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Green concrete production with waste materials as cement substitution: A literature review

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Abstract

In terms of sustainability, using waste material as a cement substitute in concrete has become a global trend. This review article focused on studies that were performed to investigate the effect of some waste materials including eggshell powder (ESP), ceramic waste powder (CWP), rice husk ash (RHA) and corn cob ash (CCA) as cement substitutes on the strength properties of the concrete mixture. The main purpose of this paper is to draw attention to the fact that the use of these waste materials mentioned above as cement substitutes is an environmentally friendly way that prevents their possible harmful effects on both the ecosystem and human beings. In addition, it is aimed to show that cement production, which causes greenhouse gas emissions, which is one of the major causes of global warming, can be reduced as a result of using waste materials as cement substitute material.

1. Introduction

Concrete is the most used construction material in nearly all civil engineering projects due to its versatility and availability around the world [1]. Having a such wide usage area, concrete's sustainability is a major topic of interest in societies. The term sustainability is crucial for societies as it helps to preserve the ecosystem, improve our quality of life, enhance the well-being of societies and prevent the excessive depletion of natural resources [2]. The sustainability of concrete is ensured by its components, primarily cement, and cement, which is the main component of concrete, both affect the cost of concrete and pose a threat to the environment as it releases a significant amount of CO_2 greenhouse gas in its production. For this reason, the construction industry is faced with some challenges in bringing sustainability to production processes, especially cement. This can be achieved by seeking new more environmentally friendly raw materials and products that contribute to the minimization of greenhouse gases released into the environment. In this context, waste from other industrial activities can be a good solution for this purpose [3-6].

Increasing industrialization along with population growth and urbanization produces copious amounts of waste. It is claimed that around 2 billion tons of waste are produced annually all over the world, and it is estimated that by 2050, 3.4 billion tons of waste will be produced annually worldwide [7]. About 62% of these wastes are not handled properly, which causes pollution of the environment and global warming, and threats to public health [8]. An effective way that has emerged is to recycle these wastes. [9]. Recently, the interest in the use of waste materials in the construction industry, especially in concrete production, as a cement substitute has been increasing and remarkable results have been obtained [10]. This review focused on studies performed on the usability of some wastes as cement replacement in the production of green and sustainable concrete. Waste materials such as eggshell powder (ESP), ceramic waste powder (CWP), rice husk ash (RHA), and corn cob ash (CCA) have been subject to this review study. In this regard, the current studies performed about this concern were reviewed and their results on the strength properties of concrete mixtures were submitted comprehensively.

In addition, one of the main purposes of this study is to raise awareness of sustainable waste management in the construction sector and to shed light on researchers and sector representatives on this way.

2. Eggshell powder (ESP)

2.1. Physical and Chemical Properties of ESP

Eggshell is a bio-waste material that emerged from bakers, fast-food restaurants and poultry farms. The food industry produces enormous amounts of eggshells every year, and improper disposal of this waste into the environment causes health problems and environmental pollution due to the release of toxic gases [11]. Bashir et al. [12] stated that eggshell is one of the most environmental problems. There is an urgent need for a way to use eggshells to prevent their harmful effects on the environment and public health. The eggshell is made up of calcium and so it can be used as partial cement replacement material in concrete [13]. The use of eggshell powder as a cement substitute material in concrete is a good way in terms of sustainability. Before using eggshells as a cement replacement material, the cleaning process should be applied to remove the organic wastes from their surface. After the cleaning phase, the eggshell is dried with a help of sunshine or an electrical oven to make grinding easier [14,15]. The physical and chemical properties of eggshells differ based on the sources of the egg. Its specific gravity ranges from 0.85 to 2.66 and is lower than that of cement which has a specific gravity of 3.13 to 3.24 [12,16,17]. ESP mainly consists of $CaCO_3$ and the main oxide of ESP is CaO which reaches 99.8 % by weight [18]. The visual appearance of eggshell and ESP are presented in Figure 1.

