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Comparative Evaluation of Potential Impacts of Agricultural and Industrial Waste Pozzolanic Binders on Strengths of Concrete

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ABSTRACT

Concrete is one of the most widely used construction material in the world which uses aggregates and cement as a binder. Use of cement concrete and mining/ transportation of raw materials makes the construction industry the biggest emitter of CO_2 by contributing up to 7-10% of global emissions. The waste materials from different industries and agriculture contribute to 90% of waste disposal/ recycling effort in the world. This research has focused to use a selection of waste materials as supplementary cementitious materials (SCM) to minimize the emission of CO_2 and recycling/ absorption of waste from other industries to construction industry to make it more sustainable. The contemporary research has established use of pulverized fly ash (PFA), silica fume (SF), metakaolin (MK) and granulated ground blast furnace slag (GGBS) as suitable SCMs. This study has focused on using two established industrial waste SF and MK and two agricultural wastes, rice husk ash (RHA) and palm ash (PA), to determine and compare their potential use as pozzolanic SCMs and to expand the family of alternative pozzolanic binders in addition to PFA and GGBS. The w/c (w/b) ratio was 0.4 with an intended design mix strength classification of C50/60. The chemical composition of all the materials was determined through x-ray spectrometry/ diffraction test to ascertain the chemistry. All four materials satisfied the ASTM constituent criteria for pozzolans. In comparison to the control mix (100% cement content), all these materials improved the compressive strength from 2.5% to 30% and enhanced tensile strength from up to 17%, indeed all the SCM mixes had a higher compressive strength than the control. RHA exhibited the best performance in agricultural waste with 10% optimum quantity to give maximum compressive strength of 83 MPa and PA exhibited the optimum performance with 2.5% content and gave maximum compressive strength of 78 MPa. The addition of MK progressively increased the compressive strength with 20% content mix giving a strength of 84 MPa. The SF performed the best at optimum quantity of 2.5% and exhibited the highest compressive strength of 90 MPa. The results suggest that these SCM based concrete are recommended for formulation of high-strength concrete applications, i.e., 60+ MPa. Furthermore, all the SCMs had at least one mix which satisfied the C60/75 classification without reducing the w/b ratio below 0.4; this has significant positive ramifications for the development of sustainable high-performance concrete. The absorption of waste materials from industrial and agricultural fields can substantially reduce waste disposal and more pertinently facilitate in reducing the CO2 emission associated with the construction industry.

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Introduction

The ordinary Portland cement (OPC) concrete has revolutionized the construction industry due to its intrinsic mechanical properties, quick setting and ease of use and has become the most widely used construction material [1-10]. The shift of use from naturally occurring lime as construction material in ancient time to present use of cement concrete has successfully enabled the construction of mega infrastructure but has also posed a serious sustainability threat to the environment because of its large-scale contribution to greenhouse gas's emission. The cement industry is considered to be one of the biggest CO_2 emitters in the world. It is estimated that around 4 billion tons of CO_2 is contributed annually that makes 7-10% of global CO_2 emissions [11]. The mining of raw materials, transportation, cement production, delivery, concrete preparation and fuel usage by the industry all are considered hazardous to the environment and raising serious questions on sustainability and environment protection [2]. The researchers are in quest of formulating SCMs to produce improved cement composites with partial/ full cement replacement using sustainable pozzolanic industrial and agricultural waste materials. The faster growth, urbanization, increased population and technological advancement in the world are resulting into invention of new materials/ resources and production of more waste especially in developing African and Asian countries. World's waste production is estimated to be 2.2 billion tons per year by 2025 including 50% agricultural waste, 40% industrial waste and 10% domestic or miscellaneous waste [3]. If this enormous waste is recycled into other products in different industries instead of dumping/ disposal then sustainability issues can be addressed successfully. Previous research has focused on using industrial waste like silica fume (SF), pulverized fly ash (PFA), metakaolin (MK) & slag (GGBS), as pozzolanic / cementitious binder for cement replacement. Recent work is endeavouring to establish agricultural based waste such as rice husk ash (RHA), palm ash (PA) and corn cob ash (CCA) as alternative pozzolans. Researchers have explored shredded glass, plastic, rubber and crushed tyres etc. as replacement of fine/ coarse aggregate [4-10]. The contemporary research has established that the materials having around 70% pozzolanic ingredients like silicate/ aluminates/ oxides of certain metals exhibit an improved tendency to react with excess $Ca(OH)_2$ found in concrete during hydration process to form increased quantity of C-S-H gel which is responsible for binding/ strength of concrete. In initial hydration phase of cement concrete, tricalcium silicate and dicalcium silicate react with water to produce calcium silicate hydrate gel and calcium hydroxide as shown in below chemical reaction equations [11].

