Innovative and sustainable green concrete—A potential review on utilization of agricultural waste

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Abstract. Concrete is the most versatile product used as building material in world's construction industry, and it generates carbon to the atmosphere. In manufacturing of cement, 8% to 10% of global carbon dioxide (CO₂) gas is generated. The maximum utilization of cement contributes to global warming and climate change. Therefore, many scholars have conducted a research to develop green and sustainable concrete incorporating different waste materials. By utilizing waste materials as cement replacement, the CO₂ gas emissions will decrease. This paper reviews the potential and innovative utilization of agricultural waste as partially cement replacing material to make green concrete. Agricultural waste possesses the pozzolanic materials, when finely grinded, generate pozzolanic reaction, in which silica responds with calcium oxide to create calcium silicates which is responsible for higher strength attained in the concrete. It is concluded from previous studies the agricultural waste which consist the high silica contain generated the pozzolanic reaction in concrete mix which contributes the enhancement in strength. The RHA, SCBA POFA are the pozzolanic material, 10%-20% utilization of these waste is optimum and enhance the 20%-30% strength of concrete. The Banana Skin Powder (BSP) also possesses the high silica contain which will generate the pozzolanic reaction in concrete mix and will improve the strength of concrete such as the other agricultural waste improves.

1. Introduction
Concrete is the most versatile product used as building material in world’s construction industry. It possesses high compression strength, resistance to water and fire, lower maintenance cost and higher service life respect to other building material [1]. These are among many advantages of using concrete as building material. However, concrete production has caused interference with the conservation of natural resources. This is because, concrete is prepared by mixing cement, coarse aggregate, fine aggregate, water and admixtures [2]. Cement is a water-based binder utilized to bind other constituent of concrete. In construction industry, cement is broadly utilized as binding material. This makes it the most demanding material in concrete production. It is recorded that the world cement production produces 8% to 10% of anthropogenic global carbon dioxide (CO₂) gas emissions into the atmosphere...
as shown in Figure 1, which creates the weathering and climatic changes. With the rapid growth of cement industry, it is expected that CO$_2$ emission will continue to increase [3]. Therefore, to protect the environment from global warming, the utilization of cement must be minimized.

![Figure 1. Carbon dioxide (CO$_2$) emission in atmosphere [3].](image)

Figure 1. Carbon dioxide (CO$_2$) emission in atmosphere [3].

Meanwhile, municipal solid waste is the waste produced from residential area, commercial business and institutions. Municipal waste includes paper, food, fruits, glass and other daily life things as shown in Figure 2. The municipal waste contains the 55% organic waste (agricultural waste), which will be significantly increased more due to increasing in urbanization, growing economy and changing in livings standards [3]. In present 1.3 billion tons per annum global municipal solid waste is generated because of increase in population and improve in standard of living, approximately 1.2 kg/capita/day municipal waste is generated daily, but it rises to 1.42 kg/capita/day in 2020 [4]. One of the attractive solution to overcome this problem is to recycle these wastes by adding them as new materials in concrete admixtures. The proportions of the particles from these wastes, and the proportion to be added are determined from the chemical properties possessed in the waste.

![Figure 2. Typical municipal solid waste composition in Malaysia [7].](image)

Figure 2. Typical municipal solid waste composition in Malaysia [7].

Green concrete does not represent the colour green, but it shows the surrounding environment. Concrete produced from concrete wastes which are eco-friendly can be named as green concrete. It may be defined as green concrete since it saves the natural resources and decreased the environmental pollution in the context of CO$_2$ emission. Green concrete is a concrete in which waste material is utilized, and at least one of its ingredients or its manufacturing process does not affect the environment. Manufacturing procedures, life cycle sustainability impacts and quantity of cement replaced are the key factors which are used to categorize whether a concrete is green or not [5]. The
The main purpose of producing green concrete is to minimize the CO\textsubscript{2} gas emissions, to utilize the natural resources and the utilization of waste materials in concrete, which causes environmental pollution.

This paper reviews the potential usage of agricultural wastes in concrete to form a green innovative sustainable concrete by utilizing agricultural waste which may solve the environmental issues and reduce the CO\textsubscript{2} gas emissions and save the natural resources which are widely utilized in the manufacturing of cement.

2. Agricultural waste
Agricultural wastes are the byproduct of manufacturing and processing of raw agricultural products like fruits, vegetables and crops. Agricultural wastes include the animal wastes (manure, animal carcasses), food manufacturing waste (only 20% of maize is preserved and 80% is waste), crop wastes (corn stalks, sugarcane bagasse, drops and culls from fruits and vegetables, pruning’s), and hazardous and toxic agricultural wastes (pesticides, insecticides and herbicides) as shown in Figure 3 [6-8].

