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ORIGINAL PAPER

Influence of Binary Blend of Corn Cob Ash and Glass Powder as Partial Replacement of Cement in Concrete

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Abstract

The increasing demand for concrete for various infrastructure construction has led to significant production and usage of Portland cement which is the main binder used for concrete. The production of Portland cement poses a sustainability threat as its production emits a large amount of carbon dioxide into the environment coupled with the high consumption of natural resources. Therefore, the use of alternative materials will result in a significant reduction in these carbon emissions and deformation of the environment. On the other hand, the increasing population coupled with urbanization has led to the generation of several tonnes of solid wastes annually from various processes. Some of these wastes generated can be recycled and used as partial replacement of Portland cement in concrete mixtures. In order to improve the sustainability of concrete mixtures, this study was undertaken to evaluate the performance of concrete mixture incorporating recycled products as partial replacement of Portland cement. Corn cob ash and glass powder which are waste products from the agricultural and manufacturing industry respectively were used as binary cementitious material (BCM) to replace Portland cement up to 20% in concrete production. The effects of the BCM on the slump and mechanical properties were evaluated. Results from this study showed that the incorporation of BCM resulted in a decrease in the slump of the concrete mixtures. In terms of mechanical properties, 10% BCM was deemed the optimum due to the enhancement of the compressive and split tensile strength. Sustainability analysis of the mixtures also indicates BCM can be used to reduce the embodied energy and carbon of concrete mixtures.

Keywords Concrete · Cement · Corn cob ash · Glass powder · Sustainability

1 Introduction

There is a high demand for Portland cement (PC) for the production of various cement-based composites such as concrete. This high demand of PC has resulted in a significant high carbon dioxide emissions that emanates from its production [1, 2]. The overexploitation of natural resources for the production of PC has also caused a significant deformation and deterioration of our environment. With the increasing urbanization and increase in population, higher demand for PC is anticipated. In order to meet these future demands of concrete while conserving the environment, it is pertinent to find alternative materials to replace the conventional components in concrete. Several attempts have been made by various studies to replace the natural aggregates used in concrete with waste materials [3–7]. However, the carbon footprint of concrete persists as the PC has the highest embodied energy and carbon out of all the components used for conventional concrete. Therefore, finding other waste materials that can be used to replace the PC will lead to more reduction in the carbon footprint of concrete.

Several types of supplementary cementitious materials such as slag and fly ash have been extensively used to replace Portland cement in concrete mixtures. However, these SCMs are not readily available at all places and where available; the supply is limited. The increasing sustainability awareness all over the world will lead to continuous decommissioning of coal power plants and a corresponding decrease in the supply of fly ash. Therefore, it is pertinent to find alternative materials that can be used to replace PC in concrete mixtures. Glass powder (GP) which is obtained from recycling waste glass into small sizes is one of the materials that can be used as a

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replacement of PC in concrete mixtures. Several tonnes of glass wastes are generated annually, and these wastes end up in the environment where they pose a safety, health and aesthetic threat. The utilization of GP as replacement of PC in concrete mixtures will not only help to reduce the embodied carbon and energy of concrete mixtures but will also ensure glass wastes are managed effectively. On the other hand, there exist several wastes from the agricultural industry that can be incinerated, and the resulting ash used as a replacement of Portland cement [5, 8–15]. Of such promising agricultural waste is corn cob which can be recycled into corn cob ash (CCA) and use as a cementitious material in concrete. Countries like the United States produce about 50 million tonnes of corn annually [16]. This high production of corn means there will be a corresponding generation of an equal amount of corn cob. Therefore, incorporation of these waste materials into the concrete will also help to manage these wastes effectively while creating a supply for the future demand of binders for concrete mixtures. Some studies have utilized CCA or GP as cementitious components in concrete. However, there exists no study on the use of these waste materials as binary cementitious materials (BCM) in concrete mixtures. Also, studies on the use of either CCA or GP have evaluated only compressive strength while properties such as slump and split tensile strength were neglected. Besides, none of the past studies on the use of these materials (i.e. CCA or GP) in concrete have evaluated their sustainability benefits. Therefore, there is a need to evaluate the performance and sustainability of such concrete made with BCM composed of CCA and GP.