Tricalcium silicate reaction:
$2CaO_3SiO_5 + 7H_2O \longrightarrow 3CaO.2SiO_2.4H_2O + Ca(OH)_2 + Heat$

Dicalcium silicate reaction:
$2CaO_2SiO_4 + 5H_2O \longrightarrow 3CaO.2SiO_2.4H_2O + Ca(OH)_2 + Heat$

In the follow up reaction, the pozzolanic materials which contain sufficient silicon dioxide but lacks in calcium react with excess calcium hydroxide produced during hydration phase of cement and further produce calcium silicate hydrate gel which improves the strength of pozzolanic composite. The reaction has been illustrated by following chemical equation:

Pozzolanic reaction to form additional C-S-H gel during hydration of cement:
$2SiO_2 + 3Ca\,(OH)_2 \longrightarrow 3CaO.2SiO_2.4H_2O + Ca\,(OH)2 + Heat$

The above chemical reactions explain the role of pozzolanic materials as SCMs and increase of strength to certain percentage depending upon availability of silicon dioxide in pozzolans and excess calcium hydroxide provided by hydration of cement. Therefore, use of pozzolans like SF, MK, RHA and PA etc. are considered suitable for partial cement replacement and enhancer of strength [11-13].

Methodology

In this project 100 mm cubes have been casted for the mixes using CEM1 52.5 along with varying percentages of SCMs with 1:2:3 ratio concrete to be tested on 7, 14 and 28 days for assessment of compressive strength in accordance with BS EN 12390-3:2019 [14]. SF, RHA and PA have been mixed at 2.5%, 5% and 10% whereas MK has been mixed at 5%, 10% and 20% of cement weight to make different ratios as shown in table 1. All materials were tested for elemental quantitative analysis from a laboratory using x-ray spectrometry and diffraction test as shown on table 2. Cubes were casted, water cured and tested under standard compressive testing machine (fig 1) at 7, 14 and 28 days. The compressive strength has been calculated using the equation "P/A" where P is load in 'N' and A is area in mm2. 150 x 300 mm cylinder has been casted for each mix for all ratios to be tested at 28 days in accordance with BS EN 12390-6:2019/ BS1881-117 [15]. Cylinders were casted, water cured and tested for split tensile strength in standard tensile testing machine and a compressive load of 400N/sec was applied on longitudinal axis i.e., length of cylinder till it fractured (fig 2). The split tensile strength was calculated using expression "2P/πDL" (where P is max load in 'N', D is dia and L is length of cylinder in mm).

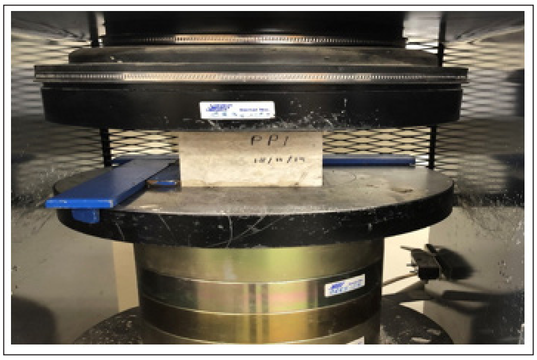


Figure 1: Cubes testing for compressive Strength

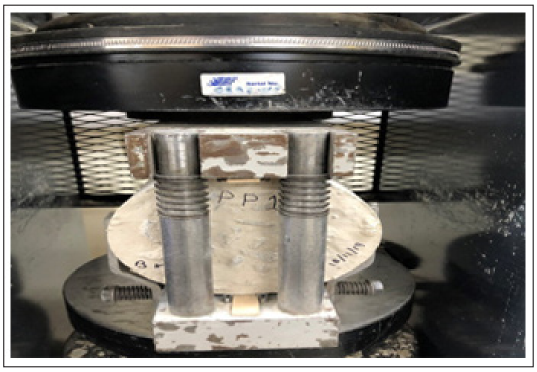


Figure 2: Cylinder Testing for Tensile Strength

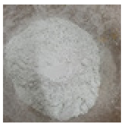
Table 1: Preparation Composition of Mixes

