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Influence of Some Selected Supplementary Cementitious Materials on Workability and Compressive Strength of Concrete – A Review

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Abstract Premature deterioration of our nation's concrete structures has been a persistent and frustrating problem to those responsible for maintaining them as well as to the public. One of the ways to minimize these problems is to make the concrete less permeable by densifying the cementitious paste. This densification is achieved by using a lower water-cement ratio and supplementary cementitious materials (SCMs). Many researchers have successfully provided a rundown of the current facts about the favorable use of supplementary cementitious materials. These summaries contain a limited number of SCMs considered. This paper reviews the influence of twelve (12) selected supplementary cementitious materials, which are; Cupola Furnace Slag Powder (CFSP), Blast Furnace Slag Powder (BFSP), Silica Fume (SF), Fly Ash (FA), Rice Husk Ash (RHA), Metakaolin (MK), Coconut Husk Ash (CHA), Palm Oil Fuel Ash (POFA), Wood Waste Ash (WWA), Sugar Cane Bagasse Ash (SCBA), Corn Cob Ash (CCA), Bamboo Leaf Ash (BLA), workability and compressive strength of concrete, thus providing a larger database of the current facts about the favorable use of industrial and agricultural byproducts in the concrete industry. Review of literature and careful observation of results were used in generating the useful information provided in this paper. This review considered the compressive strength and workability of concrete containing partial substitute of ordinary Portland cement by the aforementioned supplementary cementitious materials. The chemical compositions of each of these selected supplementary cementitious materials were also reported. This study revealed that the incorporation of these twelve SCMs significantly improves the strength and workability of concrete. It is therefore recommended that arrangements be made by those interested in this paper for processing of these SCMs into commercial cement rather than being disposed of as wastes.

Keywords: Supplementary cementitious materials, Cement, Concrete, Workability, Compressive strength. Pozzolans

1 Introduction

Among the very important construction materials in civil engineering is concrete [1]. While construction with concrete continually leads to socio-economic development in both developed and developing countries, it is apparent that a few operations in concrete making cause a number of negative transformations to the natural environment. Firstly, the large consumption of natural materials for concrete production diminishes the world's natural materials reserves. If this consumption pattern continues, there will be fewer natural resources available in future, and the energy needed to extract the diminishing stocks and haulage distance will undoubtedly increase. Secondly, cement which is among the very versatile concrete constituents is energy intensive in its manufacture. This was also emphasized in the study of *Ede, Bamigboye, Olofinnade and Shittu* [2]. Cement plants have made attempts in lowering both the CO_2 release due to the de-carbonation of the source materials (CO_2-D) and those obtained from the kiln (CO_2-K). CO_2-D is minimized when part of the source materials are replaced by wastes from the industry. *Awoyera, Olofinnade, Busari, Akinwumi, Oyefesobi and Ikemefuna* [3] and *Olofinnade, Ndambuki, Ede and Booth* [4] pointed out that reusing some waste materials as concrete constituents provides sustainability in the preservation of natural deposits. These by-products are silica fume, blast furnace slag, fly ash and natural pozzolans. They generally are called supplementary cementitious materials (SCMs). CO_2-K is minimized by increasing the heat capacity of the kiln and by co-processing wastes, such as biomass in the kiln.

Many researchers have successfully provided a rundown of the current facts about the favorable use of supplementary cementitious materials. These summaries contain a limited number of SCMs considered. This article aims to review the influence of twelve (12) selected supplementary cementitious materials, which are; Cupola Furnace Slag Powder (CFSP), Blast Furnace Slag Powder (BFSP), Silica Fume (SF), Rice Husk Ash (RHA), Fly Ash (FA), Metakaolin (MK), Coconut Husk Ash (CHA), Palm Oil Fuel Ash (POFA), Wood Waste Ash (WWA), Sugar Cane Bagasse Ash (SCBA), Bamboo Leaf Ash (BLA), Corn Cob Ash (CCA), over the workability and compressive strength of concrete, thus providing a larger database of the current facts on the favorable utilization of industrial and agricultural by-products as constituents of concrete. This review considers only the compressive strength and workability of concrete incorporating part substitute of ordinary Portland cement by the aforementioned supplementary cementitious materials.