Figure 1. Eggshell and Eggshell Powder [19]

2.2. Strength properties of concrete containing ESP as cement replacement

Yerremala [20] replaced cement with ESP in proportions of 0%, 5%, 10% and 15% and investigated compressive and splitting tensile strength changes of concrete mixtures. The water to cement ratio was 0.6 and constant for all mixtures. The concrete specimens were exposed to water curing and the mechanical tests were conducted at 1, 7 and 28 days. From test results, the author state that the strength increased with the curing age for all concretes. When comparing the 1-day strength of concretes, they were nearly the same and comparable to each other. For 7 days, the strength of 5% ESP concrete passed the control concrete. At the end of 28 days of curing, the compressive strength of mixtures was shaped as 22.3, 24, 18.9 and 16.1 MPa for control concrete, 5% ESP, 10% ESP and 15% concrete respectively. It was observed that the concrete with 5% eggshell powder gave the highest compressive strength compared with control concrete. Further increase in ESP content resulted in a decrease in compressive strength. For splitting tensile strength, control concrete and 5% ESP concrete showed the same tensile strength as 2.4 MPa at 28 days. When ESP content reached 10%, the decrease is approximately 4% and nearly negligible. However, 15% introduction of ESP resulted in a 33% decrease in splitting tensile strength of concrete when compared with control concrete.

Kumar et al. [21] analyzed experimentally the effect of cement replacement with ESP on the strength properties of concretes. In this context, the cement was replaced with ESP in levels of 0%, 5%, 10% and 15% by weight. To determine this effect, the mechanical strength test including compressive, flexural and splitting tensile strength was conducted at 7 and 28 days. The compressive strength results of concrete specimens were 17.15, 18.01, 17.83 and 17.61 MPa for concrete mixtures of control, E5%, E10% and E15% respectively. This value increased to 31.52, 35.21, 34.45 and 31.50 MPa respectively at 28 days of curing. From the compressive strength test result, it was concluded that the ESP introduced to concrete enhanced the resistance of the mixture against compression, and the highest compressive strength was obtained with 5% ESP. In the flexural strength test, all ESP incorporated concretes showed better performance compared to control concrete. 5% ESPs flexural strength was higher than control concrete by 5.28% and 6.70% at 7 and 28 days of curing. These values were 6.19 and 2.61, 6.70 and 1.56

for concretes E10% and E15% at 7 and 28 days respectively. Splitting tensile strength of mixtures of control and 5% ESP concrete was nearly the same as 2.11 and 2.12 MPa respectively at 7 days. At 28 days test, a slight difference was obtained as 3.14 and 3.23 MPa for control concrete and 5% ESP concrete respectively. The strength values were 1.89 and 2.56 MPa, 1.65 and 2.31 MPa for concretes 10% and 15% ESP at 7 days and 28 days respectively. When analyzing whole mechanical strength test results, the 5% replacement of cement with ESP comes into view as the optimum percentage to achieve enhanced strength performance compared with control concrete.

Waidya and Bastwadkar [13] made an experimental study of partial replacement of cement with ESP in concrete. In their study, ESP was replaced with cement at 5% intervals from 0% to 20%. After curing specimens, the specimens were subjected to compressive, flexural and splitting tensile strength tests at 7, 14 and 28 days. They reported from experimental analyses that the compressive, flexural and splitting tensile strength increased by 7.15%, 11.62% and 3.5% with the introduction of 10% ESP instead of cement.

Arif et al. [22] conducted a study to analyze the strength performances of concrete mixtures by replacing cement at levels of 0-15% with a 5% increment. The specimens were exposed to water curing for 7 and 28 days and the compressive strength of each mixture was tested. The results of the test were summarized in Figure 2 as shown.

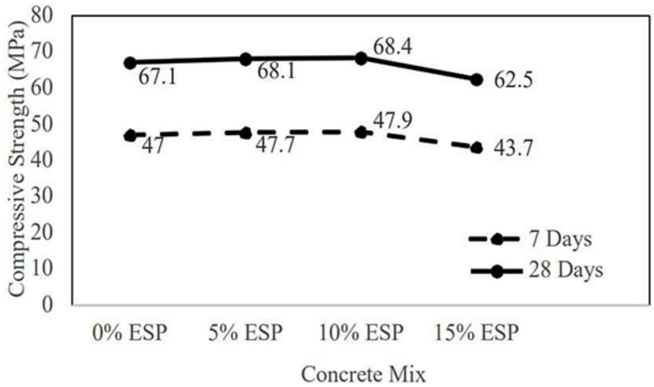

Figure 2. Compressive strength of concrete incorporating ESP [22]

Jhatial [23] performed an experimental study to reduce cement content in concrete by replacing it in ratios of 5%, 10% and 15% by weights. They stated that it was possible to achieve higher strength than control concrete by partial replacement of cement with ESP, and the optimum substitution ratio was declared as 10%. Some studies performed to investigate the effect of cement replacement with ESP were summarized in Table 1.