Pozzolanic Binder	Mix Ratio	Pozzolan in Mixes (%)	Water Cement Ratio
SF	1:2:3	2.5, 5, 10	0.4
MK	1:2:3	5,10,20	0.4
RHA	1:2:3	2.5, 5, 10	0.4
PA	1:2:3	2.5, 5, 10	0.4

Materials

In this study the suitability of two established industrial waste pozzolanic materials SF and MK and two potential agro-waste materials of RHA and PA were investigated. The objective is to carry out a comparative analysis to determine their performance with use of different quantities versus their impacts on engineering properties of concrete composites. X-ray diffraction and spectrometry was used to determine elemental composition and comparative analysis of these proposed SCMs based on presence of SiO_2 and other metal oxides as shown in table 2 and fig 3. Table 2 shows that SF has got maximum quantity of SiO_2 (99%) followed by RHA (97%), PA (62%) and least by MK (52%). As per ASTM C 125-19 and C 618, all four materials have a combined value of silicate, alumina, ferric oxide and oxides of certain metals greater than 70%, therefore, can be considered a good pozzolanic material suitable for cement replacement [11-13]. These materials when mixed with cement as partial replacement are suggested to be enhancing the properties of concrete and can recycle a large quantity of industrial/ agricultural waste in an economical and environmentally friendly manner. SF & MK are already established pozzolans.

Table 2: Elemental Composition of Cement Replacement Materials Using X-Ray Diffraction Test

Ingredients (%)	CEM1 52.5	SF	MK	RHA	PA
					
Fe_2O_3	0.32	0.43	0.45	1.66	3.12
SiO_2	25.2	99.1	52.1	97.6	62. 5
TiO_2	0.18	<0.1	0.88	<0.1	0.12
CaO	67.1	<0.1	0.31	<0.1	19
K_20	0.30	<0.1	0.17	0.21	2.0
Al_2O_3	3.18	<0.1	45.1	<0.1	4.5
Mg0	1.33	<0.1	0.20	<0.1	1.18
Na_20	<0.1	<0.1	0.25	<0.1	<0.1
P_2O_5	<0.11	<0.1	<0.1	<0.1	<0.1
Cl	<0.23	<0.1	<0.1	<0.1	0.1
SO_3	<1.57	<0.1	<0.1	<0.1	0.53
Total % of Pozzolan (SiO_2 + Fe_2O_3 + Al_2O_3)	28.7	99.6	97.6	99.4	70.1

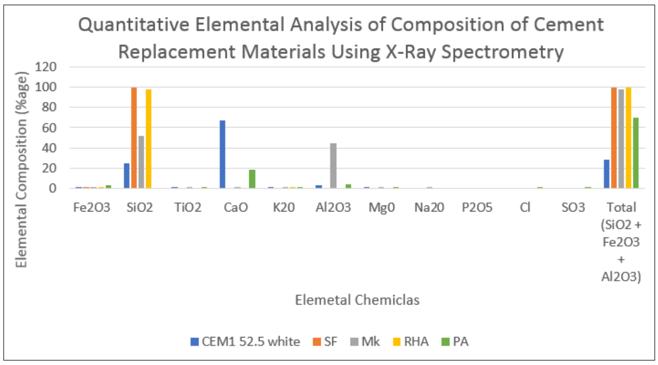


Figure 3: Quantitative Elemental Analysis of Composition of SCMs

Silica Fume (SF)