2. Supplementary cementitious materials (SCMs)

Supplementary cementitious materials are alternative products which supplement clinker and not weaken the work of cement as a concrete constituent. SCMs contain basic properties of cement. They are used alongside clinker because they lower clinker quantity, thereby saving the cost of energy, source materials as well as gas discharge. Supplementary cementitious materials also include the many products that are mixed with either water or some other liquid or both to form a cementing paste that may be formed or molded whole plastic but will set into a rigid shape. Cement containing these materials are called blended cement. Utilization of supplementary cementitious materials began with the Greeks who incorporated volcanic ash with hydraulic lime to create a cementitious mortar. The Greeks passed this knowledge onto the romans, who constructed such engineering marvels as the Roman's aqueducts and the Coliseum, which still stand today [5].

Early SCMs consisted of natural, readily available materials such as volcanic ash or diatomaceous earth. More recently, strict air pollution control and regulation have produced an abundance of industrial by-products that can be used as SCMs which are blast furnace slag, silica fume and fly ash. The use of such by-products in concrete construction enables concrete making industry to utilize several millions of tons of waste materials which would have been land-filled as waste. It also reduced the environmental

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impacts from extracting and processing virgin materials [6]. Supplementary cementitious materials are primarily used for improved workability, durability and strength. These materials allow the concrete producer to design and modify the concrete mixture to suit the desired application. Concrete mixtures with high Portland cement contents are susceptible to cracking and increased heat generation. These effects can be controlled to a certain degree by using supplementary cementitious materials. Furthermore, their use reduces the utilization of Portland cement per amount of concrete. Also, much energy consumption as well as emission accompanying the manufacture of Portland cement is reduced [7]. On the basis of reaction type, supplementary cementitious materials are grouped into two, namely hydraulic and pozzolanic materials. Hydraulic SCMs combine with water, forming compounds that possess cementitious qualities [8], while pozzolanic SCMs are materials rich in silicates and aluminates that have very little cementitious qualities but in their powdery form and with water will combine with calcium hydroxide to produce cementitious materials [9].

Supplementary cementitious materials include Cupola Furnace Slag Powder (CFSP), Blast Furnace Slag Powder (BFSP), Silica Fume (SF), Fly Ash (FA), Rice Husk Ash (RHA), Metakaolin (MK), Coconut Husk Ash (CHA), Palm Oil Fuel Ash (POFA), Wood Waste Ash (WWA), Sugar Cane Bagasse Ash (SCBA), Corn Cob Ash (CCA), Bamboo Leaf Ash (BLA), They are added to cement either through intergrinding with cement clinker, or by blending with cement after grinding, or can be added during concrete batching to supplement the cement. Due to the difference in chemistry, SCMs affect the performance of cement in concrete to suit different applications. The use of SCMs allows the construction industry to maintain the performance expected of cement while reducing the amount of clinker required in cement. As a result, the emission of greenhouse gases is reduced.

2.1. Cupola furnace slag powder (CFSP).

Cupola furnace slag is obtained from cupola furnaces which are acclaimed to be the oldest type of furnaces used in foundries. It is a dense, solid, vitrified material that varies in color from cream to black, but the predominant colorations are from green to brown. Lighter colored slag is sometimes associated with high basicity materials and darker slag with more oxidizing conditions in the furnace. Usually, some slag will exhibit lighter coloured grains in its makeup which are usually refractory particles eroded from the furnace lining. Generally, the cupola slag may be divided into two categories which are the basic and the acidic, depending on the properties of the lining materials and charging operations employed also, the porosity and physical conditions of the slag may be influenced by the collection practice. Based on chemical composition, research revealed that cupola furnace slag powder can be regarded as a pozzolan but based on its physical properties, it possesses minimal pozzolanic characteristics. It has been discovered by *Aderibigbe and Ojobo* [10] that firing CFSP at 700^0C at a period of 5 hours will help boost its physical characteristics. A chemical analysis of cupola furnace slag powder carried out by *Sinhamahapatra and Kar* [11] is presented in Table 1.

Table 1. Chemical composition of CFSP [11].

Chemical constituents	**CaO**	**SiO_2**	**Al_2O_3**	**MgO**	**S**	**SO_2**	**Loss on ignition**
Percentage composition	27.72	48.74	17.09	1.14	0.80	0.18	-