Table 1. Strength of concrete mixtures containing ESP at 28 days of water curing

Reference	Mix ID	ESP, %	Binder, %	CS (MPa)	FS (MPa)	ST (MPa)
[24]	NC	0	100	52.43		
	E5	5	95	61.25		
	E10	10	90	49.33		
	E15	15	85	44.65		
[25]	CS	0	100	36.50	5.90	
	E10	10	90	37.00	8.10	
	E20	20	80	30.60	6.60	
[26]	C-0	0	100	24.20		2.20
	C-1	6	94	25.00		2.48
	C-2	12	88	27.30		2.10
	C-3	18	82	26.00		1.83
	C-4	24	76	24.80		1.76
[27]	RPC	0	100	26.90	4.30	
	PCF1E5	5	95	26.60	4.28	
	PCF1E10	10	90	25.70	4.14	
	PCF1E15	15	85	24.90	3.98	
	PCF1E20	20	80	23.80	3.80	
[28]	M1	0	100	20.26	4.35	3.34
	M2	2.5	97.5	24.49	4.96	3.47
	M3	5	95	27.38	5.06	4.26
	M4	7.5	92.5	25.53	4.92	3.84
	M5	10	90	24.70	4.82	3.98

***Note: CS** is Compressive Strength, **FS** is Flexural Strength, **ST** is Splitting Tensile Strength*

3. Ceramic waste powder (CWP)

3. 1. Physical and chemical properties of CWP

Ceramic wastes are generated from the ceramic tiles industry and construction sites during the packing and labor process in tremendous amounts yearly [29]. It is estimated that the CWP that is produced globally during the final polishing process of ceramic tiles surpassed 22 billion tons [30]. These wastes are disposed of in landfills and pose a threat to both human health and the environment by causing soil, water and air pollution. There is a need to evaluate this waste in the concern of sustainability, and using it in concrete as cement replacement material is a beneficial way to create a positive environmental impact, reduce the greenhouse effect of cement, and support the sustainability of construction materials [31]. The specific gravity of CWP changes between 2.30 and 2.85. The major oxides of CWP detected with chemical analysis are SiO_2 which constitutes approx. 60-80% of it [32,33]. The other oxides that follow SiO_2 are AI_2O_3 and Fe_2O_3 respectively. The presence of SiO_2, AI_2O_3 and Fe_2O_3 in a noteworthy amount in CWP composition makes it usable as cement replacement material. The visual appearance of ceramic waste and CWP are presented in Figure 3.

Figure 3. Ceramic waste and CWP [34]

3.2. Strength properties of concrete containing CWP as cement replacement

Manigandan and Saravanakumar [33] carried out an experimental study to look into the effect of partial cement replacement with CWP at levels of 10%, 20% and 30% by weight. They produced concrete mixtures, cured in water at 7, 14 and 28 days and tested for compressive strength to compare with the control concrete result. The compressive strength of control concrete was 38.2, 43.3 and 46.6 MPa on 7, 14 and 28 days of curing respectively. These values decreased to 32.4, 36.2 and 40.1 MPa for 7, 14 and 28 days respectively when cement was replaced with CWP in the proportion of 10%. When the replacement was 20% and 30%, the compressive strength was 26.4, 27.13 and 28 MPa for the 20% replacement ratio and 21.5, 23.5 and 24 MPa for the 30% replacement ratio for 7, 14 and 28 days curing respectively.

Bhargav et al. [35] aimed to evaluate the CWP as cement replacement in the concrete to improve the strength properties of mixtures. In this context, cement was substituted with CWP in various ratios ranging from 0% to 20% with an increment of 5%. Each concrete's compressive strength was evaluated at the end of 7, 14 and 28 days of water curing and compared with control concrete. The compressive strength of concretes containing CWP was higher than control concrete for all curing days. The compressive strength increased by 2.75%, 7.05%, 10.89% and 4.40% for ratios of 5% ,10% ,15% and 20% respectively at 28 days.