SF is an amorphous crystalline industrial waste material produced during reaction of quartz with coal in arc furnace for manufacturing of silicon or ferrosilicon alloys [16]. The elemental composition of SF was found to contain 99.1% SiO_2 and 0.9% of oxides of other metals as shown in table 2 and fig 3. The bulk quantity of silica available in SF make it an excellent partial cement replacement material at certain percentages of cement replacement. The silica in SF reacts with excess $Ca(OH)_2$ to increase C-S-H gel in concrete as explained in section 1 [11]. However, excess quantity of SF is found to be reducing the concrete strength due to excessive supply of silica from SF and reduced reaction/ consumption of silicate from cement and depletion of $Ca(OH)_2$ which impacts the utilization of cement and formulation of C-S-H gel to the fullest extent. In other words, after complete depletion of Ca $(OH)_2$, the residual pozzolanic material assumes the role of filler material and then starts adversely impacting on strength of composites [11]. SF is categorized as micro (greater than 0.5μm) and nano SF (0.1-0.2 μm) based on particle size. The surface area of 0.1-0.2-micron SF is 30,000 m^2/ kg and density is 150-700 kg/m3 [16]. There are varying results of strength improvement with use of different percentages of SF as cement replacement basing on cement/ concrete grade, w/c (w/b) ratio and other concrete formulation conditions. The maximum quantity of SF for partial cement replacement was suggested as 20% [17, 18]. 10% optimum quantity of SF is considered sufficient for better strength improvement [19]. SF quantity of 7.5% cement replacement was suggested optimum for high grade 60 MPa concrete [20]. Jain and Pawade [21] studied the properties of SF-concrete composite with 5, 10, 15, 20, 25%, it was suggested that 15% SF is the best performing mix ratio for better durability. A study with 0, 3, 6, 9,1 2 & 15% SF cement composites for M35 grade concrete suggested that compressive, tensile and flexural strength at 7, 14 and 28 days were improved for all mixes as compared to the control mix [22]. Another study found that increased percentages of SF decrease the workability and, optimum quantity of SF with high grade concrete is 10-15% [23]. Through extensive research the properties and performance of concrete containing SF is well established, findings show enhancement of mechanical properties of concrete composite, improvement of durability and absorption of industrial waste from silicon industry to construction industry. Furthermore, many concrete superstructures in the world now contain SF as an admixture [11].

Metakaolin (MK)

Metakaolin is obtained by calcination of naturally occurring Kaolinite clay mineral at 450 - 650°C. It is dehydroxylated aluminum silicate (Al_2O_3.$2SiO_2$.$2H_2O$) which is formed by weaker but more reactive structure after losing hydrate ion during calcination [24]. The elemental composition of MK is 52% Si_2O and 45% aluminum oxide as shown in table 2 and fig 3. It gives combined value of pozzolanic elements more than 90% so is considered a suitable pozzolanic material as per ASTM C 618/ C125-19 [12]. It is amorphous crystalline material and tends to react with the excess Ca $(OH)_2$ molecules during cement hydration reaction to form the strength enhancing C-S-H gel thus improving the mechanical properties of concrete composite as shown in section 1. However, if more than a specified quantity is used then it will start to weaken the cement concrete hydration process by rendering silicate molecules in cement as redundant as discussed in sections 1 and 3.1. Once all the $Ca(OH)_2$ molecules are consumed during pozzolanic reaction then excess quantity of MK is used as filler in the concrete and does not contribute to strength anymore [13]. Therefore, use of MK in cement concrete also improves the pore structure, reduces porosity and permeability [25]. Different researchers studied use of MK and found improvement in mechanical properties, shrinkage and durability under chloride environment with 10% use of MK as optimum quantity [26-28]. MK use with cement decreased workability of concrete and requires use of suitable quantity of plasticizer to maintain consistency and to control the water / cement ratio [29]. A composite of MK with fly ash and iron oxide in cement concrete gave considerable increase of up to 20% in compressive and tensile strength of the composite [30, 31].

Rice Husk Ash (RHA)

Rice is considered as the second biggest edible crop as main food ingredient in the world and its production is estimated to be around 700 million tons per year. The rice plant absorbs silicon from soil and stores it in the husk which forms a cover around rice seed to protect it. During milling of rice, the husk is removed from seed and then it is used as burning material in other industries [32-35]. The quantity of milled rice husk is estimated to be around 100 million tons per year. The husk is converted into ash after burning, with the resultant ash comprising of more than 97% silica and 3% oxides of other metals as shown in table 2 and fig 3. It gives the value of pozzolanic component (SiO_2) of greater than 97% thus can be considered potentially a pozzolanic material as per ASTM C 618/ C125-19 [12]. The milled RHA is of 45-50 μm size and is thus similar in size to PFA; with such a fine particle size RHA can reduce the permeability and thus improve the durability of concrete [11, 36, 38-39]. There is limited work done on RHA, however, Ahmed et al [11] found RHA concrete to have excellent early age strength, similar to silica fume.

