted on the mechanical properties of concrete with the replacement of cement partially by fly ash [9], wood ash [10], blast furnace slag [11], waste paper sludge ash [12], palm oil fuel ash [13], waste glass [14], rice husk ash [15], and others. The replacement of cement by some waste byproduct with a specified proportion will enhance the mechanical properties of concrete [16, 17]. The studies considered marble slurry, rice husk, and bamboo leaf ash as a partial replacement. The performance of concrete is significantly affected by the chemical composition of replaced cement material [18]. This paper aimed to use low C3A cement with fly ash, which has suitability on the mechanical properties of concrete. In general, the substitution of concrete ingredients with different recycled waste materials mainly allows the sustainability of the resource and reduces the cost of construction and environmental pollution [19, 20].

Moreover, industrial and agricultural wastes having pozzolanic properties have a high probability of replacing cement. For instance, coffee husk ash possesses pozzolanic behavior, as confirmed by research investigation [21]. Additionally, pozzolanic properties of coffee husk ash have been investigated in some countries and confirmed to have some properties of the pastes, water tightness, concrete-like compressive strength, and mortar [22]. On average, 7 million tons of coffee beans were produced annually, based on the International Coffee Organization report [23]. On the other hand, sugarcane bagasse ash is one of the industrial byproducts, which can be exploited in concrete with a fractional replacement of cement because of their fibrous and pozzolanic characteristics [24, 25]. Burning sugarcane bagasse at a suitable temperature, specifically between 600°C and 800°C, allows producing ash that holds a significant quantity of amorphous silica with outstanding pozzolanic behaviors [26]. The amount of silica in bagasse is suitable to replace cement in concrete materials [27]. Furthermore, around 500 tons per year of sugarcane is approximately produced worldwide [28]. A considerable amount of sugarcane bagasse biomass is drawn from sugar production, outdoor incineration, energy recovery, laboratory experiments, and prototype incinerators built to oversee the pozzolanic attributes of the ash.

As a particular case, in Ethiopia, there is an enormous amount of coffee husk and sugar bagasse ash, which was not utilized efficiently [29, 30]. Around sugar and coffee processing factories, there were wastes dumped in high volume. Studies showed that around 192000 metric tons of coffee husk leftover were wasted in Ethiopia as a byproduct per year [29]. Furthermore, the organic materials in coffee husk wastes make it extremely a pollutant and need an excessive amount of oxygen for degradation [31]. Therefore, the greenhouse gas emissions and construction costs can be reduced by incorporating coffee husk and bagasse ash waste in the production of concrete. So far, some studies have shown partial replacement of cement in concrete production using coffee husk and sugarcane bagasse ash independently. However, to the authors' knowledge, no study showed the combined effects of the two materials as partial replacement of cement in making concrete. Therefore, this study aims to make application of the combination (hybrid) of sugarcane bagasse ash (SCBA) and coffee husk ash (CHA) produced in Ethiopia as a considerable pozzolanic content to substitute cement partially. To this end, this study performed an experimental study to observe the influence of adding hybrid of CHA and SCBA ash on the physical and mechanical characteristics of concretes and pastes by surveying specifically its consistency, setting time, workability, the unit weighs, compressive strength, split tensile strength, and flexural strength, which is used to analyze and identify the suitability of the hybrid ash as cement in the concrete production with full information. In another case, it is used to minimize energy consumption and environmental damage, which may realize the objective of sustainable development. Therefore, the use of hybrid ash could increase the sustainability of its supply, in case of increasing demand when compared to its independent use alone, and cover some proportion of resources used in the production of concrete. This has a great contribution to environmental conservation and construction cost reduction and increases the sustainability of the resource.

2. Experiment

2.1. Materials. The study specimens were prepared using a combination of different materials like hybrid coffee husk and bagasse ash, ordinary Portland cement, fine aggregate, coarse aggregate, and water.

Hybrid coffee husk and sugarcane bagasse ash: coffee husk was collected from Jimma town, Ethiopia, and was burned in a carbonate furnace for three hours at 550°C to get coffee husk ash as proposed in [21]. Figure 1(a) shows burned coffee husk in the furnace. Sugarcane bagasse ash (SCBA) sample was gathered from Arjo Didessa Sugar factory, East Wollega, Ethiopia, which is already burned, to ash in the furnace and it was sieved by 75 μm sieve size to discard impurities and course size particle. Figure 1(b) shows the sugarcane bagasse ash obtained from Arjo Didessa.

The hybrid is made from an equal proportion of its ingredients, which means 50% from coffee husk ash and 50% from sugarcane bagasse ash. The complete silicate analysis was conducted to determine significant and minor oxide elements of hybrid ash at the Geological Survey Center of Ethiopia using LiBO2 Fusion, HF attacks, Gravimetric, Colorimetric, and Atomic Absorption Spectrophotometer (AAS) methods. Hybrid CHA&SCBA ash was found to constitute Al2O3, Fe2O3, and MgO within the range, as described in ESA [32] and ASTM C150 [33] standard, and resulted in the formation of compounds like C3S and C3A, which are mainly accountable for the initial strength of concrete. Moreover, the hybrid CHA&SCBA ash was affirmed to possess a significant alkali content like K2O (16.70%). Therefore, when aggregates rich in silica are used to produce concrete, there is a high probability of reaction with alkali silica. Table 1 illustrates the chemical composition of hybrid coffee and bagasse ash obtained from the investigation.

(a)

(b)

Figure 1: (a) Coffee husk ash and (b) sugarcane bagasse ash.

Table 1: Major and minor oxides of hybrid of CHA and SCBA.

Component	SiO2	Al2O3	Fe2O3	CaO	MgO	K2O	MnO	P2O5	TiO2	H2O	LOI
Hybrid ash	31.32	3.16	1.66	5.86	1.68	16.70	0.08	2.30	0.20	1.52	36.32

Fine aggregate (sand): Natural sand having a maximum size of 4.75 mm was collected from the river and used for the test. Fine aggregate fully passing through 9.5 mm sieve size was used. By using the particle size distribution data, the average fineness modulus (uniformity of grading) used for mix design was calculated to check its conformity according to the ASTM C33 [34] recommendation. Table 2 and Figure 2 present the physical and particle size distribution of fine aggregate used for the tests, respectively.

Coarse aggregate: Coarse aggregates of an average weight extracted from crushed rock with a maximum diameter of 20 mm were used. Then, the excess fines in coarse aggregates were removed by sieving through a 4.75 mm sieve in conformity as per the requirements of the ASTM C33 [34] standard, and the result is illustrated in Figure 3. Its physical properties were presented in Table 3.

Cement: Portland Pozzolana cement of Dangote product with 32.5 R grade was used for mixing based on standard specification requirement of ASTM C187 [35], ASTM C191 [36], ASTM C184 [37], and ASTM C188 [38] to examine the physical properties of cement-like: the standard consistency, setting time, fineness, and specific gravity, respectively. The cement fineness obtained from the laboratory experiment showed that 100% passed the 150 μm, 97.4% passed the 100 μm, and 93.1% passed 90 μm and 77.8% passed 63 μm. Table 4 illustrates the physical properties of cement obtained from laboratory investigations.