This study forms part of an extensive study evaluating the performance of concrete mixtures incorporating various recycled materials as components in concrete. In this study, CCA and GP which are waste products were used as a BCM to replace the PC up to 20%. A total of five mixtures were made with varying proportions of PC replaced with the BCM. The effect on the slump and mechanical properties was evaluated and presented. A simplified sustainability analysis was also carried out to assess the sustainability benefits of using these wastes as cementitious materials in concrete mixtures.

2 Experimental Program

2.1 Materials

Portland cement (PC) alongside corn cob ash (CCA) and glass powder (GP) with a specific gravity of 3.12, 2.54 and 2.56, respectively was used as the binder in this study, and their chemical composition presented in Table 1. The corn cob used to produce the CCA was obtained from the Jamshoro region of Pakistan and milled to smaller sizes before combusted at a temperature of about 600 °C for 10 h. After the combustion, the CCA was sieved and only particles lower than 75 μm were used in this study. The GP used was obtained from the Hyderabad region of Pakistan and was ground and sieved. GP particles lower than 75 μm was also used. Coarse aggregate (CA) and fine aggregate (FA) with a maximum aggregate size of 19 mm and 4.75 mm respectively, and properties presented in Table 2 were used as aggregate in all mixtures. Potable water was used as the mixing solution for all mixtures.

Table 1 Chemical composition of the binders

Compound	PC	CCA	GP
SiO_2	18.11	67.23	71.23
Al_2O_3	4.31	6.34	1.24
Fe_2O_3	2.38	5.33	0.73
CaO	60.22	10.75	9.28
SO_3	2.87	1.04	0.33
Na_2O	0.18	0.37	11.19

2.2 Mixture Design and Sample Preparation

Five mixtures presented in Table 3 were designed and made for this study. Corn cob ash (CCA) and glass powder (GP) were used at equal proportion as a binary cementitious material (BCM) to replace the Portland cement (PC) up to 20%. One of the mixtures was made as the control by using only PC as the binder (i.e. 0BCM). The mixture ID in Table 3 represents the percentage proportion of PC replaced with the BCM. For example, 10BCM and 20BCM indicate mixtures in which the PC was replaced with 10% and 20% BCM respectively. The water to binder ratio for all mixtures was fixed at 0.50. A total of 75 samples comprising of 30 cylinders and 45 cubes were made.

The mixing process entails first dry mixing the binder and aggregates for three minutes followed by the slow addition of water as mixing continues. After all the water has been added, the mixing was continued for an additional three minutes in order to achieve a homogenous mixture. Immediately after mixing, the slump of the mixture was evaluated followed by

Table 2 Properties of the aggregate

Property	FA	CA
Fineness Modulus	2.25	----
Specific Gravity	2.65	2.72
Absorption (%)	1.70	1.25
Density (kg/m^3)	2650	2720

Table 3 Mixtures composition

Mixture ID	PC	CCA	GP	Fine aggregate	Coarse aggregate
0 BCM	1.00	0	0	1.5	3
5BCM	0.95	0.025	0.025	1.5	3
10BCM	0.90	0.050	0.050	1.5	3
15BCM	0.85	0.075	0.075	1.5	3
20BCM	0.80	0.100	0.100	1.5	3

pouring the fresh mixtures in pre-oiled molds for the mechanical properties to be evaluated.

2.3 Test Methods

2.3.1 Slump

Immediately after the mixing was concluded for each mixture, the slump was evaluated in accordance with the test procedures in BS EN12350 [17].

2.3.2 Mechanical Properties

The mechanical properties of the mixtures were evaluated in terms of the compressive strength and split tensile strength. The compressive strength was carried out using cubic samples with a dimension of 150 mm in accordance with the test procedures in BS EN 206 [18]. For the split tensile test, cylindrical samples with a diameter of 100 mm and a height of 200 m were used for the evaluation in accordance with the requirements of BS 12390 [19]. The compressive strength was evaluated at 7, 14 and 28 days while the split tensile strength was evaluated at 7 and 28 days. For each age, the results presented represent the average of three samples tested.