2.2. Blast furnace slag powder (BFSP).

The non-metallic manufactured waste out of a blast furnace when iron ore has been reduced to pig iron is called blast furnace slag. The liquid slag is rapidly cooled to form granules, which are then ground to fineness similar to Portland cement [1]. BFSP should conform to the standard specification, [12]. Three grades, 80, 100 and 120 are defined in *ASTM C989* [12] with the higher grade contributing more to strength potential. BFSP has cementitious properties by itself but these are enhanced when it is mixed with Portland cement. Slag is used at 20% to 70% by mass of the cementitious materials. The Slag Cement Association estimated that the use of slag cement as a cement substitute in concrete has the potential to eliminate 3 million metric tons of carbon dioxide emissions annually. The slag cement comprises of calcium-bearing siliceous and aluminosiliceous materials. The relative density of the slag cement ranges from 2.85 - 2.95. This has been in use as an SCM since 1900. Slag cement tends to prolong the initial setting time. This is advantageous when the weather is warm. When the weather is cold, accelerators can be used or the proportion of the slag cement can be reduced in order to reduce the initial time of setting. Its compressive strength from 7 to 14 days of curing is low but its strength at 28 days of curing and above is high [1]. The chemical constituents of BFSP according to *Leung, Yuen and Wong* [13], is depicted in Table 2.

Table 2. Chemical composition of BFSP [13].

Chemical constituents	CaO	SiO_2	Al_2O_3	MgO	Fe_2O_3	Na_2O	K_2O	SO_2	Loss on ignition
Percentage composition	36.00	32.60	14.80	10.30	0.5	0.4	0.6	0.20	1.1

2.3. Fly ash (FA).

The byproduct of coal-fired furnaces at power generation facilities can be regarded as fly ash and it is the non- combustible particulate removed from the fuel gases. Fly ash used in concrete should conform to the standard specification [9]. The amount of fly ash in concrete can vary from 5% to 65% by mass of the cementitious materials, depending upon the origin and composition regarding FA as well as performance requirements regarding concrete. Characteristics of FA can vary significantly depending on the source of the coal being burnt. The American Coal Ash Association estimated that utilization of FA as cement replacement in concrete has great potential in eliminating 10 to 14 million tons of carbon dioxide emissions annually [14]. FA remains generally abundant all over the United States of America. On the other hand, it is small in quantity in certain places. About 71 million tons of FA was produced in 2004, whereby almost 40% of them were reused while almost 60% was landfilled. Most fly ash suitable for use in concrete is used and not landfilled [15]. FA consists majorly of silicate glass which contains alumina, silica, calcium and iron. Secondary elements include sulfur, magnesium, potassium, carbon and sodium. Crystalline occur in minute quantities. The relative density of FA generally varies from 1.9 to 2.8 while it is grey in color. Class C fly ash and Class F fly ash satisfying the requirement of *ASTM C6*18 [9] have remained in use for all-purpose in concrete. Class F fly ash is rich in silicate, iron and aluminate while it is deficient in calcium. It has as low as 15% in carbon while few are higher than 15% in carbon. Its strength at early days of curing is low and can affect the construction schedule [16]. Class C fly ash has as high as 10% -20% of calcium oxide while it has as low as 2% content of carbon. Class C fly ash generates more strength at early days of curing than class F fly ash. Most of class C fly ashes harden within 45 minutes when mixed with water. For this reason, many readily mixed concrete suppliers use more class C than class F fly ash. Fly ash varies in composition and carbon content. Some fly ashes meet both class F and class C classifications [17]. The chemical composition of FA presented in the study of *Kosmatka, Kerkhoff and William* [18], is shown in Table 3.

Table 3. Chemical composition of FA [18].

Chemical constituents	CaO	SiO_2	Al_2O_3	MgO	Fe_2O_3	SO_2	Loss on ignition
Class F (%)	3.0	56.8	28.2	5.2	5.3	0.7	3.9
Class C (%)	27.7	35.0	18.5	5.5	5.4	2.4	0.2

2.4. Silica fume (SF).

It can be regarded as a highly active pozzolan and is an industrial by-product of high-purity quartz when coal and wood are burnt in an electric furnace in the process of producing ferro silicon alloys. Silica is removed from exhaust gases as it cools and condenses into ultra-fine droplets of silica glass. It possesses SiO_2 of about 92% to 94%. It is spherical in shape and is extremely small, having an average diameter of about one-tenth of a micron [19]. It is available as a densified powder or in a water-slurry form. It is generally used at 5% to 12% by mass of cementitious materials for concrete structures that need high strength or significantly reduced permeability to water. Due to its extreme fineness, special procedures are warranted when handling, placing and curing silica fume concrete [20]. The chemical analysis of silica fume, according to *Titherington and Hooton* [21], is shown in table 4.

Table 4. Chemical oxide composition of silica fume [21].