Water: portable drinking water of Jimma municipality town was used for curing and mixing the concrete, which conforms to ASTM C1602 [39] specification requirements.

Table 2: Physical properties of fine aggregate.

Properties	Result	ASTM C33 limit
Density (kg/m3)	1578	—
Bulk specific gravity	2.52	2.4–2.9
Apparent specific gravity	2.47	2.4–2.9
Water absorption capacity (%)	1.32	0–4%
Free surface moisture (%)	0.5	—
Silt content (%)	4.2	≤5.0
Particle size (mm)	9.5–0.15	9.5–0.15
Fine modulus	2.4	2.3–3.1

2.2. Mixing Design, Casting, and Curing. For this particular investigation, a mix ratio proposed according to ACI 211-1 [40] was employed to get the intended C25 concrete grade. To prepare and cast the test specimens, the methods and procedure stated in ACI-C31 [41] were followed. Three-layer casting was considered for all test specimens, in which the compaction was undertaken manually by steel tamping rod with 25 number blows for each layer. Before mixing, each ingredient of concrete was prepared based on their respective weighted proportion by measuring with a weighting system as presented in Table 5 to keep the variation of proportion. At the initial stage, the coarse aggregate was put into the drum, then followed by sand. Then both ingredients were dry-blended with the required amount of cement (OPC) and hybrid ash. After a time being water was poured to dry-blended ingredients. The blending was performed for 10 minutes of duration for all test specimens under a 30 rev/min constant mixing rate. Figure 4 illustrates a way of casting concrete specimens. After casting, the test specimens were cured in a water tank which is available in Jimma University laboratory room and the temperature was kept in a range of 21°C and 25°C as recommended according to ASTM C511 [42].HA is hybrid ash.

2.3. Specimen Testing. Fresh concrete test: slump and compaction factor test have been conducted based on ASTM C143 [43] and BS 1881-103 [44] standard specification, respectively, to check the workability of the concrete specimen having 0%, 5%, 10%, and 15% of partial replacement of cement by hybrid CHA and SCBA ash. The reported value was determined from the average value of 3 specimens' measurements.

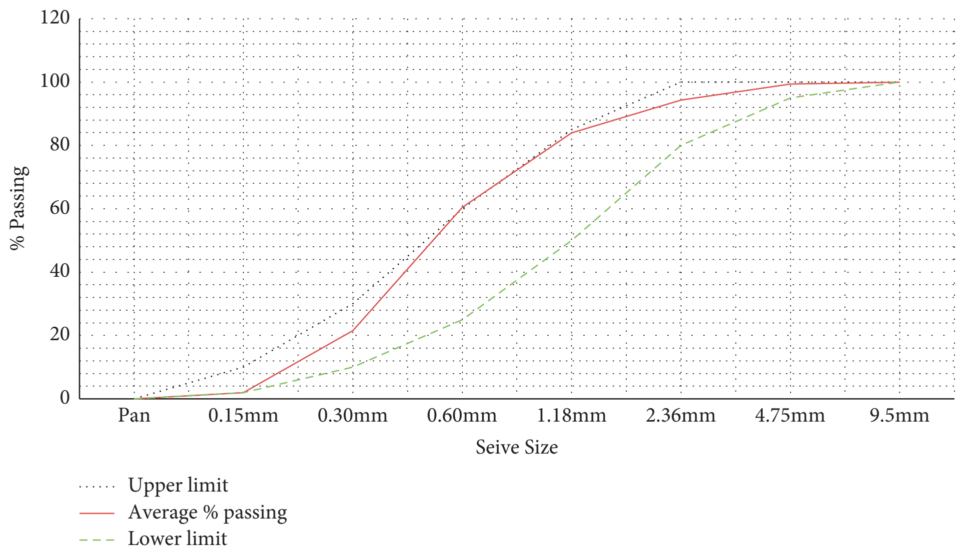

Figure 2: Fine aggregate particle size distribution.

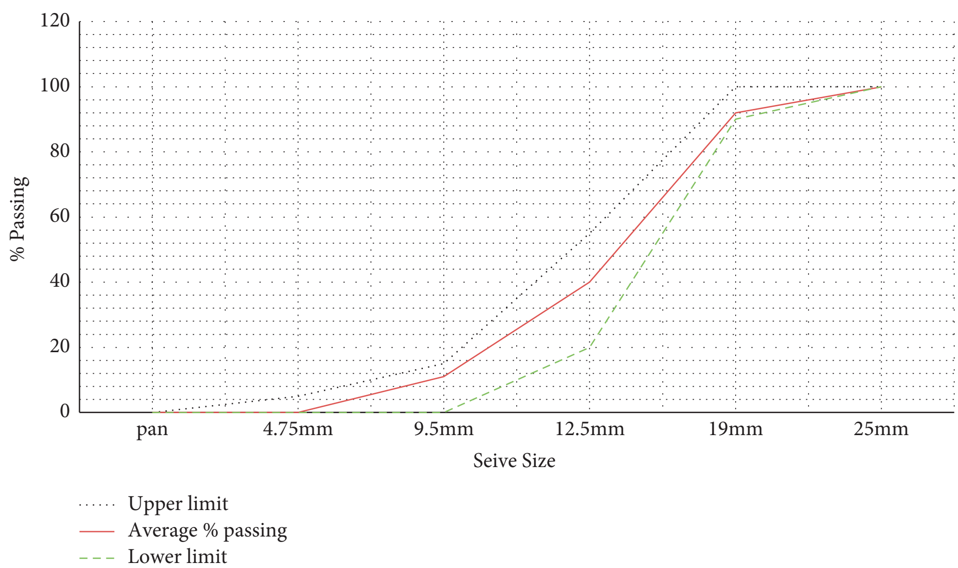

Figure 3: Coarse aggregate particle size distribution.

Table 3: Physical properties of course aggregate.

Properties	Result	ASTM C33 limit
Density (kg/m3)	1676.5	1200–1750
Bulk specific gravity	2.87	2.4–2.9
Apparent specific gravity	2.82	2.4–2.9
Water absorption capacity (%)	0.9	0–4%
Free surface moisture (%)	0.4	—
Particle size (mm)	25–9.5 mm	—

Table 4: Setting time, specific gravity, and standard consistency of the cement.

The physical properties of Dangote OPC cement	
Standard consistency (%)	29
Specific gravity	2.9
Initial setting time (min)	150
Final setting time (min)	270

Water absorption and density: the water absorption and density of the specimen have been determined based average value of three cubic specimens in conformity of ASTM C642 [45].