In another study, El-Dieb et al. [31] conducted a research study to analyze the CWP content effect on the compressive resistance of concrete specimens. The authors reported that the compressive strength increased with the introduction of 20% of CWP. However, when surpassing this ratio, resulted in a decrease in the compressive resistance of concrete specimens. Kannan et al. [36] produced high-strength concrete mixtures by replacing cement in proportions ranging from 10 to 40% with a 10% increment. The authors reported from the experimental analyses that the concrete mixtures containing CWP in large quantities could show high compressive resistance as shown in Figure 4.

Lasseuguette [37] made an experimental analysis to measure the change in compressive strength when cement was partially replaced with CWP at a level of 15%. The compressive strength of concrete mixtures was tested on 7, 28 and 56 days, and results were compared with control concrete. The author indicated that the concrete containing CWP showed higher resistance than control concrete on all test days.

Karthika et al. [38] focused on their study to investigate the effect of cement replacement with CWP ranging from 10% to 40% with a 10% increment on the strength properties of concrete mixtures. They noted that the compressive, flexural and splitting tensile strength increased when cement was replaced with CWP up to a level of 30%. The optimum strength values in their study were obtained at a 30% substitute ratio as 42.15 MPa, 5.50 MPa and 3.85 MPa at 28 days for compressive, flexural and splitting tensile stress respectively.

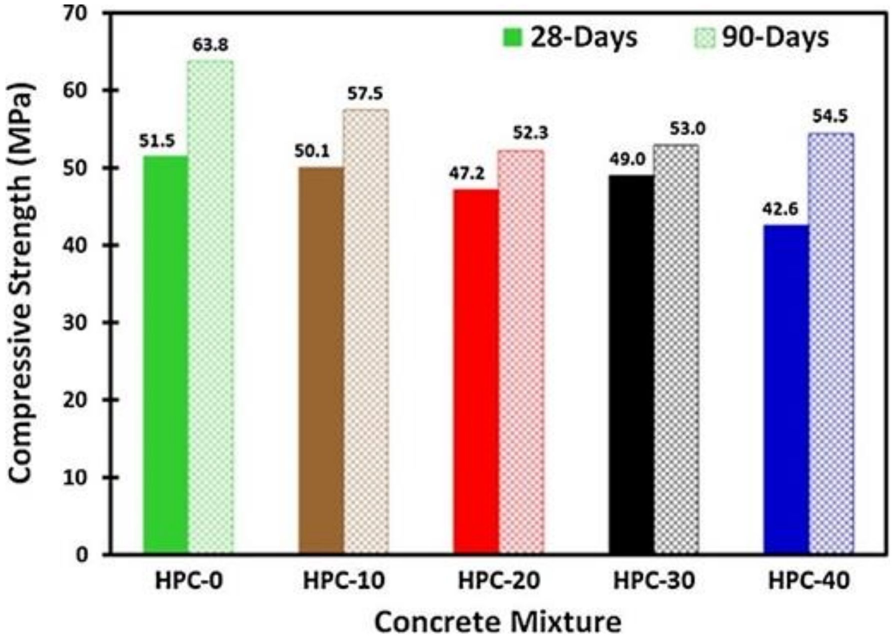

Figure 4. Compressive strength of concrete incorporating CWP [36]

Some studies conducted to investigate the effect of cement replacement with CWP were summarized in Table 2.

Table 2. Strength of concrete mixtures containing CWP at 28 days of water curing

Reference	Mix ID	CWP, %	Binder, %	CS (MPa)	FS (MPa)	ST (MPa)
[39]	0%	0	100	35.11		
	5%	5	95	35.89		
	10%	10	90	37.29		
	15%	15	85	38.34		
	20%	20	80	32.34		
[40]	1	0	100	34.10	5.44	4.38
	2	5	95	35.70	5.51	4.44
	3	10	90	36.40	5.77	4.56
	4	15	85	38.56	5.89	4.61
	5	20	80	33.80	5.38	4.33
	6	25	75	30.60	5.21	4.03
	7	30	70	28.74	5.13	3.73
[41]	Control	0	100	30.00		
	A1	15	85	28.90		
	A2	30	70	27.50		
	A3	35	65	23.50		
	A4	40	60	18.00		
	A5	45	55	16.00		
[42]	1	0	100	50.81		
	2	10	90	56.29		
	4	30	70	40.43		
	5	40	60	39.84		
	6	50	50	30.81		
[43]	1	0	100	38.46		3.10
	2	5	95	37.28		2.92
	3	10	90	37.92		3.12
	4	15	85	38.98		3.42
	5	20	80	36.35		2.78
	6	25	75	36.12		2.66
	7	30	70	35.09		2.52