Malaysia is counted as among the top agricultural countries in the world. Rice, sugar cane, palm oil, fruits, coconut and rubber are the major agricultural product of Malaysia. Almost 40% of the total land in Malaysia is covered by agriculture land. The rice and sugarcane product are also cultivated in a large scale because their demand is high. However, development of these products creates a lot of agricultural waste which cause the environmental pollution [8].

This paper will discuss the material and mechanical properties of various agro-wastes (rice husk ash, sugarcane bagasse ash, palm oil fuel ash and banana skin powder) which possess pozzolanic properties; namely, silica calcium gel, which would enhance the strength of concrete up to certain limit. The discussion on RHA, SCBA, and POFA are based on reviews of previous work while discussion on properties of BSP is based on authors’ experimental work. The discussion revolves around their physical, fresh and hardened properties, and mechanical properties. From the review, the content of pozzolanic materials in each type of agro-waste will be determined. From this result, the fresh and hardened state properties and mechanical properties of each agro-waste could also be determined because these properties are mainly influenced by the content of the pozzolanic materials.

![Figure 3. Various types of agricultural wastes [7].](image)

2.1. Rice husk ash (RHA)
Rice milling industry has generated approximately 600 million tons of rice paddy annually [8] and is predicted to increase significantly in the future. Almost 20% rice husk is generated from every paddy ton in rice mills, which is utilized as fuel in the boiler to generate electricity for the mill. Approximately 25% of the rice husk is converted into solid waste known as Rice Husk Ash (RHA) as present in Figure 4 [9].
The chemical compositions of RHA, Sugar Cane Bagasse Ash (SCBA), Palm oil fuel ash (POFA) and Banana Skin Powder (BSP) are shown in Table 1. The compositions of OPC, RHA, SCBA, and POFA were obtained from previous researches [10-12, 31, 37] whilst the compositions of BSP were conducted in the analytical laboratory faculty of civil and environmental engineering, UTHM, Malaysia.

**Table 1. Setting Word’s margins.**

| Chemicals | OPC (%) [10] | R.H.A (%) [11-12] | S.C.B.A (%) [31] | POFA (%) [37] | B.S.P (%) |
|-----------|---------------|-------------------|------------------|----------------|-----------|
| CaO       | 65.96 %       | 1.03              | 11.8             | 6.4            | 8.95      |
| SiO₂       | 20.99 %       | 93.46             | 62.43            | 65.3           | 55.98     |
| Al₂O₃     | 6.19 %        | 0.58              | 4.38             | 2.6            | 2.71      |
| MgO       | 0.22 %        | 0.51              | 2.51             | 3.1            | 1.08      |
| SO₃       | ---           | 0.6               | 1.48             | 0.5            | 0.10      |
| K₂O       | 0.60 %        | 1.82              | 3.53             | 5.7            | 28.75     |
| Fe₂O₃     | 3.86 %        | 0.52              | 6.98             | 2.0            | 1.356     |
| LOI       | 1.73          | 7.76              | 4.73             | 10.1           | 1.121     |

From Table 1, RHA possesses a great amount of silica oxide, aluminum oxide (Al₂O₃) and ferric oxide (Fe₂O₃). According to Table 2. ASTM C613 specifications the RHA is Class N pozzolanic material [13-15].

**Table 2. ASTM C618 Chemical Requirements.**

| Class                                                                 | N | F | C |
|-----------------------------------------------------------------------|---|---|---|
| Silicon dioxide (SiO₂) plus aluminium oxide (Al₂O₃) plus iron oxide (Fe₂O₃), min, % | >7 | <70 | 50 |
| Sulphur trioxide (SO₃), max, %                                        | 4 | 5  | 5  |
| Loss on ignition, max, %                                              | 10| 6  | 6  |
Pozzolanic characteristics allows it to be used as a cementitious material. When it is finely ground, it consumes calcium hydroxide \([\text{Ca(OH}_2]\) at ordinary temperatures in the presence of water. The silica and calcium hydroxide reaction generate the calcium silicate gel participating to strength gain in the concrete mixture. However, OPC has certain limit to calcium hydroxide that RHA can utilize, thus providing higher strength up to certain limit. The pozzolanic reaction depend upon the calcium present in the OPC up to certain limit it improves the strength then it reacts negative or reduces the strength of concrete.