Hardened concrete test: flexural, split tensile, and compression tests have been conducted as proposed in ASTM C78 [46], ASTM C496 [47], and BS EN 12390-03 and BS 1881-116 ([48, 49]), respectively, on a concrete specimen having 0%, 5%, 10%, and 15% of partial substitution of cement by hybrid CHA and SCBA at 7th, 14th, and 28th day of curing. The number of specimens for hardened concrete was summarized in Table 6. Standard size of 150 mm × 150 mm × 150 mm cubic, 150 mm diameter by 300 mm height cylinder, and 150 mm × 150 mm × 700 mm beam were used for compressive, split tensile, and flexural tests, respectively. Figure 5 shows the tests performed for hardened concrete

Table 5: Content of concrete constituent for test.

Specimens composition	Cement (kg/m^3)	Hybrid ash (kg/m^3)	Fine aggregate (kg/m^3)	Course aggregate (kg/m^3)	Water (kg/m^3)
100% C + 0% HA	370	0	673.40	1087.80	185
95% C + 5% HA	351.5	18.5	673.40	1087.80	185
90% C + 10% HA	333	37	673.40	1087.80	185
85% C + 15% HA	314.5	55.5	673.40	1087.80	185

Figure 4: Casting concrete test specimens.

Table 6: Summary of specimens for hardened concrete.

	Types and number of tests									
Types of specimens	Compressive			Split tensile			Flexure beam			Total
	7th	14th	28th	7th	14th	28th	7th	14th	28th	
100% C + 0% HA	3	3	3	3	3	3	3	3	3	27
95% C + 5% HA	3	3	3	3	3	3	3	3	3	27
90% C + 10% HA	3	3	3	3	3	3	3	3	3	27
85% C + 15% HA	3	3	3	3	3	3	3	3	3	27
Total										108

(a) (b) (c)

Figure 5: (a) Compressive test. (b) Tensile split test. (c) Flexural test.

specimens. The average value of three concrete specimens was reported for each test type.

3. Result and Discussion

3.1. Hybrid of Ash and Cement Blended Pastes

3.1.1. Consistency of Blended Pastes. Since the water-cement ratio affects the rate of hydration and the setting of cement, the water demand of each can be assessed and identified. Table 7 shows the detailed results of the normal consistency of cement and hybrid ash based on the ASTM C 187 [35] standard. As the substitution of hybrid ash increased from 0% to 15% in concrete production, the consistency of concrete paste increased by 13.8%, because of high absorption of water.

Table 7: The consistency of concrete pastes comprising hybrid CHA&SCBA.

S. No	Percentage of replacement	Consistency (%)
1	100% C + 0%HA	29
2	95% C + 5%HA	30
3	90% C + 10%HA	32
4	85% C + 15%HA	33

3.1.2. Setting Time for Blended Paste. According to the ASTM C150 standard [33], a limitation has been specified that the initial setting time of cement paste shall not be less than 45 minutes, and the final setting time shall not exceed 375 minutes. As indicated in Table 8, the addition of hybrid CHA and SCBA ash decreased the rate of setting of the blended paste. However, the setting time of the paste is within an acceptable range, when compared to the standard specification. The setting time of the pastes is increased because of the higher absorption of water on the hybrid of CHA and SCBA ash. With the higher proportion of hybrid CHA and SCBA ash used, the water adsorption capacity and the normal consistency are increased, which in turn slow the rate of setting of the pastes.

3.2. Physical Properties of Test Specimens

3.2.1. Workability. Slump test: Figure 6 illustrates outputs of the slump test for the control and partially replaced cement concrete specimens. The test revealed that as the percentage of hybrid CHA&SCBA ash increases, the slump value is decreased when compared to the control specimen, under constant water-cement ratio. As the percentage of hybrid ash increased from 0% to 15%, the slump value decreased by 15.2%. This implies that ordinary Portland cement with a hybrid of CHA&SCBA ash blended concrete paste needs a higher water content than control. The possible reason was that the hybrid of CHA&SCBA ash has lower density of 2416.79 kg/m3, 2383.21 kg/m3, and 2183.7 kg/m3 and higher porosity of 9.23%, 10.16%, and 11.03% for 5%, 10%, and 15% hybrid ash, respectively. To have a slump value similar to the control, the amount of water content could be increased as the hybrid of CHA&SCBA ash content increased. The required amount of water can be determined by using different water-cement ratios with try and error during concrete paste making and testing, until their range of slump value with control approaches zero. According to ASTMC143/C143 M [43] standard, concrete pastes having a slump test value less than 15 mm may not be adequately plastic and greater than 230 mm may not be adequately cohesive. The slump test values between 15 mm and 230 mm are favorable in concrete production. On another hand, ACI 211.1-91 [40] recommended a slump value in a range of 20 mm to 100 mm based on different types of construction like foundation, wall, column, beam, and others. The slump test value obtained from the experimental investigation was found in between the ranges specified in the standards. Therefore, the hybrid of CHA&SCBA ash concrete paste is good in plastic and cohesive properties and can be applied to different types of construction [29, 30]. As a result, it was found that a hybrid of CHA&SCBA ash concrete will be good to minimize the segregation of fresh concrete during placing and consolidating.

Compaction factor test: From Figure 7, it was clearly understood that as the percentage of hybrid ash content increased, the compaction factor test result decreased. As the percentage of hybrid ash increased from 0% to 15%, the compaction factor value decreased by 6.92%. This implies that a large amount of water is required for hybrid CHA&SCBA ash concrete to get a similar compaction factor with control.

3.2.2. Density of Hardened Concrete. The weights and dimensions of the cubic specimens were measured just before testing, in order to compute the density at 7th, 14th, and 28th day age. A 2400 kg/m3 is a conservative value for the density of concrete, according to most standard recommendations [50]. However, the density of concrete is largely dependent on the physical properties of its constituent. Therefore, it is highly preferred to compute the density of the specimens experimentally for analysis and design purposes. The result indicated in Table 9 and Figure 8 shows the density reduction as the percentage of replacement increased due to the low bulk density of hybrid ash. In another way, the density of concrete is increased up to 1.3%, as concrete age increases from the 7th to the 28th day due to further hydration. Such type of concrete has a significant benefit due to lowered density, specifically for a load-bearing structure having smaller cross-sections. The result also causes the corresponding decrease in the size of the foundations.

3.3. Mechanical Properties of Test Specimens

3.3.1. Compressive Strength Test. Types of cement, curing conditions, and temperature affect the compressive strength of the concrete at any time t day. At a 20°C mean temperature and following EN12390 curing, the minimum or target concrete compressive strength at time t can be predicted according to (1) [48].

$$
\begin{aligned}
& f_{ck}(t) = f_{cm}(t) - 8\,(MPa) \quad \text{for } 3 < t < 28 \text{ days}, \\
& f_{ck}(t) = f_{ck} \quad \text{for} \geq 28 \text{ days}, \\
& f_{cm}(t) = \beta_{cc}(t) f cm, \\
& \beta_{cc}(t) = \exp\left(s \cdot \left[1 - \left(\frac{28}{t} \right)^{1/2} \right] \right).
\end{aligned} \tag{1}
$$

$f_{cm}(t)$ is the mean concrete compressive strength at the age of t day, f_{cm} is the mean compressive strength, $\beta_{cc}(t)$ is a coefficient that depends on the concrete age, t is the age of the concrete in day, and s is a coefficient which depends on the type of cement.