Chemical constituents	CaO	SiO_2	Al_2O_3	MgO	Fe_2O_3	Na_2O	K_2O	SO_2	Loss on ignition
Percentage composition	0.31	96.7	0.23	0.04	0.07	0.15	0.56	0.17	2.27

2.5. Metakaolin (MK).

MK is also a pozzolan like previous SCMs described earlier. It is obtained by firing kaolinite to 650^{o}C - 900°C. At this range of temperature, calcium silicate hydrate in the paste of cement is obtained due to the reaction of calcium hydroxide with metakaolin. Truly, the reaction is important in the region within the aggregate and the paste being that it improves the strength of the resulting concrete [22]. According to *Wild and Khatib* [23], at this zone, higher content of calcium hydroxide leads to reduced strength and higher porosity. Reacting with calcium hydroxide obtained from hydration of cement, metakaolin enwraps the morphology of the paste. As to silica fume, research shows metakaolin to possess more reactiveness because of the greater degree of pozzolanicity as well as calcium hydroxide usage [24]. Likewise, the addition of metakaolin results in quicker reactivity with calcium hydroxide [22]. It can be utilized as a concrete additive in unique uses when lower permeability as well as higher strength is required [18]. Table 5 reveals chemical constituents of metakaolin.

Table 5. Chemical composition of metakaolin [25].

Chemical constituents	CaO	SiO_2	Al_2O_3	MgO	Fe_2O_3	Na_2O	K_2O	SO_2	Loss on ignition
Percentage composition	2.0	51.52	40.18	0.12	1.23	0.08	0.53	0.00	2.01

2.6. *Rice husk ash (RHA).*

The waste obtained as a result of buildup of outermost layer of rice in the course of milling is known as rice husk (RH), which in most cases are disposed of or burnt. It constitutes 20% at several heaps of rice made yearly in the universe [26]. Each country has the low-value by-product within the framework of her economic structure. Use or disposal has frequently proved difficult because of the tough woody, abrasive nature of the husk, their minimal nutritious values, as well as great ability to withstand weathering, but it is recently been used by poultry farmers as a supplement to the animal feed. They can be found at rice mill and are stored in heaps into bags for disposal. Firing rice husk at higher temperature, it is converted into ash, hence the name Rice Husk Ash (RHA). RHA can partially replace cement. Properties of RHA rely largely upon if RH is totally or partially burnt [26]. The carbon free ash is potentially utilized to partially replace cement. Use of rice husk ash include; stabilization, an abrasive component of tooth paste, dust bath for conditioning coats of fur-bearing animal, as an abrasive in mechanics, suspension agents for porcelain enamels, as thickeners, flatting or anti-skid agent for painting and other surface coatings, dehydrating agent and coating for welding rods [27]. Most rice husks are straw or gold in color, though some may be white russet, red, brown, shade of purple or sooty black, depending on species. RH is 5 mm to 10 mm long as well as 2.5 mm to 5 mm wide. Investigation conducted on pozzolanic properties of RHA by *Korisa* [28] showed RHA to be a pozzolan based on its chemical composition. Typical chemical composition of RHA obtained after burning and grinding is shown in table 6.

Table 6. Chemical composition of RHA [28].

Chemical constituents	CaO	SiO_2	Al_2O_3	MgO	Fe_2O_3	Na_2O	K_2O	SO_2	Loss on ignition
Percentage composition	0.49	96.70	1.01	0.19	0.05	0.26	0.91	0.03	4.81

2.7. *Coconut husk ash (CHA).*

Coconut husk (CH) is an agricultural waste and is largely abundant all over the tropics of the universe. Some tropical people called coconut as “THE TREE OF LIFE” because the meat and milk of the nut give them food and drink. The trunk of the tree produces beautiful and durable wood for their homes. Floor mats and clothing can also be made from the coconut husk. It has become a very useful product in the tropical part of the universe being a recent energy source [29]. Before now, CH has always being thrown away as wastage. This added tremendously towards methane and carbon dioxide discharge to the atmosphere. Nonetheless, large increment in the price of natural gas, electricity and fuel has made CH to be a source of fuel. *Bamgboye and Jekayinfa* [29] regretted that 90% of coconut (empty fruit bunches, husks, trunks, shells) was discarded of. This way, the coconut processing industrial waste according to them, contributed significantly to CO_2 and methane emissions. On the basis of economic and ecological purposes, how to use, store and dispose coconut should be aimed at. The ash obtained from burning of coconut husk at a high temperature is referred to as Coconut Husk Ash (CHA). Research carried out on physical properties of CHA by *Raghu and Chaitanya* [30] revealed that the color of the ash obtained by burning coconut husk in the Ferro cement incinerator was found to possess a darkish grey color. The ash produced was only 2.8% by weight of the unburnt coconut husk, meaning that burning 25 kg of coconut husk which was the capacity of the small Ferro cement incinerator produced only 0.7 kg of ash in one hour. The temperature of the burning was at 750^0c. The specific gravity was 2.23. Research carried out on the chemical properties of CHA by *Raghu and Chaitanya* [30] is shown in table 7.