***Note: CS** is Compressive Strength, **FS** is Flexural Strength, **ST** is Splitting Tensile Strength*

4. Rice Husk Ash (RHA)

4.1. Physical and chemical properties of RHA

Rice husk, which is the outer layer covering the rice grains, is a waste produced from the rice mill process. This is generally thrown away at the landfill without further use, thus, resulting in environmental pollution. It is obtained roughly 200 kg per ton of rice. Rice husk ash is a by-product and obtained by burning rice husk under controlled temperature. And has been taken advantage of in cement replacement materials to form sustainable concrete for years because of its high pozzolanic reactivity [44,45]. It owes its cementitious property to mainly high amorphous content [46]. The specific gravity of RHA generally changes from 2.06 to 2.11 [47,48]. From chemical analyses, the main oxides of RHA were determined as SiO_2 which ranges between 75% to 95% by weight [49-51]. The other oxides that follow the SiO_2 by weight are Al_2O_3 and Fe_2O_3 respectively [52-54]. A visual view of the rice husk and RHA is presented in Figure 5.

Figure 5. Rice Husk and RHA [55]

4.2. Strength properties of concrete containing RHA as cement replacement

Kartini et al. [56] performed a study to evaluate RHA as a cement substitute for producing green concrete. In experimental analyses, six replacement ratios as 0%, 10%, 20%, 30%, 40% and 50% were taken into consideration and compressive strength tests were applied to the mixtures at 28, 60 and 90 days of curing. In this context, two strength classes were targeted as 60 MPa and 70MPa. For the class of 60 MPa, the control concrete attained 73 MPa at 28 days, while 10% RHA concrete attained 68 MPa. When the curing period was prolonged up to 90 days, the compressive strength of the mixture increased. The concrete mixtures containing RHA at levels of 20%, 30%, 40% and 50% showed compressive strength less than 60 MPa at 28 days. For the grade of 70 MPa concrete mixtures, the control concrete gave the compressive strength of 74.4, 77.9 and 82.9 MPa for 28, 60 and 90 days of curing. For 10% RHA concrete, these values decreased by 3%, 5% and 8% for 28, 60 and 90 days. Then for 20% RHA concrete, compressive strength values were lower than control concrete by 19%, 21% and 25% for days 28, 60 and 90 respectively. Further increasing of replacement ratios gave lower strength compared to control concrete. The 30% RHA concrete showed less compressive resistance and the strength values showed a reduction of about 30%, 33% and 36% respectively for 28, 60 and 90 days. For 40% RHA concrete's compressive strength was lower than control concrete approximately 43%, 45% and 47% at 28, 60 and 90 days. The decrease in compressive strength continued with 50% replacement of cement with RHA and the 28, 60 and 90 days of compressive strength was lower at about 51%, 53% and 56% than control concrete respectively.

Takhelmayum [57] aimed to investigate the effect of RHA incorporation into the concrete on the strength properties. In this context, cement was replaced RHA in ratios varies 5 to 30% with an increment of 5%. The specimens were tested at 7 and 28 days and results showed that 10% and 15% RHA concrete gave higher compressive strength compared to control concrete. Zaid et al. [58] performed a study to detect the effect of RHA on the compressive and splitting tensile strength of concrete mixtures at 7 and 28 days. In this manner, the cement was replaced with RHA in levels of 5 to 20% with an increment of 5%. The test results showed a steady reduction obtained with increasing content of RHA for both tests.