Palm Ash (PA)

Palm trees are found all around the world notably in hot climate regions. The palm leaves and branches are considered as solid waste and create a lot of environmental nuisance when disposed of as land fill or garbage. The palm oil industry in different palm producing countries is considered a major wealth producer, particularly in the Far East where the palm oil mills produce millions of tons of waste annually. The palm leaves and branches are used for construction of mats, roofs, packing material and as burning fuel. The burning of palm waste at 700°C produces ash containing metal oxides which provide pozzolanic properties during cement hydration. It has a fine particle size similar to RHA and silica fume [40-43]. The palm ash contains 62% silicate and almost 25% oxides of certain metals as shown in Table 2. The total content of SiO_2, Al_2O_3 & Fe_2O_3 is greater than 70%, therefore, PA can be considered potentially a pozzolanic material as per ASTM C 618/ C125-19 [12]. The presence of SiO_2 in PA enables it to react with excess Ca(OH)2 during hydration of concrete and produces additional quantity of C-S-H gel to improve the strength of PA composites up to certain quantities as depicted by chemical reactions in section 1. As PA is a novel pozzolanic material, very little previous research has been conducted. However, Pone et al [43] identified PA as a potential addition to the pozzolanic family. The disposal and recycling of PA in concrete will reduce the adverse environmental impact as land fill and furthermore, facilitate in reducing the carbon footprint of concrete.

Results

The results generally showed an impressive improvement in mechanical properties with all SCMs used in this study as compared to the control (100% cement) as shown in the succeeding tables and graphs.

Compressive Strength

Rice Husk Ash (RHA)

The compressive strength of RHA composite was studied for 2.5%, 5% and 10% at 7, 14 and 28 days of curing age. An increase in compressive strength was observed with age and increased use of RHA from 2.5% to 10% from 69 MPa (control) to maximum of 83 MPa obtained with 2.5% mix, as shown in fig 4.

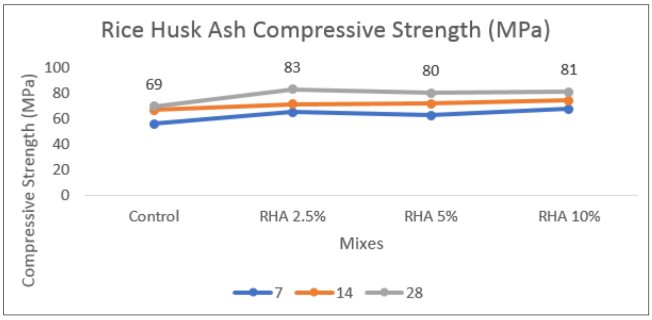


Figure 4: Compressive Strength of RHA Composite

Palm Ash (PA)

The compressive strength of PA concrete was investigated for 2.5%, 5% and 10% PA mix at 7, 14 and 28 days of curing age. An increase in compressive strength was observed with the age of hydration and increased use of PA from 0% to 2.5% from 69 MPa (control mix) to 78 MPa (optimum at 2.5% mix) but strength was decreased on use of 5% to 10% PA up to 71 MPa although it was still higher than control mix, as shown in fig 5.

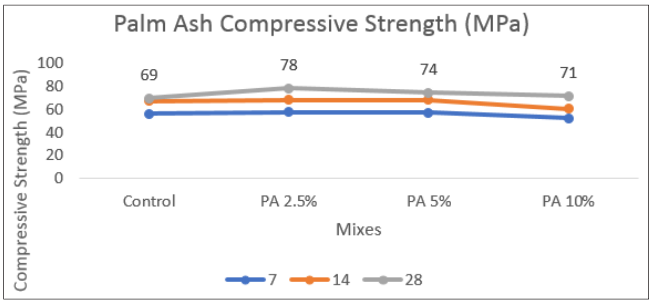


Figure 5: Compressive Strength of PA Composite

Metakaolin (MK)

The compressive strength of MK composite was determined by investigation of 5%, 10% and 20% MK mix at 7,14 and 28 days of hydration age. An increase in compressive strength was observed with age and increased use of MK from 5% to 20% from 69 MPa (control mix) to maximum of 84 MPa (optimum at 20% mix) on 28 days strength as shown in fig 6.