As it can be understood from Figure 9(a), the compressive strength of partially replaced cement of concrete specimens is decreased compared to the control specimens, except the concrete compressive strength of 5% hybrid specimen at the 7th day of curing, which has greater compressive strength. The decrease in concrete compressive strength of partially replaced concrete paste is caused by the partial substitution of cement by the hybrid ash. Except for 15% partially replaced concrete, all specimens have a compressive strength more incredible than the target design compressive strength requirement of EN12390 [48] and ACI 113 [51] specification at 28th days. This implies that cement replaced by 10% hybrid ash is the limit compressive strength greater than the target strength. Figure 9(b) illustrates the percentage of reduction of the concrete compressive strength with partially replaced cement compared to control

Table 8: Concrete paste setting time containing hybrid CHA&SCBA ash.

S. No	Code	Initial setting time (minutes)	Final setting time (minutes)
1	100% C + 0%HA	150	270
2	100% C + 5%HA	156	277
3	100% C + 10%HA	164	287
4	100% C + 15%HA	182	308

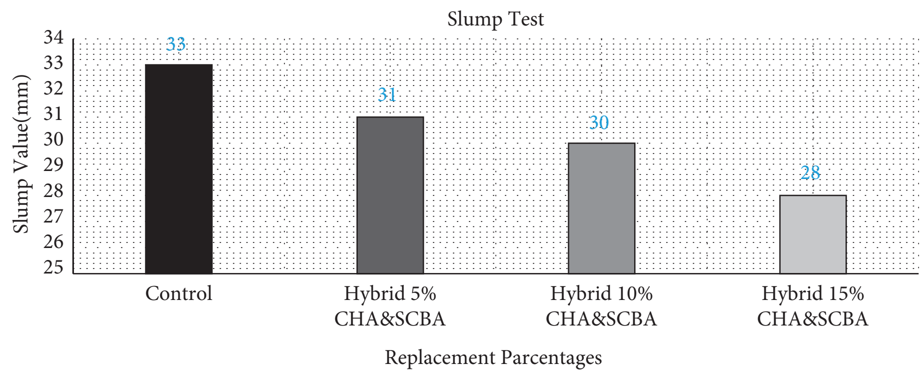

Figure 6: Slump test result.

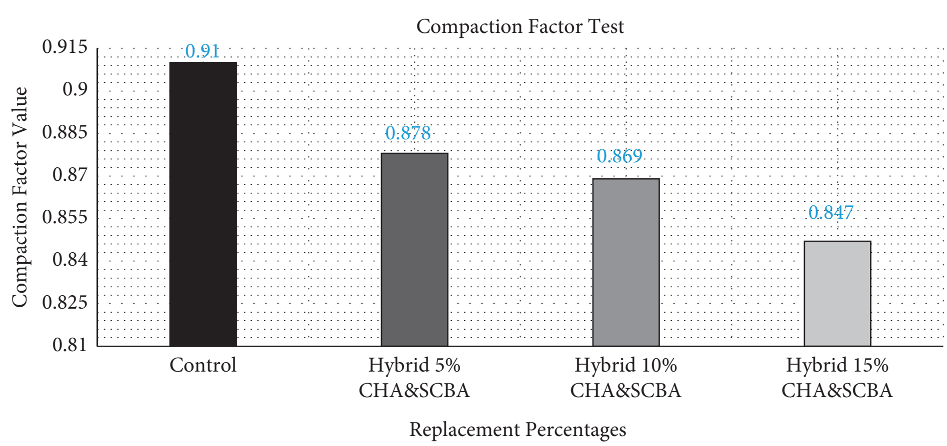

Figure 7: Compaction factor test result.

Table 9: Density of the cubes specimen.

Specimens composition	Density (Kg/m^3)			Density reduction (%)		
	7th	14th	28th	7th	14th	28th
100% C + 0% HA	2437.53	2445.43	2469.14	0.0	0.0	0.0
95% C + 5% HA	2400.99	2405.93	2416.79	1.5	1.61	2.12
90% C + 10% HA	2356.54	2380.25	2383.21	3.32	2.67	3.48
85% C + 15% HA	2272.59	2284.44	2293.33	6.77	6.58	7.12

specimens. The concrete compressive strength is significantly decreased as the percentage of partial replacement increases. Loss in compressive strength of 8.34%, 12.82%, and 27.17% was observed when 5%, 10%, and 15% of the cement were replaced by an equivalent mass of hybrid CHA and SCBA ash, respectively, on the 28th day compressive strength test.

3.3.2. Split Tensile Strength Test. The target or minimum tensile strength of the concrete also mainly depends on age, curing, and temperature, which can be estimated using [52]

$$f_{ctm} = 0.9 f_{ct,sp},$$
$$f_{ctm}(t) = (\beta_{cc}(t))^{\alpha}.f_{ctm},$$
$$\alpha = 1 \quad \text{for } t < 28, \tag{2}$$
$$\alpha = \frac{2}{3} \quad \text{for } t \geq 28$$
$$95\,\%\,\text{fractile} \quad f_{ctk,0.95} = 1.3 * f_{ctm},$$

where $f_{ctm}(t)$ is the mean concrete tensile strength at the age of t day, $f_{ct,sp}$ is the splitting tensile strength, f_{ctm} is the mean tensile strength at age of 28 days, t is the age of the

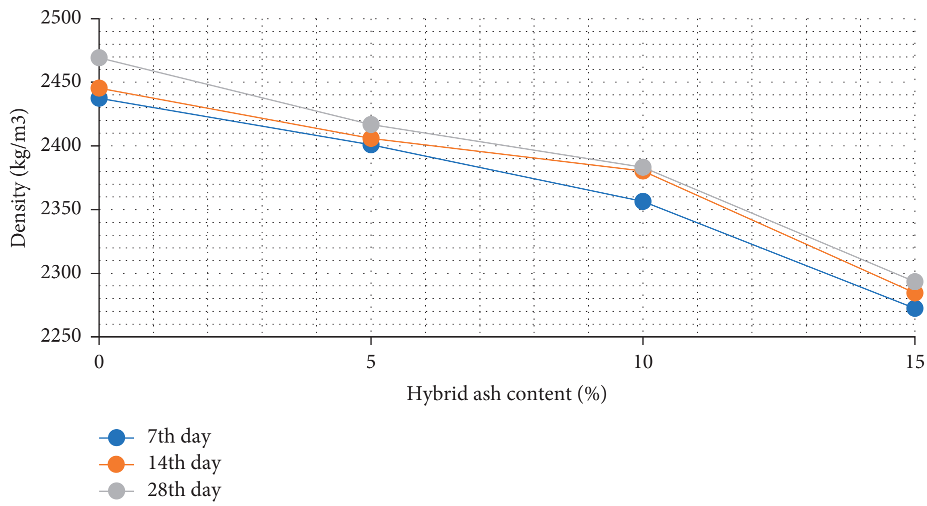

FIGURE 8: Density reduction with respect hybrid ash content.