Table 7. Chemical composition of coconut husk ash (CHA) [30].

Chemical constituents	CaO	SiO_2	Al_2O_3	MgO	Fe_2O_3	Na_2O	K_2O	S	Loss on ignition
Percentage composition	8.40	31.23	25.68	4.08	22.65	5.38	1.74	0.71	7.8

2.8. *Palm oil fuel ash (POFA).*

Another agricultural waste utilized in strengthening concrete is POFA. It is obtained by reducing to ash the shell as well as husk of oil palm. *Sata, Jaturapitakkul and Kiattikomol* [31] revealed that POFA is a pozzolan as well as an SCM. POFA is gray or darkish gray, depending on the content of carbon that is not burnt. Nevertheless, it is noteworthy that the milling arrangement determines the nature of the ash. Take for instance, a properly-maintained milling arrangement will produce a whitish-gray-ash. The by-product is normally obtained at the lowest part of the tower. Ages ago, the nation that has been producing oil palm the most is Malaysia [32]. From then on, palm oil fuel ash is considered universally a large contributor as far as concrete materials is concerned [33]. Table 8 shows the chemical analysis of palm oil fuel ash.

Table 8. Chemical composition palm oil fuel ash (POFA) [33].

Chemical constituents	CaO	SiO_2	Al_2O_3	MgO	Fe_2O_3	Na_2O	K_2O	SO_3	Loss on ignition
Percentage composition	6.40	65.30	2.50	3.00	1.90	0.30	5.70	0.40	10.00

2.9. *Sugar cane bagasse ash (SCBA)*

SCBA is known to be the end-product obtained as a result of burning sugar cane bagasse at a high temperature. Nations like Columbia, India, Malaysia, Thailand, Indonesia, Pakistan, Philippines and Brazil generate large amount of SCBA yearly [34], which are being thrown off. Research shows that SCBA is a potential pozzolana and is therefore a good SCM. *Cordeiro, Toledo and Fairbain* [35] reported that percentage weight of sugar cane bagasse ash tremendously reduced the increase in the heat of concrete. Likewise, SCBA obtained by burning to 600^0C generates reduced amount of carbon, high silica content as well as increased area [35]. Also, addition of sugar cane bagasse ash to concrete will improve the worth of waste as well as decrease CO_2 emissions globally [36]. Table 9 reveals the chemical analysis of sugar cane bagasse ash.

Table 9. Chemical composition of sugar cane bagasse ash (SCBA) [37].

Chemical constituents	CaO	SiO_2	Al_2O_3	MgO	Fe_2O_3	Na_2O	K_2O	SO_3	Loss on ignition
Percentage composition	4.0	60.00	4.70	1.10	3.10	0.30	1.40	0.10	15.30

2.10. Wood waste ash (WWA)
Recently, more than half of the waste generated from wood is thrown off in different ways [38]. Burning stage of wood generates an ash known as wood waste ash. Generally, wood waste ash uses are restricted in some ways. Nevertheless, the last stage of wood waste ash must be well monitored as a result of finer size of the ash which can easily pollute the environment and lead to havoc in respiration for those living close to the polluted area. Table 10 shows the chemical composition of wood waste ash.

Table 10. Chemical composition of wood waste ash (WWA) [39].

Chemical constituents	CaO	SiO_2	Al_2O_3	MgO	Fe_2O_3	Na_2O	K_2O	SO_3	Loss on ignition
Percentage composition	10.17	15.92	17.68	9.32	2.31	6.50	10.38	0.36	29.96

2.11. Bamboo leaf ash (BLA)
Recently, investigation focuses on using waste from agriculture as pozzolanic material. Inclusion of ashes of wastes obtained out of agriculture possesses improved characteristics in concrete as well as being favorable environmentally. Among the agricultural wastes is bamboo leaf. Its tree has been among the leading natural reserves, it grows faster as well as being utilized in place of fiber. Limited research is done regarding BLA being utilized as an SCM in concrete. Chemical analysis of bamboo leaf ash firstly carried out by *Cocina, Morales, Santos, Savastano and Frias* [40] is described in table 11.

Table 11. Chemical oxide of bamboo leaf ash (BLA) [40].