When RHA is added to the concrete mixture, the pozzolanic gel (Calcium Silicate gel) will be formed which will improve the strength performance of concrete [16]. The summary of previous studies on physical and mechanical properties of RHA shown in Table 3. It concludes the outcomes while utilizing the RHA as cement replacement concrete. It was predicted by many researchers that the RHA has great potential to execute as a Pozzolanic material, which will have considered as conventional or high strength concrete as cement replacement. Through the utilization of RHA can decrease the environmental pollution (Disposal waste and \(\text{CO}_2\) emission) and produces the sustainable construction material. The following paragraphs will discuss the previous studies on physical and mechanical properties of RHA.

Table 3. Summary on previous research on RHA.

| Ref No. | Design & % used of RHA | Findings |
|---------|------------------------|----------|
| [15]    | w/b ratio: 0.53        | 10% RHA gave compressive strength rises up to 30% at 0.53 w/b ratio was used. |
|         | Curing: 1, 7, 14 and 28 days RHA: 5%, 10%, 15% & 20% |
| [16]    | w/b ratio: 0.45 and 0.50 | 20% RHA exhibited compressive and split tensile strength increased up to 20% at 0.5 w/b ratio was utilized. |
|         | Curing: 28 days RHA: 5%, 10%, 15% 20%, 25%, 30%, 35% & 40% |
| [17]    | w/b ratio: 0.34        | 10% RHA indicated that compressive, splitting tensile and flexural strength improved 20%. |
|         | Curing: 7, 14, 28, 56 & 91 days RHA: 10%, 20%, 30% & 40% |
| [18]    | w/b ratio: 0.32, 0.40 and 0.5 | 20% RHA improved the 10% compressive and split tensile strength when 0.32 w/b ratio was adopted. |
|         | Curing: 7, 14, 28, 56 & 91 days RHA: 10% and 20% |
| [19]    | w/b ratio: 0.5         | 5% RHA improved the compressive, flexural and split tensile strength 4%, 5% and 18% respectively. |
|         | Curing: 7, 28 days RHA: 0%, 5%, 10%, 15%, 20% and 25% |
| [20]    | w/b ratio: 0.23, 0.35 and 0.47 | 20% RHA showed equivalent compressive strength when 0.35 w/b ratio was used. |
|         | Curing: 1, 3, 7, 14, 28, 56 & 91 days RHA: 10%, 20% & 30% size of RHA: 12 \(\mu\)m |
| [21]    | M40 and M50 grade concrete Curing period: 7, 28 & 56 days RHA: 5%, 10% & 15% | 10% RHA was optimum, where 5% compressive strength increase while increase in RHA content, the workability of concrete decreases. |
| [22]    | Curing period: 7, 14 & 28 days. 600 \(\mu\)m passing RHA: 5%, 10%, 15%, 20% & 25% | Compressive Strength reduced with increase in RHA. Optimum was determined to be 0-20% for better performance. |
| [23]    | Curing period: 7, 14 & 28 days Target concrete grade: M20 63 \(\mu\)m passing RHA: 5%, 15% and 25% | 5% RHA was optimum, showed lower compressive strength but achieved the target strength of M20 grade. Workability decreased with increase in RHA content. |
| [24]    | Curing period: 7, 14 & 28 days Target concrete grade: M15 RHA: 5%, 10%, 15%, 20% & 25% RHA as sand replacement Volume and Weight Batching | It was observed that compressive strength 6% decreased with increase in RHA content. Volume-based batching showed slightly higher strength compared to weight-based batching. |
From the discussion of previous research, it can be concluded that the optimum percentage of RHA that could be added in the concrete admixture is about 10% which will increase the compressive, tensile and flexural strength of concrete up to its maximum at 30 MPa and 20 MPA, respectively.

2.2. Sugarcane bagasse ash (SCBA)
Sugarcane is counted in major crops grown in over 110 countries and the production is almost 1500 million tons per year in worldwide. SCBA is 10 million tons annually, generated by the sugar mills. The sugarcane waste possesses 26% of bagasse and 0.62% of residual ash as shown in Figure 5 [25-27].

![Figure 5. Sugar cane bagasse and sugar cane bagasse ash](image)

Bagasse ash possessing high amounts of un-burnt matter, silicon, aluminum, iron and calcium oxides [27]. The chemical composition of SCBA is shown in Table 1. The chemical composition contains the high silica contain and other pozzolanic material. According to ASTM C618 shown in Table 2. The SCBA is Class N pozzolanic material because the sum of silica oxide, aluminum oxide (Al₂O₃) and ferric oxide (Fe₂O₃) greater seventy.