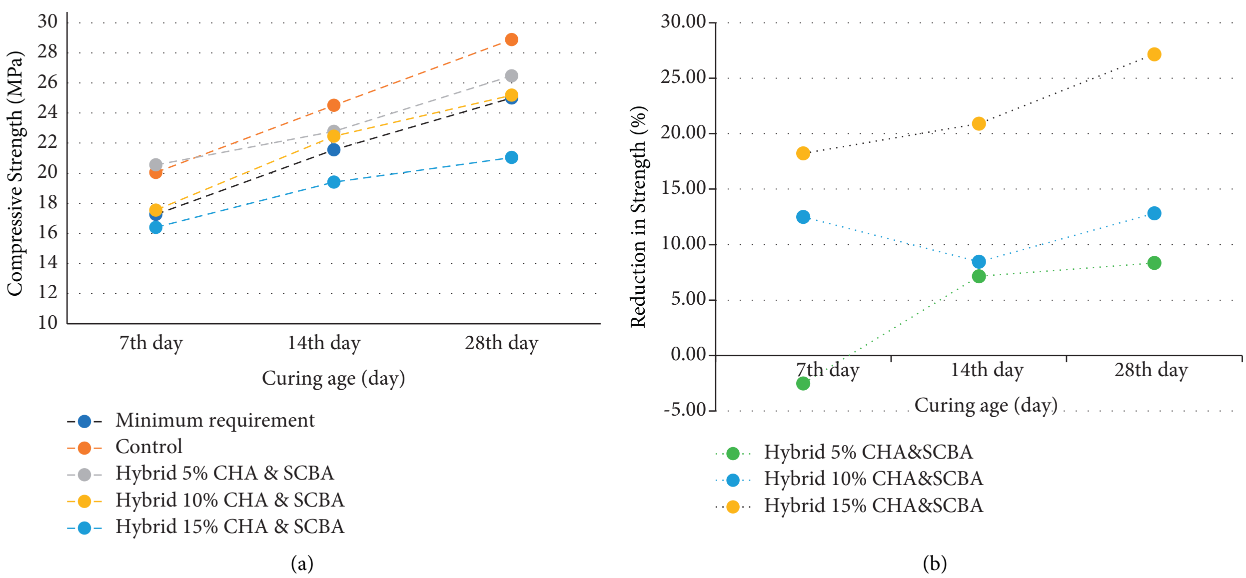

FIGURE 9: (a) Compressive strength of test specimens and (b) reduction in compressive strength of partially replaced cement concerning control specimen.

concrete in day, and α is a coefficient which depends on the age of concrete.

In Figure 10(a), a clear relationship was observed between control mix split tensile strength and hybrid of CHA and SCBA ash content. As a hybrid of CHA and SCBA ash content increased from 0% to 15%, on the 7th, 14th, and the 28th day, the split tensile strength decreased by 12.83%, 20.0%, and 25.0%, respectively. However, their values are still in a reasonable range of up to 10%, which is greater than the target concrete tensile strength proposed in ESA [52] and ACI 113 [51] on the 28th day of curing. Therefore, the percentage of replacement of up to 10% can be practically applied in concrete production, which is acceptable strength. The 15% replacement is slightly out of range for the targeted grade of concrete C25, and the concrete does not conform to the specification. Besides, as presented in Figure 10(b), the split tensile strength of hybrid CHA&SCBA ash of the 28th day was decreased within the range of 2.87% to 24.84% as compared to the control mix.

3.3.3. Flexural Test. A standard machine with two-point load at one-third span was used to investigate the flexural behavior of plain concrete beams made from different hybrid ash. The flexural test was used to evaluate the tensile strength of concrete indirectly. As it is observed from Figure 11, the flexure strength of concrete was increased as the age of curing increased. The positive percentage of variations from the control mix is observed for hybrid 5%, 10%, and 15% on the 7th day, 10% and 15% on the 14th day, and 15% on the 28th day test result. The maximum flexural

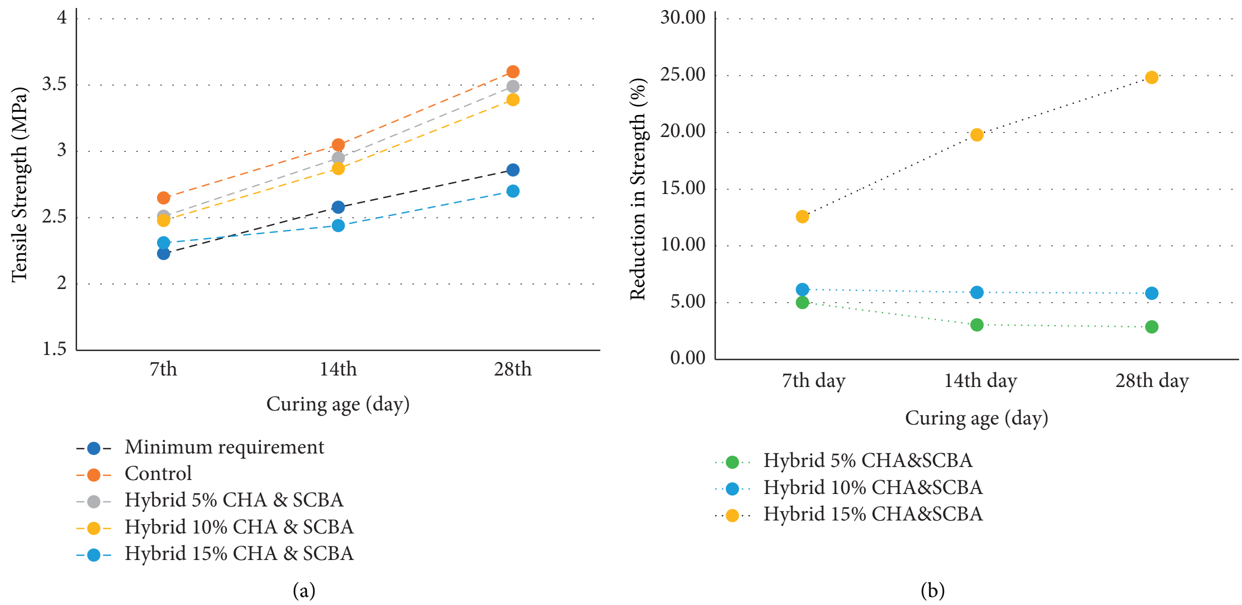

FIGURE 10: (a) Split tensile strength of test specimens and (b) reduction in tensile strength of partially replaced cement concerning control specimen.

strength of 7.17 MPa was obtained for hybrid 5% on the 28th day of curing, which is greater than the control. Based on the test result, flexural strength increased by 2.79% and 0.21% for 5% and 10% hybrid concerning control on the 28th day. However, on the 28th day, flexural strength decreased by 16.24%, when 15% hybrid ash replaced cement [53]. This confirms that the flexural strength is not affected when hybrid ash is up to 10% incorporated in concrete production.