Chemical constituents	CaO	SiO_2	Al_2O_3	MgO	Fe_2O_3	Na_2O	K_2O	SO_3	Loss on ignition
Percentage composition	5.06	80.40	1.22	0.99	0.71	0.08	1.33	1.07	8.04

2.12. Corn cob ash (CCA)
The ash generated from burning corn cob is regarded as corn cob ash (CCA). As at 2000, several tons of maize was produced in the universe [41]. South Africa leads in the cultivation of corn while Nigeria takes the second as far as Africa is concerned [41]. Earlier research [42] showed CCA to possess silicon oxide about 65% as well as aluminum oxide plus silicon oxide ranging from 70% to 75%, meaning that CCA is an SCM. Chemical analysis of corn cob ash is shown in table 12.

Table 12. Chemical Analysis of corn cob ash (CCA) [31].

Chemical constituents	CaO	SiO_2	Al_2O_3	MgO	Fe_2O_3	Na_2O	K_2O	SO_3	Loss on ignition
Percentage composition	10.30	65.4	6.0	1.80	3.80	0.40	4.20	1.00	0.90

3. Results and discussion

3.1. *Influence of cupola furnace slag powder (CFSP)*

3.1.1. Workability. Arum and Mark [43] revealed that as the content of CFSP increased in concrete the workability decreased. For CFSP to be utilized more effectively in concrete, additional water need to be introduced for better workability.

Investigation carried out by *Joseph and Alabi* [44] revealed that incorporation of cupola furnace slag powder to concrete at 0% to 10% percentage replacement levels gave a satisfactory workability.

3.1.2. Compressive strength. Arum and Mark [43] revealed that concrete strength containing CFSP improves as the days of curing advance. Likewise, as CFSP content increased, compressive strength improved. Taking 28 days crushing strength having 0% substitution of ordinary Portland cement with CFSP as the control (22.6 N/mm^2), 5% CFSP substitution yielded a crushing value of 26.5 N/mm^2. This gave a 3.9 N/mm^2 (17.3%) rise above the control. Also, 10% CFSP substitution yielded a crushing value of 27.2 N/mm^2. This gave a 4.6 N/mm^2 (20.4%) rise above the control. Lastly, 15% CFSP substitution yielded a crushing value of 29.8 N/mm^2. This gave a 7.2 N/mm^2 (31.9%) rise above the control.

Mandeep [45] showed in his report, when he partially replaced CFSP as coarse aggregate in concrete that the compressive strength was greatly improved as high as 30% replacement by CFSP. This increment was much for more w/c ratio, which stipulates that it can be used for concrete with low strength demand. *Zegichi* [46] revealed that inclusion of cupola furnace slag to partly substitute cement increased its compressive strength in the resulting mix. This increment in strength was recorded at optimum value of 30% replacement above the control mix at every curing age. Also, early age curing strength was recorded at 50% partial replacement. There was a reduction in compressive strength at 100% complete replacement with CFS early curing age.

Behera, Monika, Sudeep, Sakar and Singh [47] in their study in 2011 varied concrete compressive strength with variation in level of percentage replacement of CFSP and discovered that the compressive strength improved by 3.26% for grade M20 concrete, 10.87% for grade M40 concrete, 17.39% for grade M60 concrete, 26.09% for grade M80 concrete and by 34.78% for grade M100 concrete. He also found that complete substitution of coarse aggregate with CFSP gave a 34.78% rise in the strength.

Nadeem and Pofale [48] discovered an increment in compressive strength of concrete from 4% up to 6%, when granite and sand were partly substituted by CFSP between 30% and 50%. There was a rise in strength from 5% up to 7% when granite was totally replaced at 100% but there was a fall in strength from 10% down to 7% when sand was totally replaced at 100% by CFSP, compared to the reference at concrete grade M20. Concrete grade M30 and concrete grade M40. This was due to the fact that there was more content of coarse aggregate which did not allow for proper bonding (segregation). This can be improved by adding more fine aggregate.

3.2. Influence of blast furnace slag powder (BFSP)

3.2.1. Workability. Adding BFSP increases workability in comparison to OPC concrete. *Elahi, Basheer, Namukattan and Khan* [49] examined that, with additional quantity of slag at constant water/binder proportion, the slump value increased. Better workability obtained when BFSP was partly replaced witu OPC was due to the improved cementitious property as well as area of BFSP. As a result, the concrete took in small amount of water at the time it was mixed. According to *Oner and Akyuz* [50], increase in BFSP decreased w/b of the concrete, which indicates good effect of BFSP in terms of workability.