SCBA possesses the pozzolanic material which will develop the pozzolanic reaction in manufacturing of concrete and it will contribute to rise the strength in concrete. Various researchers conducted the experimental work to analyses the physical and mechanical performance of concrete consisting SCBA as cement replacement. The summary of previous study on SCBA as cement replacement is presented in Table 4.

The summary of previous studies on material, fresh and hardened properties of SCBA are shown in Table 3. It concludes the results while utilizing the SCBA as cement replacement concrete. It was prophesied by various scholars that the SCBA has great tendency to perform as a Pozzolanic material, which will have considered as conventional or high strength concrete as cement replacement. Through the consumption of SCBA can decline the environmental pollution (Disposal waste and CO₂ emission) and develops the sustainable construction material. The following paragraphs will elaborate the previous studies on material and mechanical properties of SCBA.

From the discussion of previous research, it can be concluded that the optimum percentage of RHA that could be added in the concrete admixture is about 10% which will increase the compressive, tensile and flexural strength of concrete up to its maximum at 30 MPa and 20 MPA, respectively.
Table 4. The summary of previous study on SCBA.

| Ref No. | Design & % used & Fineness of SCBA | Findings |
|---------|------------------------------------|----------|
| [28]    | w/b ratio: 0.45 Curing: 7 and 28 days Target mean strength: 30 Mpa SCBA: 0%, 5%, 10%, 15%, 20% & 20% | 5% SCBA was optimum and the compressive strength was increased up to 28% compared to control sample. |
| [29]    | w/b ratio: 0.48 Curing: 7 & 28 days SCBA: 0%, 5%, 10%, 15%, 20% and 25% | Slump flow was maximum at 25% replacement. The compressive strength was 27.5% increases at 5% replacement where as it decreases as percentage of SCBA rises. |
| [30]    | w/b ratio: 0.44 & 0.63 Curing: 7, 28, 56 & 90 days SCBA: 0%, 10%, 15%, 20%, 25% and 30%. Size of SCBA: 300 µm | 10% SCBA gave 15% better compressive, splitting tensile and flexural strength performance compared to other mix proportions. |
| [31]    | w/b ratio: 0.49 Curing: Compressive and split tensile strength: 7, 14 & 28 days. Flexural strength: 7 & 28 days Target mean strength: 25 Mpa SCBA: 0%, 5%, 10%, 15% & 20% . Size of SCBA: 63 µm | The compressive, split tensile and flexural strength increase linearly up to 10% SCBA replacement. In compressive 20% strength increases where as in tensile and flexural the 10% and 15% strength rises respectively. |
| [32]    | w/b ratio: 0.5 Curing: 7, 14, 28 & 60 days SCBA: 0%, 5%, 10%, 15%, 20% and 25%. Size of SCBA: 150 µm | The optimum percentage was 15% SCBA replacement where the compressive and tensile strength increases 19% and 12.5 % respectively compared to control sample. |
| [33]    | w/b ratio: 0.40 & 0.45. Curing: 7, 28, 56 & 90days SCBA: 0%, 5%, 10%, 15% and 20% | The 5% SCBA replacement gave the better slump flow compare to other proportions. The 15% replacement performance was better than other proportions. The compressive strength was increases up to 15% and the split tensile strength performance was 5% better than conventional concrete. |
| [34]    | M40 and M50 grade concrete w/b: 0.5 Curing period: 7, 28 & 90 days Target mean strength: 30 Mpa SCBA: 10%, 20%, 30%, and 40% | 20% SCBA improves the 9% compressive strength compared to conventional concrete, whereas tensile and flexural was 5% improved compared to control sample. |

2.3. Palm oil fuel ash (POFA)

Palm oil fuel ash is produced from burning of palm oil husk and palm shell in the palm oil mill as shown in Figure 5. The chemical composition of POFA is shown in Table 1, where it is shown that POFA contains the pozzolanic materials. According to ASTM C618 specifications shown in Table 2. POFA is concluded that Class F pozzolanic material because it contains silica oxide (SiO$_2$), aluminum oxide (Al$_2$O$_3$) and ferric oxide (Fe$_2$O$_3$) less then seventy. The summary of previous studies on material and mechanical properties of POFA presented in Table 5.
The various study will deliberate the previous studies on material, fresh and hardened properties of POFA.