Saand et al. [59] conducted research to produce aerated concrete by replacing cement in ratios ranging from 0 to 15 with an increment of 2.5%. The test results demonstrated that the optimum replacement ratio was 10%. At this ratio, the compressive strength increased by 22.22% when compared with control concrete. Zareei and Ahmadi [44] studied to evaluate rice husk ash as cement substitute material in high strength concrete in ratios ranging from 5 to 25% with an increment of 5%. The specimens were tested at the end of 7 and 28 days. The compressive strength of control concrete was 50.84 and 83.36 MPa for 7 and 28 days respectively. The strength values of control concrete increased by about 2.12% and 2.11% for 7 and 28 days when RHA was incorporated into concrete for 5%. This increase was shaped as 4.25% and 4.24% for 10% RHA concrete. The increase in compressive strength continued with RHA replacement in ratios of 15% and 20% and the strength increased by 10.99% and 10.97%, 11.47% and 11.90% for 7 and 28 days for 15% RHA and 20% RHA concrete respectively. After the 20% replacement ratio, the compressive strength decreased but still was higher than control concrete approximately 6.90% and 6.88% for 7 and 28 days as shown in Figure 6.

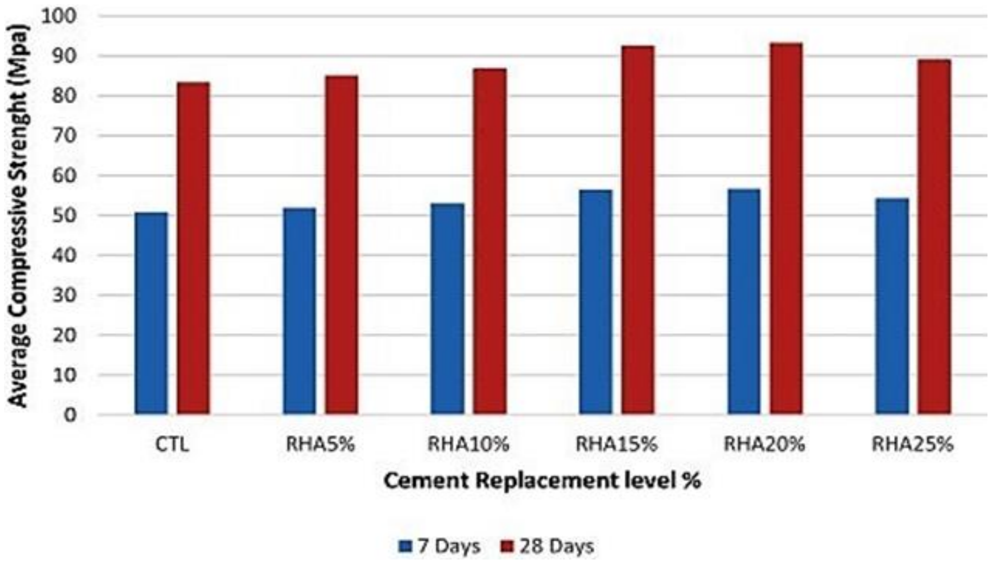

Figure 6. Compressive strength of concrete incorporating RHA [44]

Some studies carried out to investigate the effect of cement replacement with RHA were summarized and given in Table 3.

Table 3. Strength of concrete mixtures containing RHA at 28 days of water curing

Reference	Mix ID	RHA, %	Binder, %	CS (MPa)	FS (MPa)	ST (MPa)
[45]	0%	0	100	27.47		
	10%	10	90	25.80		
	20%	20	80	22.73		
	30%	30	70	19.60		
[60]	0%	0	100	27.75		1.53
	5%	5	95	30.86		1.65
	10%	10	90	31.72		1.68
	15%	15	85	32.78		1.70
	20%	20	80	32.00		0.96
	25%	25	75	28.80		0.78
[61]	0%	0	100	27.00	2.11	2.28
	5%	5	95	24.80	2.53	2.36
	10%	10	90	29.30	1.94	2.52
	15%	15	85	17.60	-	2.11
	20%	20	80	16.03	-	1.97
[62]	0%	0	100	48.12		
	5%	5	95	36.76		
	10%	10	90	33.79		
	15%	15	85	25.47		
	25%	25	75	17.32		
[63]	Control	0	100	25.72		
	RHA10%	10	90	22.28		
	RHA15%	15	85	25.12		
	RHA20%	20	80	24.43		