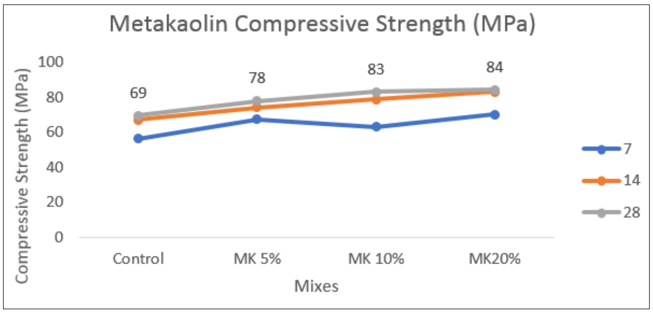


Figure 6: Compressive Strength of MK Composite

Silica Fume (SF)

The compressive strength of SF – cement concrete was determined using 2.5%, 5% and 10% SF mix at 7,14 and 28 days of hydration age. An increase in compressive strength was observed with the age of hydration and increased use of SF from 0% to 2.5% from 69 MPa to 90 MPa (optimum at 2.5%) but strength was decreased with increased use of SF from 5% to 10% from 78 MPa to 76 MPa though still higher than the control mix, as shown in fig 7.

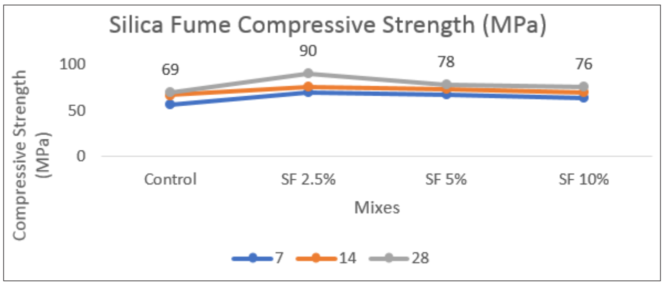


Figure 7: Compressive Strength of SF Composite

Split Tensile Strength

The split tensile strength of all the cylinders were investigated at 28 days of hydration. Results obtained showed improvement and slight variation of strengths at different percentages of use of SCMs as shown in the fig 8. However, a consistency in tensile strength was observed ranging from 3.1 to 4 MPa with all the mixes. 5% RHA, 10% PA, 20% MK and 2.5% SF gave the maximum tensile strength of between 3.8 – 4.0 MPa which is consistent with the general tensile strength of concrete.

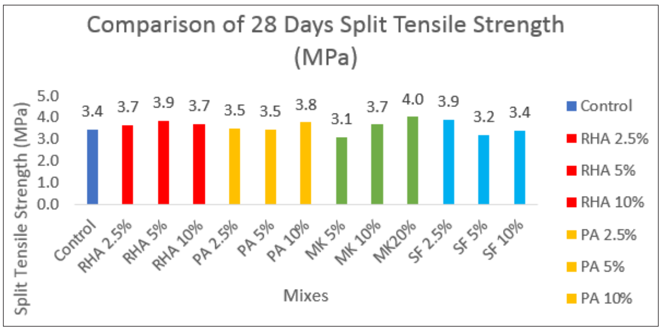


Figure 8: Split Tensile Strength of Different Pozzolanic SCM Mixes

Discussion

Comparison of Compressive Strength of Pozzolanic SCMs

The presence of the pozzolanic elements (SiO_2, Fe_2O_3, Al_2O_3) in all the SCM materials in this study by more than 70% (table 2) make them suitable materials as cement replacements as per BS C125/ BS C 618/19 [12]. The silica in pozzolanic materials react with excess $Ca(OH)_2$ produced during cement hydration, for additional formation of C-S-H gel as explained in section 1 [11]. The increased presence of CSH gel enhances the strength properties of these concrete composites. However, any excess unreacted pozzolan after depletion of $Ca(OH)_2$ starts performing as a filler and resultantly impacts the strength as discussed in section 3.1 [11]. Therefore, limited percentages of replacement materials are recommended to achieve the optimum enhancement of engineering properties of concrete, e.g. typically up to 40% replacement using PFA and up to 15% using SF. Plasticizer was used to maintain the workability (S1 slump) with 0.4 w/c ratio, it must be noted that with each SCM a coherent and compactable mix was obtained with no bleeding or segregation. However, unlike PFA & GGBS, the addition of SF, MK, RHA & PA reduced the slump, i.e. more plasticizer was required to maintain an S1 slump which needs to be taken into consideration for design mixes.