Table 5. Summary of previous research on POFA.

| Ref No. | Design & % used & Fineness of POFA | Findings |
|---------|------------------------------------|----------|
| [35]    | w/b ratio: 0.40 Curing: 28 days POFA: 10%, 20% & 30%. | 20% POFA gave 15% more strength compared to conventional concrete. |
| [36]    | w/b ratio: 0.38 Curing: 7 & 28 days POFA: 10%, 15% and 20% | The 15% POFA replacement possessed the better workability results compare to other samples. The compressive, split tensile and flexural performance enhanced 10% at 20% POFA. |
| [37]    | w/b ratio: 0.36 Curing: 7, 14, 28, 56 & 90 days POFA: 0, 5, 10, 15, 20, 25 and 30%. Fineness = 45 µm | The durability and slump of SCC was examined, AT 15% POFA replacement the slump was higher than the other proportions whereas in water absorption test the 30% replacement absorb less water compared to other mixes. |
| [38]    | w/b ratio: 0.36 Curing: 1, 7, 28, 56 & 90 days SCBA: 0%, 30%, 50% & 70% Fineness = 45 µm | The workability increases with increment of POFA percentage as cement replacement. Compressive strength and split tensile strength was 20 % maximum at 30% POFA compared to all replacement. |

The results showed that the strength (compressive, split tensile and flexural strength) increases significantly by incorporating the POFA in concrete up to 20% cement replacement because up to 20% replacement the pozzolanic reaction generated in cement paste contributes to strength after that the calcium and silica did not generate the pozzolanic activity. The pozzolanic reaction is shown below.

\[
CaO + H_2O \rightarrow Ca(OH)_2 \tag{1}
\]

\[
Ca(OH)_2 + SiO_2 \rightarrow C-S-H \text{ (Calcium Silicate Hydrate gel)} \tag{2}
\]

After 20% replacement of POFA no extra calcium left which will react with silica to generate the pozzolanic gel. So, alone silica creates negative impact on the strength of concrete.

2.4. Banana Skin Powder (BSP)
In Malaysia banana plantation is second most planted fruit, it covers the 26,000-hectare area and produced 530,000 metric ton banana per year [39- 41]. Banana waste is almost 4 ton produced annually and creates the environmental pollution [42]. Banana fruit is most used among all the fruits due to that the banana skin waste generates in huge amount which create the environmental problem.
such as odor smell and generate leachate which will affect the atmosphere and ground water respectively. The banana skin and banana skin powder are shown in Figure 7.

![Figure 7. Banana skin and banana skin powder.](image)

Many researchers did experimental work to utilize the banana as reinforcement and banana leaves as cement replacement. Zhu et al. [43] investigated the flexural performance of concrete utilizing banana fiber at different percentages as filler, between 8% and 10%. The results showed that 2 to 3% split tensile and flexural strength increased due to banana fiber reinforcement. Lukman [44] analyzed the material properties of banana trunk ash and mechanical properties of concrete utilized as cementing material. The banana trunk ash was utilized 0% to 3% with an increment of 1%. The outcomes demonstrated that banana trunk ash contains the pozzolanic material and it reduces the 30% compressive strength compared to conventional concrete.

In literature review no one utilized the banana skin powder as cement replacement so in this research the chemical composition of banana skin powder was examined the outcomes are shown in Table 1, it is seen that the banana skin powder contains the pozzolanic material in ample amount. According to ASTM C618 the banana skin powder is Class F pozzolanic material.

Due to this pozzolanic material, it can be utilized as cement replacement material which will definitely enhance the mechanical performance of concrete, made the economical, green and sustainable concrete and reduces the agricultural waste.

3. Conclusion

From the above previous research, the durability, workability and strength (compressive, split tensile and flexural strength) was investigated the strength performance of concrete containing different types of agricultural waste. The RHA gave the 20% better strength performance from 10%-20% cement replacement. The SCBA improves the strength up to 30% at 5%-15% replacement where as POFA enhances the strength 20% at 10%-20% partially replacement with POFA.

The workability performance of concrete containing the agricultural waste was better than control sample. The workability increases significantly as agricultural waste replacement percentage increased. It is concluded from the literature that RHA, SCBA and POFA possessed the pozzolanic materials due to that pozzolanic activity develop which enhance the strength of concrete. From literature it is concluded that 20% RHA, 5%-10% SCBA and 10%-20% POFA replacement with OPC are optimum.

It is concluded from this review that banana skin powder has the pozzolanic material as other pozzolanic material. Therefore, banana skin powder can be utilized as partially cement replacing material. For further extensive research is required to understand the performance of banana skin powder as partially cement replacing material on strength behavior of concrete. The use of banana skin powder as partially cement replacement in concrete leads to develop the green and sustainable concrete and resolve the environmental pollution issues produced by waste.
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