***Note: CS** is Compressive Strength, **FS** is Flexural Strength, **ST** is Splitting Tensile Strength.*

5. Corn Cob Ash (CCA)

5.1. Physical and chemical properties of CCA

The corn cob, which is an agricultural waste product obtained from maize, is the remainder of the corn cob after the corn kernels have been peeled and constitute about 75-85% of the corn cob's weight. Corn cob is burnt in a furnace at approximately 650˚C to take its ash form. Corn cob ash (CCA) is can be used as cement supplementary material to produce green and sustainable concrete [64, 65]. The specific gravity of CCA is ranging from 1.95 to 2.55 [66,67]. The main component of CCA is SiO_2 which constitutes 60-80% of it by weight obtained from chemical analyses [68,69]. The other oxides that follow the SiO_2 are Al_2O_3 and Fe_2O_3. The abundant oxides of SiO_2, Al_2O_3 and Fe_2O_3 in the composition of CCA affect the pozzolanic characteristics namely the cementitious properties of CCA and enable to use it as a cement substitute material. Using CCA in concrete to minimize the usage of cement is a beneficial way to protect the environment and human health [70,71]. The visual appearance of corn cob and CCA are presented in Figure 7.

Figure 7. Corn Cob and CCA [72]

5.2. Strength properties of concrete containing CCA as cement replacement

Adebisi et al. [64] performed a study by using CCA as partial cement replacement materials to produce green and sustainable concrete. In this manner, the cement was replaced with CCA at levels of 0%, 5%, 10%, 20% and 30%. Compressive strength tests were applied to specimens at ages 28, 56, 90 and 120 days. From the test results, they observed that the compressive strength of concrete mixtures decreased at all curing ages with increasing CCA content. At 28 days of curing, the compressive strength of mixtures of 5%, 10%, 20% and 30% were lower than control concrete by 7.28%, 14.94%, 22.99% and 42.91% respectively. These values were 13.14%, 24.23%, 28.35% and 49.74% at age of 120 days.

Tiza [73] conducted a study on the usability of CCA as a partial cement replacement material in the production of concrete. In this context, CCA was replaced with cement in proportions of 0%, 5%, 10%, 15%, 20%, and 25%. The compressive strength of concrete obtained from cube specimens at the end of the 28 days of water curing decreased by 5.05% for 5% CCA, 13.49% for 10% CCA, 23.03% for 15% CCA, 33.12% for 20% CCA concrete mixtures. The reduction in flexural tensile strength also at the end of the 28-day water curing was 7.51% for 5% CCA, 20.48% for 10% CCA, 27.52% for 15% CCA, 39.20% for 20% CCA and 46.99% for 25% CCA concrete mixtures.

Singh et al. [74] studied the effect of cement replacement with CCA on the compressive strength of concrete. Five concrete mixtures were produced by replacing cement at levels of 0%, 5%, 10%, 15% and 20%. The authors tested the compressive strength of concrete mixtures at 28 days of room temperature curing. The compressive strength of the control concrete was 36.43 MPa. The strength of concrete decreased to 32.47 MPa when incorporating CCA by 10% of cement. The more CCA content resulted in more decrease in compressive strength. When replacing cement with CCA at levels of 15% and 20%, the strength of control concrete decreased from 36.43 MPa to 23.07 and 20.15 MPa for a mixture of 15% and 20% respectively.

Bala et al. [75] investigated the compressive strength changes of concretes when replacing cement with CCA in ratios ranging from 3 % to 12% with an increment of 3%. The compressive strength of concrete mixtures was tested at the age of 7, 14, 21 and 28 days, and it increased with prolonged age for all mixtures. However, it decreased compared to control concrete when CCA was incorporated as shown in Figure 8.

Adesanya and Raheem [76] tested the effect of cement replacement with CCA in proportions of 0%, 2%, 4%, 6%, 8%, 10%, 15%, 20% and 25% by weight. They concluded that the optimum content for strength improvement emerged as 8%.

Some studies made to investigate the effect of cement replacement with CCA were summarized and presented in Table 4.