2.4 Sustainability Assessment

A basic sustainability evaluation similar to that used by Adesina and Das [20] was used to evaluate the embodied energy and carbon of the five concrete mixtures. The embodied energy for rice husk ash from Henry and Lynam [21] was used for the embodied energy of the corn cob ash as they have a similar production process. The equivalent embodied carbon of the corn cob ash was calculated based on the obtained embodied energy. The embodied energy and carbon used for other components in the concrete were obtained from sources in the literature. A detailed embodied energy and carbon used for the sustainability assessment are presented in Table 4. The embodied carbon and energy for each concrete mixture are calculated using Eqs. 1 and 2 respectively. The CO_{2e}, E_e, i and W_i in Eqs. 1 and 2 represent the overall embodied carbon, overall embodied energy and the weight per unit volume (i.e. kg/m^3) for each mixture. The CO_{2i} and E_i are the embodied carbon and energy of the concrete's components stated in Table 4.

$$CO_{2e} = \sum_{i=1}^{n} (W_i \times CO_{2i}) \quad (1)$$

$$E_e = \sum_{i=1}^{n} (W_i \times E_i) \quad (2)$$

3 Results and Discussion

3.1 Slump

The slump of the five mixtures evaluated is presented in Fig. 1. It can be observed from the figure that the slump of the concrete mixtures reduced with a higher content of the binary cementitious material (BCM). The slump of mixtures incorporating 5%, 10%, 15% and 20% BCM is 11.1%, 27.8%, 44.4% and 53.7% lower than the control mixture with no BCM. The reduction in the slump with the introduction of BCM into the concrete mixtures can be attributed to the possible high absorption rate and particle size of the CCA and the GP. The high content of silica in the BCM would also result in high demand for water to achieve excellent workability. Adesanya and Raheem [26] also observed that the slump of concrete mixtures reduced when CCA was used as a blended

Table 4 Sustainability of materials

Materials	Embodied carbon (kgCO_2/kg)	Embodied energy (MJ/kg)	References
PC	0.82	5.50	[22]
CCA	0.002	0.022	NA
GP	-0.03	-0.45	[23]
Water	0	0	[24]
FA	0.0139	0.0048	[25]
CA	0.0408	0.0048	[25]

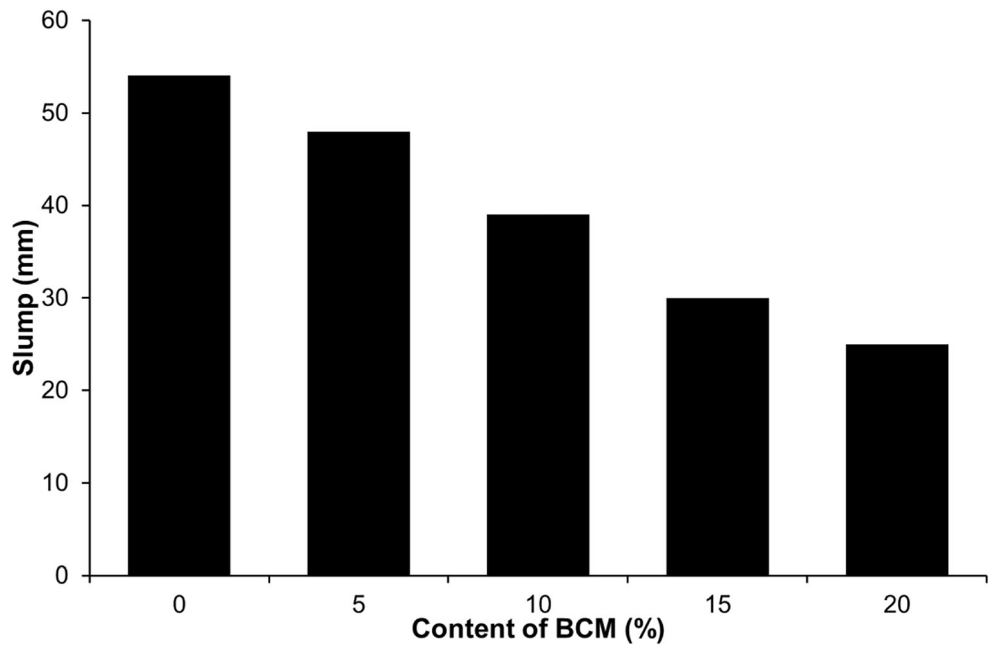

Fig. 1 Effect of BCM on the slump of mixtures

binder with PC in concrete mixtures. This observation is also similar to that of Ikponmwosa et al. [27] where coconut shell ash was used as a 10% replacement of Portland cement in concrete mixtures. Nonetheless, in order to conserve the strength properties of the mixtures, a high range water reducer admixture can be employed to improve the workability instead of adding water.