The overall compressive strength improved from 2.5% to 30% as shown in table 3 and fig 9 with all the SCM mixes satisfying the C50/60 design mix strength within 14 days. In fact, all 12 SCM mixes achieved characteristic strengths in excess of 70 MPa. Therefore, the study suggests that these waste materials can perform better in formulation of high strength/ high performance concrete of 60-90 MPa. The results show RHA as the best performing agricultural pozzolanic material as it contains around 97% silicate and gave 83 MPa compressive strength at 10% use. PA, from agricultural waste also exhibited enhancement of compressive strength of over 70 MPa strength with all mixes from 2.5 - 10% replacement, with 2.5% PA giving the optimum value of 78 MPa strength at 28 days. Metakaolin which is considered as an established cement replacement pozzolanic material gave maximum compressive strength of 84 MPa at 20% MK mix at 28 days; MK showed a consistent progressive increase in compressive strength from 5 - 20 %. Another industrial waste, SF which is an established cement replacement contains 99% silica and performed the best at 2.5% mixing ratio with 90 MPa strength. However, increased quantities from between 5 and 10% showed decrease in strength although they were still higher than the control mix. The water/cement ratio of 0.4 has been used in this study, however, as per Abram's Law, which states the compressive strength of concrete is inversely proportional to the water/cement or (water/binder) ratio, the reduction of w/c ratio from 0.4 to 0.3 or 0.35 is likely to increase the strength of these SCM mixes even higher into the high-performance concrete classification (80+ MPa). Thus, potential for usage in high strength and robust structural applications [11, 44].

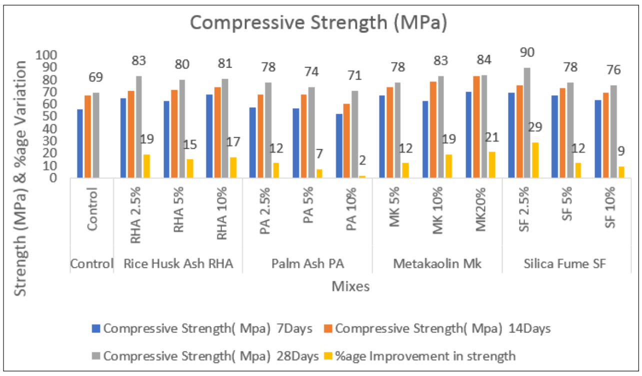


Figure 9: Comparison of Compressive Strength of Different Pozzolanic SCMs

Table 3: Compressive Testing Results and %Age Improvement in Compressive Strength Over the Control Mix

Type of Material	Mix Ratio	Compressive Strength (MPa)			% Improvement in compressive strength
Days of Hydration		7	14	28	
Control		56	67	69	
Rice Husk Ash RHA	RHA 2.5%	65	71	83	19
	RHA 5%	63	72	80	15
	RHA 10%	68	74	81	17
Palm Ash PA	PA 2.5%	58	68	78	12
	PA 5%	57	68	74	7
	PA 10%	52	61	71	2
Metakaolin MK	MK 5%	67	74	78	12
	MK 10%	63	78	83	19
	MK20%	70	83	84	21
Silica Fume SF	SF 2.5%	70	76	90	29
	SF 5%	67	73	78	12
	SF 10%	64	70	76	9

Comparison of Split Tensile Strength of Pozzolanic SCMs

Most of the SCM mixes exhibited improvement in tensile strength as compared to the control mix. The overall improvement in tensile strength was observed from 1% to 17% as shown in table 4 and fig 10. The impact of SCMs on tensile strength is observed as minimal and is not very significant, ranging from 3.1 MPa to 4.0 MPa. The results show that RHA performed as the best agricultural pozzolanic material and gave best results of 3.8 MPa tensile strength at 5% replacement which is 12% improvement in tensile strength. On the other hand, PA exhibited enhancement of tensile strength mainly with 10% use and gave 3.8 MPa strength showing an increase of 10%. Metakaolin gave 17% increase in tensile strength to 4 MPa at 20% MK mix. SF performed the best at 2.5% mixing ratio by giving a 13% increase in tensile strength to 3.9 MPa. It must be born in mind, however, that the tensile strength range for all mixes remained between a narrow range of 3.4 – 4.0 MPa which is as expected as generally the tensile strength of concrete is usually about 5 – 10% of the compressive strength. Also, for standard application of structural concrete, the tensile strength is not of paramount importance as they are primarily used for their compressive strength and are reinforced with steel for better performance under tensile stresses.