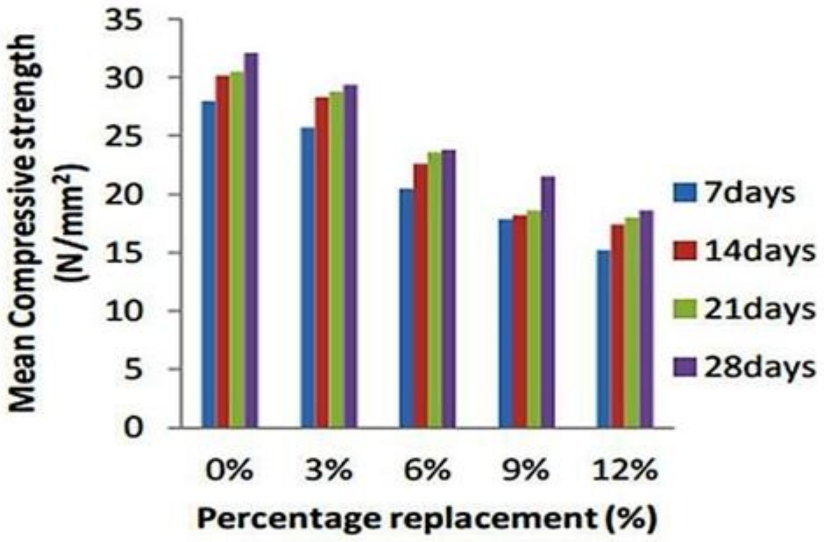

Figure 8. Compressive strength of concrete incorporating CCA [75]

Table 4. Strength of concrete mixtures containing CCA at 28 days of water curing

Reference	Mix ID	CCA, %	Binder, %	CS (MPa)	FS (MPa)	ST (MPa)
[77]	0%	0	100	24.69		2.01
	10%	10	90	20.00		1.72
	20%	20	80	13.78		1..15
[78]	Control	0	100	61.60	3.60	
	5%	5	95	49.00	3.50	
	7.5%	7.5	92.5	51.30	2.30	
	10%	10	90	37.90	2.80	
	15%	15	85	34.30	1.30	
	20%	20	80	23.50	2.10	
	25%	25	75	18.90	1.60	
	30%	30	70	19.30	2.20	
[79]	0%	0	100	17.78		
	10%	10	90	17.70		
	20%	20	80	17.11		
	30%	30	70	18.44		
[80]	0%	0	100	24.04	4.75	4.06
	10%	10	90	22.68	4.68	4.29
	20%	20	80	21.85	4.51	3.84
	30%	30	70	20.87	4.19	3.51
[81]	CS	0	100	29.33	13.77	6.30
	CCA 5	5	95	28.40	12.88	5.65
	CCA 10	10	90	26.22	11.55	5.09
	CCA 15	15	85	22.60	9.77	4.10

***Note: CS** is Compressive Strength, **FS** is Flexural Strength, **ST** is Splitting Tensile Strength.*

6. Conclusion

This review study focused on prior studies that were performed to investigate the effects of ESP, CWP, RHA and CCA replacement with cement on the strength properties of concrete mixtures. And with this study, it is aimed to raise awareness about green and sustainable concrete production among both researchers and concrete industry representatives. The accumulation of these waste materials in landfills causes toxic gases and poses a threat to the environment and public health. Therefore, the use of these wastes as cement substitutes is a useful way to reduce environmental pollution and protect the health of living things. In addition, minimizing the use of cement in concrete production is an effective way to reduce greenhouse gas emissions to the ecosystem, where cement production is a major threat in terms of triggering global warming. The following can be deduced from this article;

1. ESP can be used as a cement replacement up to a level of 10% to improve the strength properties of concrete.

2. CWP can be utilized as a cement substitute up to a level of 10% to enhance the mechanical strength of the concrete mixture.

3. RHA generally decreased the strength of concrete mixtures when replaced with cement. But, up to a level of 5% substitution is applicable when compared with control concrete.

4. CCA's replacement with cement has a negative effect on the strength properties of concrete. However, the replacement ratio of 5% is feasible to produce green and sustainable concrete.

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Author contributions

Muhammed Tanyıldızı: Conceptualization, Methodology, Software, Investigation, Validation, Writing-Reviewing and Editing, Visualization **Erden Ozan Karaca:** Data curation, Writing-Original draft preparation, Software, Validation.

Conflicts of interest

The authors declare no conflicts of interest.

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