3.3.4. Stress-Strain Curve. Figure 12 illustrates the stress-strain curve of 5%, 10%, and 15% partially replaced and control mix of the 28th day test result. The slope of stress-strain curves is slightly decreased as the percentage of partial replacement increases. Moreover, once the peak load is reached, the load-carrying capacity (ductility properties of concrete) from the yield strain up to the point of rupture (ultimate strain) for hybrid coffee husk and sugarcane bagasse ash concrete was less than the control mix. This shows that as the percentage of replacement increases, the elastic modulus, strength, and ductility will decrease [54]. As the slope of the curve becomes steep, the elastic modulus gets high value. In another case, concrete with high elongation or strain at ultimate failure is more ductile than concrete with low elongation or strain.

3.4. Regression Analysis. Regression analysis is significantly important to know the influence of at least one independent variable on the dependent variable. For this particular study, regression and correlation were conducted in Microsoft Excel. Figure 13 illustrates the correlation between concrete compressive and tensile strength using output obtained from the experimental test. There is a strong positive relationship

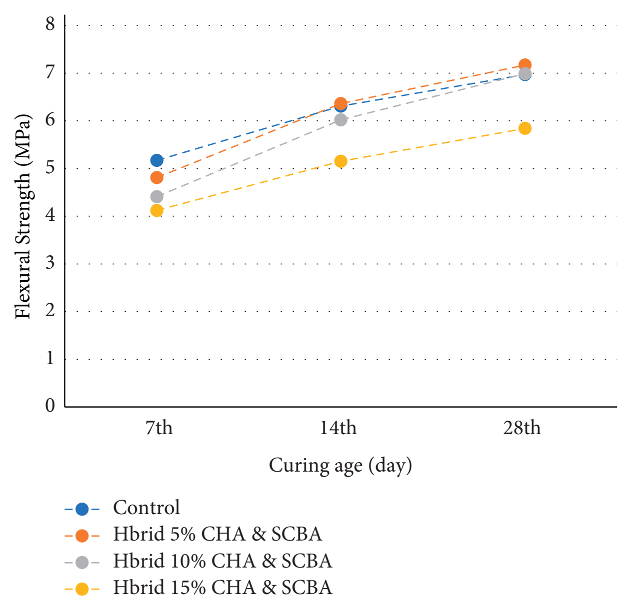

FIGURE 11: Flexural strength of test specimens.

between the two variables with the coefficient of determination of 0.8506. This implies that as concrete compressive strength increases, the concrete tensile strength is also increased. Furthermore, the regression analysis was conducted to access the effect of independent variables (hybrid ash and curing days) on compressive and tensile strength. Equation (3) is used to predict the compressive strength of concrete for a given percentage of hybrid ash and curing days. Using empirical formula derived from regression analysis for compressive strength, 9.41% is the maximum percentage of replacement, which resulted in a compressive strength greater than the target. Based on the coefficient of

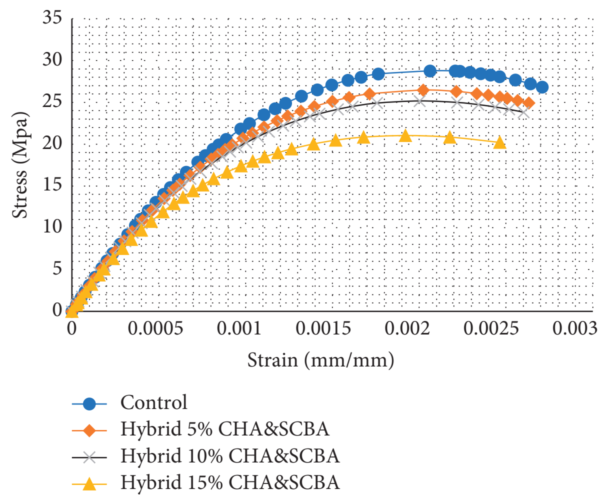

FIGURE 12: Stress-strain curve of test specimens at 28th day.

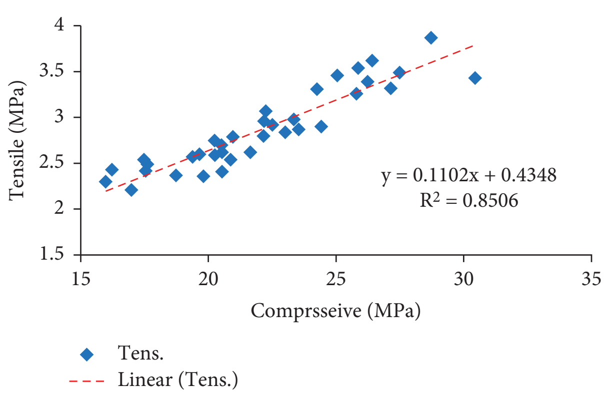

FIGURE 13: Relationship between tensile and compressive strength. x is the concrete compressive strength in MPa, and y is the concrete tensile strength in MPa.

independent variables, there is a negative relationship between hybrid ash and compressive strength and a positive relationship between curing days and compressive. The same relationship was observed for tensile strength as illustrated in (4).

$$f_c = -0.3633a + 0.30751\ d + 19.81, \quad (3)$$

$$f_t = -0.0381a + 0.037662\ d + 2.5411, \quad (4)$$

where f_c is the concrete compressive strength in MPa, f_t is the concrete tensile strength in MPa, a is the content of hybrid ash in %, and d is the curing period in days.

4. Conclusions

In this study, hybrid ash made from an equal proportion of coffee husk and sugarcane bagasse ash was utilized as cement-substitution materials in the production of concrete to investigate its physical and mechanical properties. Hybrid ash with 0%, 5%, 10%, and 15% was used to access the concrete properties on the 7th, 14th, and 28th day of curing. Depending on the test results, the following conclusions are drawn:

(i) As the hybrid ash replacement value increased from 0% to 15%, the workability and density of concrete decreased by 15.15% and 11.56%, respectively. However, the normal consistency and setting time of concrete increased by 13.79% and 18.35%. Therefore, for certain workability, higher water content is required.

(ii) Concrete compressive strength is decreased, as the value of percentage of replacement increases. However, on the 28th day, concrete made from the partial substitution of cement by up to 10% resulted in a compressive strength greater than the target (25 MPa). Therefore, 10% of replacement is the maximum limit, in order to get strength greater than the target.

(iii) Split tensile strength is also decreased, as the percentage of replacement increases. Split tensile strength on the 28th day was slightly decreased within the range of 2.87% to 24.84% for hybrid ash content in the range of 5% to 15% replacement. However, the specimens with up to 10% showed a tensile strength greater than the target.

