Effect of Using Agricultural Waste as a Cement Replacement on Fresh and Hardened Concrete Properties

khaled. M. Osman[1], Magdy. A. ALyamany[2], Adel. Abd EL Tawab[3], and Asmaa Thabet[4]

[1]Assistant Professor, Dep.of Civil Engineering, Faculty of Engineering, Fayoum University, Fayoum, Egypt
[2]Professor of structural Eng, Dep. of Civil Engineering, Faculty of Engineering, Fayoum University, Fayoum, Egypt
[3]Assistant Professor, Dep. of Essential Science, Future High Institute for Engineering &Technology, Fayoum, Egypt
[4]Post-graduate student, Dep. of Civil Engineering, Faculty of Engineering, Fayoum University, Fayoum,Egypt

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Abstract - *Concrete plays an important role as a construction material in most of infrastructure projects because of its low cost and ease of manufacture. Plain concrete possesses a very low tensile strength, limited ductility and little resistance to cracking. This study investigated effect of using agricultural waste as a cement replacement on fresh and hardened concrete properties. Two type of agricultural waste used were date palm ash **(DPA)** and corn cob ash **(CCA)**. Four classes of cement replacement 6%, 8%, 10% and 12% with **DPA** and **CCA** are used. Proportions of mixes determined using **ACI 318-2019** recommendations. Cubes have a dimension of 100*100*100 mm were chosen to study compressive strength of concrete. Beams have a dimension of 100*100*500 mm were chosen to study flexural strength of concrete. The tested samples were curing in pure water. The concrete cubes and beams were tested at the curing ages of 28, 60 and 90 days. Slump and compacting factor tests were carried out to check the effect of cement replacement with **DPA** and **CCA** on consistency and workability of concrete. From results, it was observed that the slump and compacting factor decreased with increasing amount of **DPA** and **CCA**. Replacement of **8% DPA** has increased compressive strength and flexural strength. While, replacement of **6% CCA** has increased compressive strength and flexural strength.*

Key Words: Concrete, Date palm ash (**DPA**), Corn cob ash (**CCA**), Slump, Compacting factor, Compressive strength, Flexural strength.

1. INTRODUCTION

Concrete is widely used around the globe due to its useful mechanical and durability properties. It was reported in a research that 500 billion cubic yards or more concrete is produced annually that requires a huge amount of cement and other raw materials. Portland cement is a most common binder for production of traditional concrete. The cement industry is a second largest source of carbon dioxide emission (5–7% of global CO2 emission) into the environment with the roughly one-ton emission of carbon dioxide for each ton production of cement **[1–3]**.The expected rise in the global production of cement is 4.83 billion metric tons (2030) from 3.27 billion metric tons (2010) **[4]**. The process of cement production is highly energy consuming and most importantly it causes excessive emission of greenhouse gasses (GHG) to the environment **[5]**. The search for alternative binder or cement replacement materials led to the discovery of the potentials of using industrial by products and agricultural wastes as a cementitious material. If these fillers have pozzolanic properties, they impart technical advantages to the resulting concrete and also enable larger quantities of cement replacement to be achieved **[6]**. To improve the durability of concrete, many additives are used. These additives also decrease the cost of cement **[7–12]**. Several researches **[13–15]** proved that utilization of ash-based cementitious material are not only environment friendly but it also showed more or less same or better characteristics as compared to ordinary Portland cement concrete. For instance, found a research **[13]** studied the effect of POFA replacement (0–25%) and oil palm shell (OPS) on fresh and mechanical properties of lightweight concrete. They reported highest workability and compressive strength of concretes prepared with 10% POFA due to packing effect and pozzolanic reactivity, contrary, there was reduction in the pulse velocity, split tensile strength, flexural strength and modulus of elasticity due to the weak interfacial zone between the POFA particles. In terms of durability, Mujah **[14]** evaluated the chloride ion penetration in grounded POFA based grout obtained from fruit bunches and kernels at replacement level of 0–40%. They found reduction of about 30% and 60% in charges passed in these grouts, respectively due to the filler effect. Walid Al-Kutti, Saiful Islam and Muhammad Nasir **[16]** discussed Potential use of date palm ash in cement-based materials. This paper presented an experimental investigation on the mechanical, durability and microstructural performance of date palm ash (PA) with varying dosage. Mortar and concrete specimens were cast at 10%, 20% and 30% replacement of ordinary Portland cement (OPC). Replacement of 10% PA has increased compressive strength up to 360 days than conventional 100% OPC concrete. And the regression model successfully predicts

the compressive strength of each mixture up to 360 days. Corn cob is the agricultural waste product obtained from maize or corn, which is the most important cereal crop in sub-Saharan Africa. According to Food and Agriculture