3.2 Compressive Strength

Figure 2 presents the compressive strength of the mixtures evaluated. It can be seen from Fig. 2 that the compressive strength of all mixtures increased with age regardless of the binder composition. The compressive strength of 0BCM at 28 days is 42.2% higher than that at 7 days. It can also be observed that all mixtures achieved more than 90% of their 28 days compressive strength at 14 days. The viability for mixtures incorporating BCM to exhibit this similar behaviour indicates they can be used successfully in an application where conventional concrete mixtures are used without any detrimental effects on the early age strength. Figure 2 also indicates that the incorporation of the BCM as a partial replacement of the PC led to an increase in the compressive strength up to 10% replacement. At higher replacement (i.e. greater than 10%) of the PC with BCM, the compressive strength

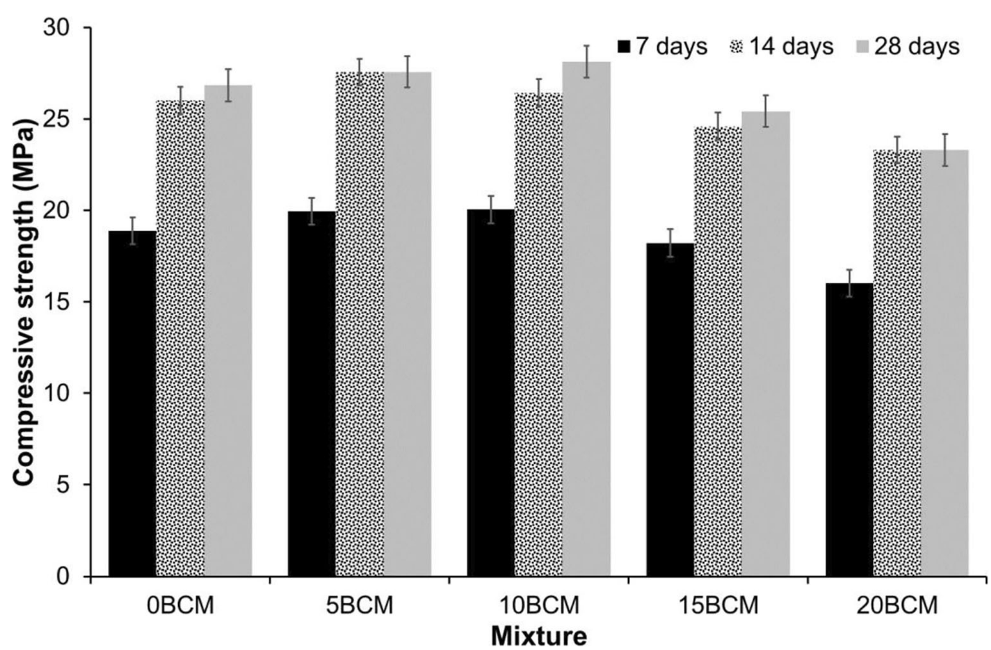

Fig. 2 Compressive strength of mixtures

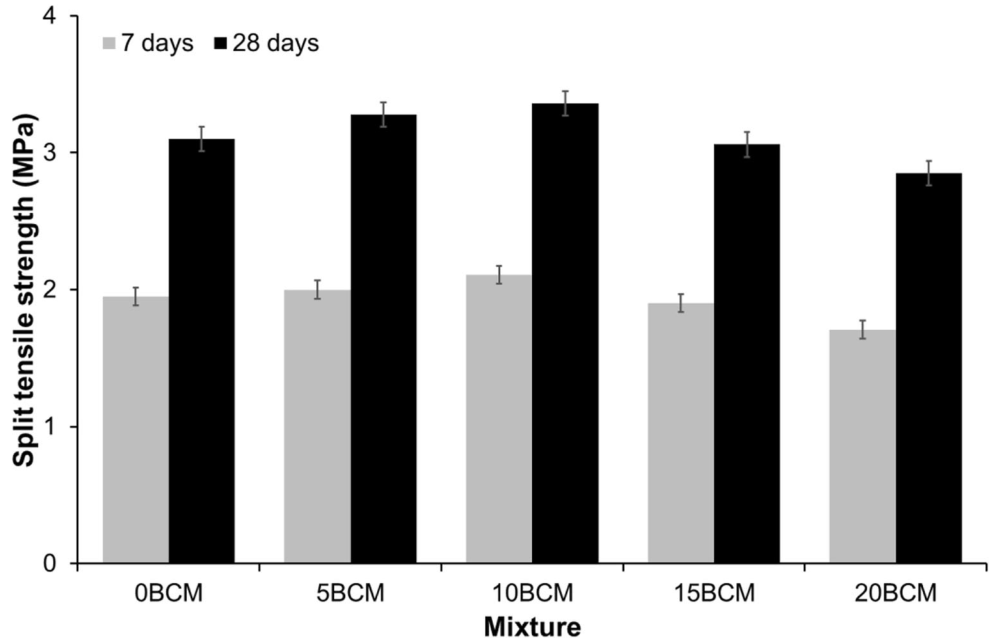

Fig. 3 Split tensile strength of mixtures

reduced. This observation contradicts that of Adesanya and Raheem where the reported an optimum replacement of PC with CCA to be 15%. The difference in their study when compared to this present study can be associated with the binary cementitious material (i.e. CCA and GP) used in this study compared to theirs where only CCA was used solely to replace PC. Nonetheless, there is no significant difference in the compressive strength of mixtures incorporating 20% BCM and the control mixture (i.e. 0BCM). The compressive strength of 0BCM and 20BCM at 28 days is 26.6 MPa and 23.3 MPa respectively. Based on these results, a 10% replacement of the PC with BCM can be deemed the optimum. Nevertheless, as the compressive strength of all mixtures including those with 20% BCM have a compressive strength higher than 20 MPa; they are all suitable for structural applications.

3.3 Split Tensile Strength

The split tensile strength of the five concrete mixtures is shown in Fig. 3. Similar to the compressive strength, it can be observed that the split tensile strength of all mixtures increased with age. For example, the split tensile strength of 0BCM and 20BCM at 7 days is 2 MPa and 1.7 MPa at 7 days. This tensile strength increased to 3.1 MPa and 2.9 MPa at 28