3.2.2. Compressive strength. Bilm, Atis, Tanyildizi and Karahan [51] discovered that increment in BFSP content lowered the compressive strength of concrete at early age as the long term age value was more than that of control mix. *Boukandakdji, Kadri and Kenai* [52] observed that, as replacement level was increased, there was decrease in short term strength although long term strength was higher than the control. This was caused by slow absorption of water. It was noted that at later age, slag absorbs more water resulting in C–S–H paste and possesses higher strength compared to the concrete without BFSP [53].

3.3. Influence of fly ash (FA)

3.3.1. Workability. Including FA increases concrete workability of concrete. *Khatib* [54] developed SCC by replacement of OPC from 0% to 80% fly ash with fixed 0.36 water/binder proportion. He discovered all mixes obtained slump flow of diameter greater than 700 mm except control mix, which means that inclusion of FA improved the workability of the resulting concrete with admixture dosage of 0.7% binder mass. *Siddique* [55] investigated that adding more fly ash with 40%, 45% and 50% partial replacement of OPC, shows increase in the slump varying from 85, 90 and 100 mm respectively.

3.3.2. Compressive strength. Using fly ash decreases early day's concrete strength at because this pozzolan reacts in slower manner in concrete but attains strength equivalent or more than OPC concrete at later age. *Hassan, Cabrera and Maliehe* [56] showed that incorporating fly ash of 30%, 0.29 w/b proportion, decreased the short term strength compared to reference concrete and obtained the same crushing value at 28 days but improved the strength after 1 year. The strength decrease is because FA reacts in slower manner, which require longer period of curing for gain of strength compared to OPC concrete. *Wang* [57] investigated that incorporation of fly ash from 0% to 30%, decrease 28 days strength below the control. He also found out that 56 days as well as 90 days concrete strength containing FA improved due to the way the pozzolan reacted.

3.4. Influence of silica fume

*3.4.1. Workability***.** According to *Bagheri, Zanganeh and Moalemi* [58], partly substituting OPC with silica fume decreased the workability and increase water demand for required slump due to being finer material. *Khatri and Sirirvivatnanon* [59] reported that mixes incorporating high silica fume quantity possesses greater cohesion than the ones without silica fume.

3.4.2. Compressive strength. Yan, Sun and Chen [60] reported that partly substituting cement with SF improve interfacial zone due to the effects of pozzolan, crystals as well as fillers in SF. *Jianyong and Pei* [61] produced concrete by blending of silica fume with cement. There was improvement in the compressive strength in later age but early age strength was less as compared to control mix.

3.5. Influence of metakaolin

*3.5.1. Workability***.** Use of MK in concrete mix decreases workability, which requires increment in water content. Sometimes, water reducers can be utilized. *Paiva, Velosa, Cachim and Ferreira* [62] found that water reducers make concrete more workable. Sometimes, it makes the workability remain the same but reduces the amount of water needed. *Young, Mindess, Gray and Bentur* [63] found that addition of water reducers produce water that greases the concrete mix

3.5.2. Compressive strength. Incorporating metakaolin as part substitution of ordinary Portland cement increases early concrete strength, as a result of faster rate of reaction of the pozzolan. *Courard, Danimont, Schonterden, Feraucher, Willem and Degeimbre* [64] prepared concrete with part substitution of OPC between 5% and 20%, there was reduction in crushing value during the first days below the control but achieved more strength in compression after 14 and 7 days respectively. *Arum, Kumapayi and Aralepo* [65] found that concrete strength containing metakaolin that increased is because of the effects of the filler in metakaolin, accelerating how water is absorbed in cement as well as how metakaolin responds when there is calcium hydroxide.

3.6. Influence of rice husk ash (RHA)

3.6.1. Workability. Research carried out by *Arum, Kumapayi and Aralepo* [65] showed that workability increases when RHA percentage replacement levels is increased. This indicates that concrete with OPC/RHA is more workable than the control mix.

3.6.2. Compressive strength. Arum, Kumapayi and Aralepo [65] revealed there was increase in strength when RHA was partly substituted with cement till 10%. At 15% upward, there was continuous reduction.

3.7. Influence of coconut husk ASH (CHA)

*3.7.1. Workability***.** Research carried out by *Arum, Kumapayi and Aralepo* [65] showed that workability increases with increase in CHA percentage replacement, meaning partly substituting ordinary Portland cement by CHA makes the concrete more workable than the control mix.

3.7.2. Compressive strength. Arum, Kumapayi and Aralepo [65] revealed there was increment in concrete strength as more coconut husk ash was added.

3.8. Influence of palm oil fuel ash (POFA)

3.8.1. Workability. Aldahdooh, Bunnori and Megatjohari [66] revealed that partly substituting POFA with OPC decreases the amount of water required in concrete, thereby making such concrete more workable.