(iv) In addition, as the percentage of replacement increased, the flexural strength also decreased at all curing days except the concrete test specimen made from 5% hybrid ash which showed a flexural strength greater than the control specimen on the 14th and 28th day and the test specimen made from 10% showed almost equal flexural strength with control specimen on 28th day.

(v) Regression analysis showed a strong correlation between concrete compressive and tensile strength with the coefficient of determination of 0.8506. This implies that, as concrete compressive strength increased, the tensile strength also increased [55–60].

Data Availability

All data used to support the findings of the study are included within the article.

Conflicts of Interest

The authors have no conflicts of interest regarding the article.

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References

[1] S. K. Das, J. Mishra, S. K. Singh et al., “Characterization and utilization of rice husk ash (RHA) in fly ash - blast furnace slag based geopolymer concrete for sustainable future,” *Materials Today Proceedings*, vol. 33, pp. 5162–5167, 2020.

[2] H. Mikulčić, J. J. Klemeš, M. Vujanović, K. Urbaniec, and N. Duić, “Reducing greenhouse gasses emissions by fostering

the deployment of alternative raw materials and energy sources in the cleaner cement manufacturing process," *Journal of Cleaner Production*, vol. 136, pp. 119–132, 2016.

[3] H. M. Hamada, B. Tayeh, and F. M. Yahaya, "Use of oil palm shell as an aggregate in cement concrete: a review," *Construction and Building Materials*, vol. 265, Article ID 120357, 2020.

[4] T. Taher, "Exploitation of the nanowaste ceramic incorporated with nano silica to improve concrete properties," *Journal of King Saud University - Engineering Sciences*, vol. 33, no. 8, pp. 581–588, 2021.

[5] A. M. Zeyad, M. A. Johari, Y. R. Alharbi et al., "Influence of steam curing regimes on the properties of ultrafine POFA-based high-strength green concrete," *Journal of Building Engineering*, vol. 38, Article ID 102204, 2021.

[6] A. M. Zeyad, A. Abutaleb, B. A. Tayeh, and B. A. Tayeh, "The effect of steam curing regimes on the chloride resistance and pore size of high-strength green concrete," *Construction and Building Materials*, vol. 280, Article ID 122409, 2021.

[7] J. He, Y. Jie, J. Zhang, Y. Yu, and G. Zhang, "Synthesis and characterization of red mud and rice husk ash-based geopolymer composites," *Cement and Concrete Composites*, vol. 37, no. 1, pp. 108–118, 2013.

[8] R. Rumman, M. S. Bari, T. Manzur, M. R. Kamal, and M. A. Noor, "A durable concrete mix design approach using combined aggregate gradation bands and rice husk ash based blended cement," *Journal of Building Engineering*, vol. 30, Article ID 101303, 2020.

[9] S. Hansen and P. Sadeghian, "Recycled gypsum powder from waste drywalls combined with fl y ash for partial cement replacement in concrete," *Journal of Cleaner Production*, vol. 274, Article ID 122785, 2020.

[10] Z. Hamid and S. Rafiq, "An experimental study on behavior of wood ash in concrete as partial replacement of cement," *Materials Today Proceedings*, vol. 46, pp. 3426–3429, 2021.

[11] X. C. Zhao, R. Huang, and Q. Wang, "Properties of foamed mortar prepared with granulated blast-furnace slag," *Materials*, vol. 8, no. 2, pp. 462–473, 2015.

[12] S. S. Sharipudin, A. R. M. Ridzuan, and M. Ridzuan, "Influence of waste paper sludge ash (WPSA) and fine recycled concrete aggregate (FRCA) on the compressive strength characteristic of foamed concrete," *Advanced Materials Research*, vol. 626, pp. 376–380, 2012.

[13] C. P. Chua, U. J. Alengaram, M. Z. Jumaat, and M. Z. Jumaat, "Utilization of palm oil fuel ash as binder in lightweight oil palm shell geopolymer concrete," *Advances in Materials Science and Engineering*, vol. 2014, Article ID 610274, 6 pages, 2014.

[14] Q. S. Khan, M. N. Sheikh, T. J. Mccarthy, M. Robati, and M. Allen, "Experimental investigation on foam concrete without and with recycled glass powder: a sustainable solution for future construction," *Construction and Building Materials*, vol. 201, pp. 369–379, 2019.

[15] C. O. S. Trength and U. S. T. Aguchi, "The influence of microwave incinerated rice husk ash on foamed concrete workability and compressive strength using taguchi method," *J. Teknol.*vol. 1, pp. 265–274, 2015.

[16] K. M. Mini, "Study on concrete with partial replacement of cement by rice husk ash," *IOP Conference Series: Materials Science and Engineering*, vol. 149, Article ID 012109, 2016.

[17] G. Abebaw, B. Bewket, and S. Getahun, "Experimental investigation on effect of partial replacement of cement with bamboo leaf ash on concrete property," *Advances in Civil Engineering*, vol. 2021, Article ID 6468444, 9 pages, 2021.

[18] K. Bazzar and A. H. Alaoui, "A study on strength properties of concrete with replacement of low C3A cement by fly ash," *Journal of Materials Science and Engineering B*, vol. 11, no. 1, pp. 7–15, 2021.

[19] S. Noshin, M. A. Khan, M. Salman et al., "Evaluating the compressive strength of concrete containing recycled aggregate in different curing conditions," *Journal of Applied Engineering Sciences*, vol. 11, no. 2, pp. 127–136, 2021.

[20] G. G. Prabhu, J. W. Bang, B. J. Lee, J. H. Hyun, and Y. Y. Kim, "Mechanical and durability properties of concrete made with used foundry sand as fine aggregate," *Advances in Materials Science and Engineering*, vol. 2015, Article ID 161753, 11 pages, 2015.

[21] A. Demissew, F. Fufa, and S. Assefa, "Partial replacement of cement by coffee husk ash for c-25 concrete production," *Journal of Civil Engineering, Science and Technology*, vol. 10, no. 1, pp. 12–21, 2019.

[22] L. K. Lin, T. Kuo, and Y. Hsu, "The application and evaluation research of coffee residue ash into mortar," *Journal of Material Cycles and Waste Management*, vol. 18, no. 3, pp. 541–551, 2015.

[23] M. Ilangovan, C Hu, A. Takemura, Z. Leman, and N. Reddy, "Dehulled coffee husk-based biocomposites for green building materials," *Journal of Thermoplastic Composite Materials*, vol. 34, no. 12, pp. 1623–1638, 2019.

[24] M. R. Puppala and M. K. M. V. Ratnam, "An experimental study on concrete with sugarcane bagasse ash as a partial replacement of cement under sulphate attack using Mgso4 solution," *International Journal of Innovative Research in Science, Engineering and Technology*, vol. 03, no. 12, Article ID 18121, 2014.