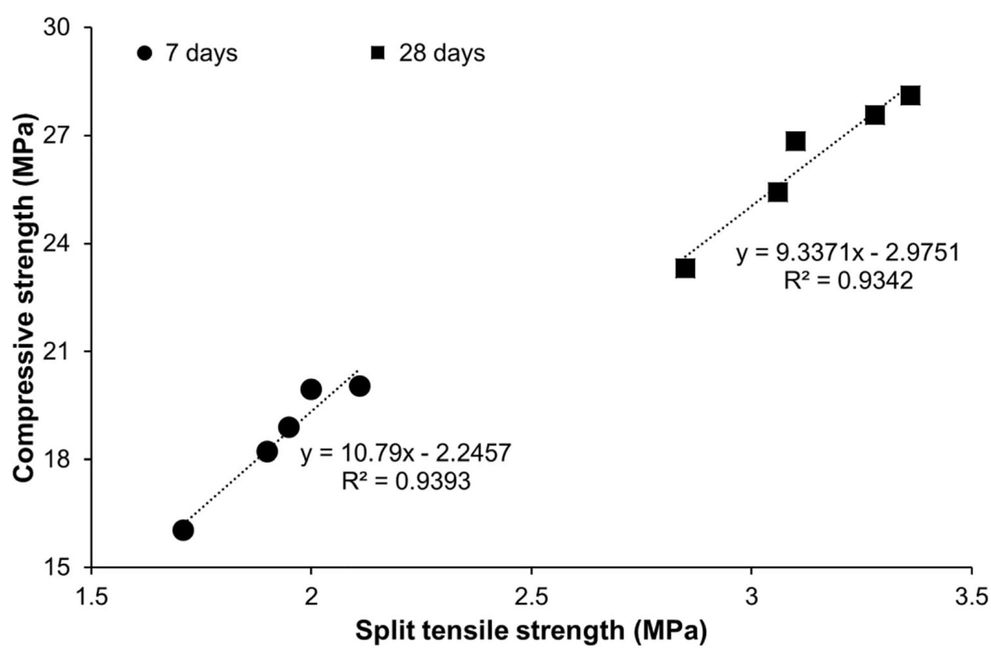

Fig. 4 Correlation between split tensile strength and compressive strength

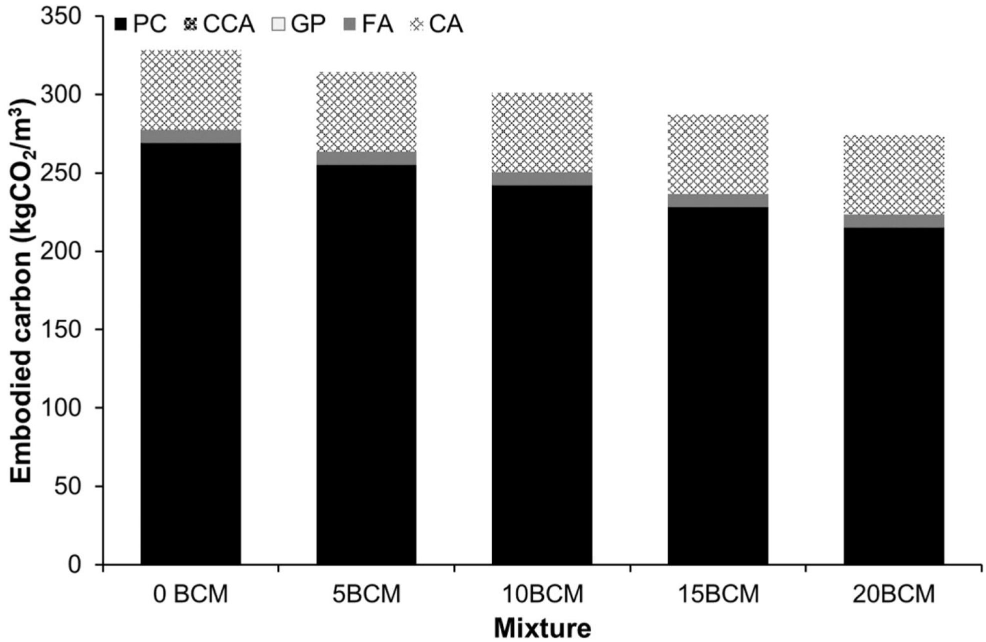

Fig. 5 Contributions of components in concrete to embodied carbon

days respectively. The increase in strength with age can be attributed to the continuous hydration reaction of PC and the pozzolanic reaction of the BCM with time which results in more product formation and densification of the microstructure. It can also be observed that the incorporation of BCM up to 10% replacement of the PC led to a slight increase in the split tensile strength. The split tensile strength of mixtures incorporating 5% and 10% BCM is 5.8% and 8.4% higher than the concrete mixture with no BCM. Similar to the compressive strength, it can be seen that a 10% replacement of the PC with BCM is optimum for the split tensile strength.

A correlation between the compressive strength and split tensile strength was made and presented in Fig. 4. It can be seen from Fig. 4 that there exists a strong correlation between the compressive strength and split tensile strength of the mixtures. These equations presented in Fig. 4 can be used to estimate either the compressive strength or the split tensile strength when the other parameter is known.