3.8.2. Compressive strength. Jaturapitakkul, Tangpagasit, Songmue and Kiattikomol [67] researched on concrete strength as a result of partly substituting palm oil fuel ash with OPC. They observed that the short term strength was small, but the long term age was larger. They likewise discovered that as more palm oil fuel ash was added, there was increment in concrete strength. Also, it was used in making high performance concrete and the maximum concrete strength was 86 MPa at 20% substitution and at curing age of 28 days [68]. The high value of strength was as a result of the way the pozzolan reacts.

3.9. Influence of sugar cane bagasse ASH (SCBA)

3.9.1. Workability. Rukzom and Chindaprasirt [69] reported that sugar cane bagasse ash has more fineness than ordinary Portland cement, thus, there was more intake of water. Including sugar cane bagasse ash to concrete reduces workability.

3.9.2. Compressive strength. Ganessan Rajagopal and Thangavel [70] revealed that including SCBA to partly substitute ordinary Portland cement increases early strength of concrete. According to them, this was due to the way sugar cane bagasse ash reacted with silicate and also because it was finer.

3.10. Influence of wood waste ash (WWA)

3.10.1. Workability. Incorporation of WWA into concrete increases intake of water, thereby, decreasing the workability of OPC/WWA concrete. This is as a result of increased carbon content in WWA [71].

3.10.2. Compressive strength. Ramos, Matos and Coutinho [71] researched the crushing strength of OPC when partly substituted with WWA from 0 - 40% as well as water/binder proportion of 0.4 for 7 days till 180 days curing days and discovered the crushing value to be maximum at 10% substitution. 42 MPa, 52 MPa, and 61 MPa were the crushing value at 7 days, 28 days as well as 90 days accordingly. This means that inclusion of WWA increases the concrete compressive strength.

3.11. Influence of bamboo leaf ASH (BLA)

*3.11.1. Workability***.** Based on the research carried out by *Cocina, Morales, Santos, Savastano and Frias* [40], partial replacement of cement with BLA reduced the workability of the resulting concrete. This was similar at all percentage levels of substitution with BLA. It was so, because the resulting concrete had thick consistency as a result of finer particles of bamboo leaf ash and its absorptive nature.

3.11.2. Compressive strength. Cocina, Morales, Santos, Savastano and Frias [40] revealed that there was reduction in the early age strength when BLA was partially replaced, but at latter age, the strength increased more than the control concrete. This is due to too watery concrete mix for maintaining adequate workability.

3.12. Influence of corn cob ASH (CCA)

3.12.1. Workability. According to *Adesanya* [42], addition of corn cob ash to OPC concrete makes it more workable.

3.12.2. Compressive strength. Adesanya [42] showed that when corn cob ash was partly substituted with OPC, the crushing strength improved up to ten percent and started reducing in strength beyond ten percent.

4. Conclusions and recommendations

i. Based on the discussions aforementioned, conclusion can be made that incorporation of these SCMs significantly increases the workability and compressive strength of concrete.
ii. This paper has provided database sources, chemical composition of the selected locally sourced SCMs as well as how they affect compressive strength as well as workability of concrete, which will serve as user’s guide, of interest to engineers.

iii. Those manufacturing cement need to establish mixing plants for producing Portland pozzolan cement, since there are economic, technical and environmental advantages of using these materials as SCMs for providing cheaper housing.
iv. Arrangements should be made by those interested in this paper for processing of these SCMs into commercial cements rather than being disposed of as wastes.
v. Concrete manufacturers should exploit the unlimited opportunity to a more cost effective concrete production through utilizing Cupola Furnace Slag Powder (CFSP), Blast Furnace Slag Powder (BFSP), Silica Fume (SF), Fly Ash (FA), Rice Husk Ash (RHA), Metakaolin (MK), Coconut Husk Ash (CHA), Palm Oil Fuel Ash (POFA), Wood Waste Ash (WWA), Sugar Cane Bagasse Ash (SCBA), Corn Cob Ash (CCA), Bamboo Leaf Ash (BLA) resources available around as SCMs.
vi. The improvement on the current information as well as research on alternative relevant industrial by-product as well as by-product from agriculture being utilized as SCMs will contribute immensely towards sustaining concrete and producing greener ecology.
vii. SCMs should be used in proper proportion to produce a more workable, durable and stronger concrete, based on requirements.
viii. Using SCMs will eradicate challenges arising technically, environmentally as well as economically when producing OPC.

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