Empirical Relationship of Compressive and Tensile Strength of Pozzolanic SCMs

An empirical formula has also been devised by plotting compressive strength versus tensile strength to give a relationship for assessment of strengths of different ratios/ mixes as shown in fig 11. The expression $y = 0.0237x + 1.7179$ with $R^2 = 0.2443$ can be used to determine value of tensile strength from compressive strength of a composite.

Table 4: Split Tensile Strength Testing Results and %Age Improvement in Tensile Strength

Type of Material	Mix Ratio	Tensile Strength MPa	% Improvement of Tensile Strength
Control	Control	3.4	
Rice Husk Ash (RHA)	RHA 2.5%	3.7	6
	RHA 5%	3.9	12
	RHA 10%	3.7	8
Palm Ash (PA)	PA 2.5%	3.5	1
	PA 5%	3.5	1
	PA 10%	3.8	10
Metakaolin (MK)	MK 5%	3.1	-
	MK 10%	3.7	7
	MK20%	4.0	17
Silica Fume (SF)	SF 2.5%	3.9	13
	SF 5%	3.2	-
	SF 10%	3.4	-

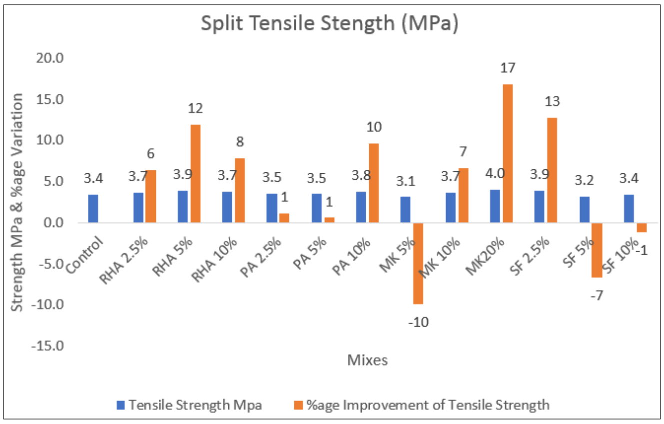


Figure 10: Comparison of Split Tensile Strength of Pozzolanic SCMs

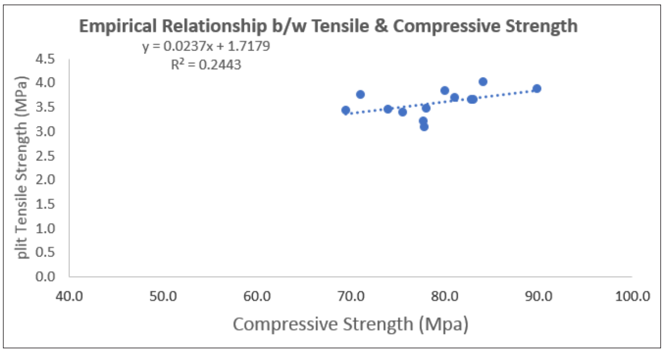


Figure 11: Empirical Relationship of Compressive and Tensile Strength of Pozzolanic SCMs

Conclusion

This paper focused on a comparative study between the established (metakaolin & silica fume) and potential (rice husk ash & palm ash) SCMs in concrete with a w/b ratio of 0.4. Chemical analyses found all four SCMs satisfy the chemical requirement as a pozzolanic material. Furthermore, the findings show all SCM mixes satisfied the C50/60 and had a higher compressive strength than the control (100% cement); indeed all 12 SCM mixes achieved strengths in excess of 70 MPa. Therefore, by expanding the pozzolanic family by incorporating both agricultural wastes will facilitate the construction industry combat the adverse effects of climate change. Not only do the SCM's reduce the embodied CO2 of concrete, they also enhance the eventual strength [45, 46].

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