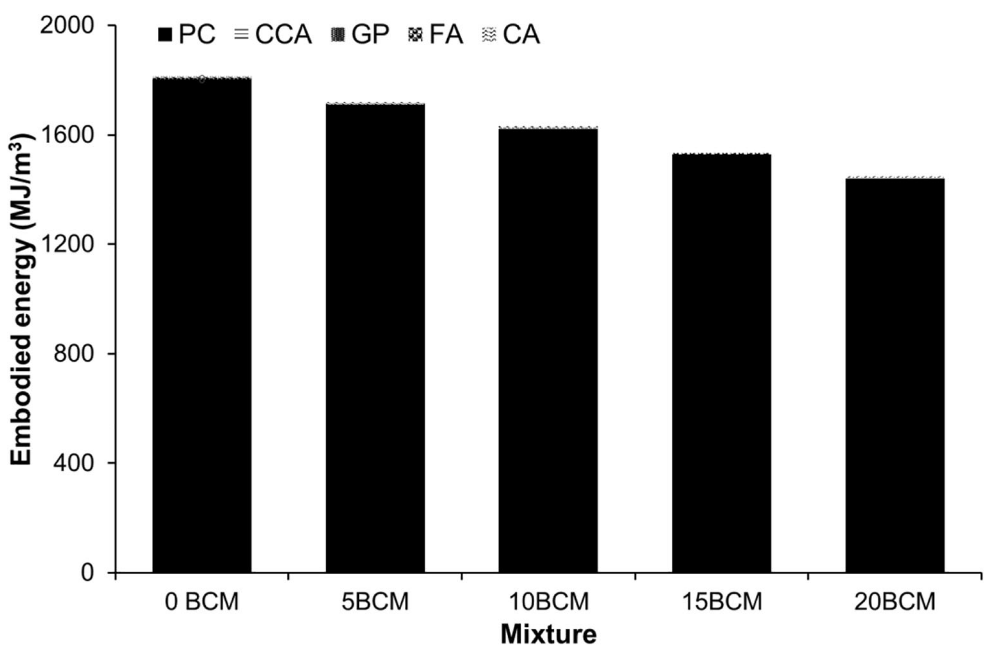

Fig. 6 Contributions of components in concrete to embodied energy

Table 5 Sustainability of concrete mixtures

Mixture	Embodied carbon ($kgCO_2/m^3$)	Embodied energy (MJ/m^3)
0BCM	328.3	1812.9
5BCM	314.1	1715.9
10BCM	300.7	1624.4
15BCM	286.6	1527.4
20BCM	273.2	1435.9

3.4 Sustainability Assessment

Based on the embodied carbon and energy of the concrete's components presented in Table 4, the embodied carbon and energy of each mixture was calculated and presented in Table 5. It can be seen from Table 5 that the use of BCM as partial replacement of the PC led to a significant reduction in the embodied carbon and energy of the concrete mixtures. The embodied carbon and energy of concrete mixtures incorporating 20% BCM as replacement of the PC is 16.8% and 20.7% lower than the mixture made with only PC as the binder. This improvement in the sustainability of the concrete mixtures with the incorporation of BCM indicates the sustainability and performance of concrete mixtures can be improved with the use of these waste materials as the binder in concrete.

Figures 5 and 6 show the individual contributions of the components in the concrete mixtures to the embodied carbon and embodied energy respectively. It can be seen from Fig. 5 that the majority of the carbon emission is from the PC followed by the coarse aggregate and fine aggregate. It can also be seen that the contribution of the BCM is not evident in the figure as their contribution is very low to the embodied carbon. The reduction in the carbon emissions of the concrete mixtures with a higher content of the BCM can be attributed to their lower embodied carbon compared to that of PC. The PC is responsible for most of the embodied energy in concrete as shown in Fig. 6. The other components are not visible in the figure as their contribution is very low in comparison to that of PC. Nevertheless, it can be seen that the replacement of the PC with BCM in the concrete mixtures also led to a reduction in the embodied energy. These results indicate that the sustainability of concrete mixtures can be improved by incorporating wastes material such as CCA and GP as components in concrete.

4 Conclusions

This study evaluated the effect of the binary blend of corn cob ash and glass powder as partial replacement of cement in concrete mixtures. The slump and mechanical performance of the resulting concrete mixtures were assessed. The sustainability of the mixtures in terms of embodied energy and carbon was also evaluated. Based on the results of this study, the following conclusions can be drawn:

1 The use of waste products such as glass powder and corn cob ash in concrete is an effective way to manage the wastes while creating a source of cementitious materials for concrete mixtures.
2 The incorporation of BCM into concrete results in a reduction in the slump of concrete mixtures. In cases where high slump is required, high range water reducers can be used to achieve workability in order to conserve the mechanical properties.
3 The use of 10% BCM was found to be optimum for the mechanical properties. The compressive strength and split tensile strength of mixtures incorporating 10% BCM as replacement of Portland cement was increased by 8.4% and 4.9% respectively. Nonetheless, the use of BCM as a replacement of Portland cement up to 20% does not result in any significant detrimental effects on the mechanical properties.
4 The use of BCM in concrete mixtures can be used to improve their sustainability. Concrete mixtures incorporating 5%, 10%, 15% and 20% BCM as partial replacement of Portland cement have 4.3%, 8.3%, 12.7% and 16.8% lower embodied carbon control to the mixtures without BCM. Similarly, the incorporation of BCM into the mixtures led to a reduction of approximately 21% in the embodied energy of the concrete.

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