[25] J. A. Patel and D. B. Raijiwala, "Experimental study on compressive strength of concrete by partially replacement of cement with sugar cane bagasse ash," *Jayminkumar A. Patel Int. J. Eng. Res. Appl.*vol. 5, no. 4, pp. 117–120, 2015.

[26] M. Sadique, P. Paloma, A. Bras, A. William, and R. Mike, "Potential use of sugar cane bagasse ash as sand replacement for durable concrete," *Journal of Building Engineering*, vol. 39, Article ID 102277, 2021.

[27] D. S. M. Inbasekar and P. Hariprasath, "International journal of engineering sciences & research technology study on potential utilization of sugarcane bagasse ash in steel fiber reinforced concrete," *Int. J. Eng. Sci. Res. Technol.*vol. 5, no. 4, pp. 43–50, 2016.

[28] P. O. Modani and M. R. Vyawahare, "Utilization of bagasse ash as a partial replacement of fine aggregate in concrete," *Procedia Engineering*, vol. 51, pp. 25–29, 2013.

[29] W. Sime, R. Kasirajan, S. Latebo, A. Mohammed, and E. Seraw, "Coffee husk highly available in Ethiopia as an alternative waste source for biofuel production," *International Journal of Scientific Engineering and Research*, vol. 8, no. 7, 2017, http://www.ijser.org.

[30] M. Mamaye, Z. Kiflie, S. Feleke, A. Yimam, and S. A. Jabasingh, "Valorization of Ethiopian sugarcane bagasse to assess its suitability for pulp and paper production," *Sugar Tech*, vol. 21, no. 6, pp. 995–1002, 2019.

[31] L. S. Oliveira, A. S. Franca, R. R. S. Camargos, and V. P. Ferraz, "Coffee oil as a potential feedstock for biodiesel production," *Bioresource Technology*, vol. 99, no. 8, pp. 3244–3250, 2008.

[32] Ethiopia, *Standard Agency, Cmposition, Specification and Conformity Criteria for Common Cement*, Addis Ababa, Ethiopia, 2013.

[33] ASTM C150, *Standard Specification for Portland Cement*, ASTM International, West Conshohocken, PA, USA, 2004.

[34] Astmc33, *Standard Specification for Concrete Aggregate*, ASTM International, West Conshohocken, PA, USA, 2003.

[35] ASTMC187-11, *Standard Test Method for Normal Consistency of Hydraulic Cement*, ASTM International, West Conshohocken, PA, USA, 2011.

[36] ASTMC191-13, *Standard Test Methods for Time of Setting of Hydraulic Cement by Vicat Needle*, ASTM International, West Conshohocken, PA, USA, 2013.

[37] Astmc184, *Standard Test Method for Fineness of Hydraulic Cement by the 150-Micrometer (No. 100) and 75-Micrometer (No. 200) Sieves*, ASTM International, West Conshohocken, PA, USA, 1994.

[38] ASTMC188-17, *Standard Test Method for Density of Hydraulic Cement*, ASTM International, West Conshohocken, PA, USA, 2017.

[39] ASTM C1602, *Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete*, ASTM International, West Conshohocken, PA, USA, 2012.

[40] ACI 211-1, *Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete*, American Concrete Institute, Farmington Hills, MI, USA, 2002.

[41] Aci-C31, *Making and Curing Concrete Test Specimens in the Field*, ASTM International, West Conshohocken, PA, USA, 2020.

[42] ASTM C511, *Standard Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes*, ASTM International, West Conshohocken, PA, USA, 2005.

[43] ASTM C143, *Standard Test Method for Slump of Hydraulic-Cement Concrete*, ASTM International, West Conshohocken, PA, USA, 2003.

[44] BS 1881-103, *Testing Concrete: Method for Determination of Compacting Factor*, British Standards Institution, London, UK, 1993.

[45] ASTM C642, *Standard Test Method for Density, Absorption, and Voids in Hardened Concrete*, ASTM International, West Conshohocken, PA, USA, 2006.

[46] ASTM C78/C78M-16, *Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)*, ASTM International, West Conshohocken, PA, USA, 2016.

[47] ASTM C496, *Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens*, ASTM International, West Conshohocken, PA, USA, 2004.

[48] BS EN 12390-03, *Testing Concrete Compressive Strength of Test Specimens*, British Standards Institution, London, United Kingdom, 2009.

[49] BS 1881-116, *Testing Concrete: Method for Determination of Compressive Strength of Concrete Cubes*, British Standards Institution, London, United Kingdom, 1983.

[50] BS 8110-1, *Structural Use of Concrete:- Part 1: Code of Practice for Design and Construction*, British Standards Institution, London, UK, p. 168, 1997.

[51] ACI Committee 113, *Manual of Concrete Inspection*, American Concrete Institute, Farmington Hills, MI, USA, 2009.

[52] EN 1992-1-1:2015, *Compulsory Ethiopian Standard Design of Concrete Structures-Part 1-1: General Rules and Rules for Buildings*, Ethiopian Standards Agency, Addis Ababa, Ethiopia, 2015.

[53] S. Chowdhury, M. Mishra, and O. Suganya, "The incorporation of wood waste ash as a partial cement replacement material for making structural grade concrete: an overview," *Ain Shams Engineering Journal*, vol. 6, no. 2, pp. 429–437, 2015.

[54] A. Okeola, S. Abuodha, and J. Mwero, "Experimental Investigation of the Physical and Mechanical Properties of Sisal Fiber," *Fibers*, vol. 6, no. 3, p. 53, 2018.

[55] I. Almeshal, B. A. Tayeh, R. Alyousef, H. Alabduljabbar, and A. M. Mohamed, "Eco-friendly concrete containing recycled plastic as partial replacement for sand," *Journal of Materials Research and Technology*, vol. 9, no. 3, pp. 4631–4643, 2020.

[56] J. Ahmad, O. Zaid, O. Zaid, M. Shahzaib, M. U. Abdullah, and A. Ullah, "Mechanical properties of sustainable concrete modified by adding marble slurry as cement substitution," *AIMS Materials Science*, vol. 8, no. 3, pp. 343–358, 2021.

[57] J. Ahmad, . R. García, J. d. Prado-Gil et al., "Concrete with partial substitution of waste glass and recycled concrete aggregate," *Materials*, vol. 15, no. 2, p. 430, 2022.

[58] A. Ferraroe, F. Colangelo, I. Farina et al., "Cold-bonding process for treatment and reuse of waste materials: technical designs and applications of pelletized products," *Critical Reviews in Environmental Science and Technology*, vol. 51, no. 19, pp. 2197–2231, 2021.

[59] O. Rezaifar, M. Gholhaki, and M. Gholhaki, "Investigating the properties of bentonite and kaolin modified concrete as a partial substitute to cement," *SN Applied Sciences*, vol. 2, no. 12, pp. 2023–2114, 2020.

[60] R. Srinivasan, "Experimental study on bagasse ash in concrete," *International Journal for Service Learning in Engineering, Humanitarian Engineering and Social Entrepreneurship*, vol. 5, no. 2, pp. 60–66, 2010.