Organisation (FAO) data, 589 million tons of maize were produced worldwide in the year 2000 **[17]**. The United States was the largest maize producer having 43% of world production. Africa produced 7% of the world's maize **[18]**. Nigeria was the second largest producer of maize in Africa in the year 2001 with 4.62 million ton. South Africa has the highest production of 8.04 million ton **[17]**. Adesanya and Raheem **[19]** determined the workability and compressive strength characteristics of corn cob ash blended cement concrete. Nine classes of CCA-blended cements were employed with the CCA content ranging from 0% to 25%. The 0% CCA replacement involved the use of normal ordinary Portland cement and it served as the control. The mix proportions of cement: sand: granite used were 1:1½:3, 1:2:4 and 1:3:6 with 0.5, 0.6 and 0.7 water to cement ratios, respectively. The concrete cubes were tested at the curing ages of 3, 7, 28, 60, 120, and 180 days. Slump and compacting factor tests were carried out to check the effect of CCA on the workability of concrete. The results showed that the concrete slump and compacting factor decreased as the CCA content increased indicating that concrete becomes less workable (stiff) as the CCA percentage increases. The compressive strength of CCA blended cement concrete was lower than the control at early ages, but improves significantly, and outperforms the control at later ages (120 days and above). The optimum compressive strength of 57.10 N/mm^2, 40.30 N/mm^2 and 28.07 N/mm^2 for 1:1½:3, 1:2:4 and 1:3:6 mix proportions, respectively at 180 days were obtained at 8% CCA replacement level. It was concluded that only up to 8% CCA substitution is adequate where the blended cement is to be used for structural concrete. The concrete slump and compacting factor decrease as the CCA content increases. There are other types of agricultural waste such as bagasse Ash (BA) and rice husk ash (RHA). Nuntachai Chusilp, Chai Jaturapitakkul and Kraiwood Kiattikomol **[20]** published a paper proposing effects of LOI of ground bagasse ash on the compressive strength and sulfate resistance of mortars. Raw bagasse ash collected from the Thai sugar industry has a high loss on ignition (LOI) of 20%. When ground and ignited at 550 ^oC for 45 min, the LOI was reduced to 5%. These high and low LOI of ground bagasse ashes were blended in the ratios of 1:2 and 2:1 by weight to give ground bagasse ashes with LOIs of 10% and 15%, respectively. Each of these ground bagasse ashes was used to replace Portland cement type I at 10%, 20%, 30%, and 40% by weight of binder to cast mortar. The replacement rate of Portland cement type I by ground bagasse ash had a greater effect on the compressive strength of the mortar than did the LOI values (5–20%) of ground bagasse ash. Ground bagasse ash with an LOI less than 10% provided an excellent pozzolanic material and could be used to partially replace Portland cement in concrete. This use of ground bagasse ashes will reduce the amount disposed as waste and be good for the environment. Mohammad Badrul Ahsan and Zahid Hossain **[21]** investigated supplemental use of rice husk ash (RHA) as a cementitious material in concrete industry. RHA is an agro based by-product and treated as waste material. In this study, three different sizes of RHA (600 mm, 150 mm, and 44 mm) with two different percentages (10% and 20%) were used to modify concrete as a partial replacement of ASTM Type I OPC. A predominantly used local Class C fly ash (CFA) was also incorporated in this study for comparative analysis with RHA-modified concrete specimens. The 10% replacement dose was found to be the better of the two amounts evaluated in this study. Findings of this study are expected to give a better understanding of the use of RHA in producing concrete.

2. RESEARCH SIGNIFICANCE

The main goal of this study is to investigate experimentally effect of using agricultural waste as a cement replacement on fresh and hardened concrete properties. Two type of agricultural waste were used date palm ash **(DPA)** and corn cob ash **(CCA).** Mix design according to **ACI 318 -2019 [22]** recommendations, introduced to achieve the compressive and flexural strength of concrete. In order to achieve this objective, a total of 81 cubes (100 mm*100 mm*100 mm) and 81 beams (100 mm *100 mm *500 mm) were casted and tested.

3. EXPERIMENTAL WORK

3.1 Material Properties

Materials used in concrete mixtures were ordinary Portland cement grade 42.5, specific gravity of cement used was 3.15, fine aggregate, coarse aggregate (basalt), agricultural waste (corn cob ash and date palm ash) and pure water. Fine and coarse aggregate were tested according to Egyptian standard specifications **[23]** and ASTM. List of tests presented following:

1. Sieve analysis as shown in **Fig -1** and **Fig -2.**
2. Bulk density and specific gravity of **DPA** and **CCA** as shown in **Table -1.**
2. Maximum aggregate size of coarse aggregate and fineness modulus of sand as shown in **Table -2.**
3. Specific gravity of coarse and fine aggregate as shown in **Table -2.**
4. Unit weight of coarse and fine aggregate as shown in **Table -2.**

Table -1: Properties of **DPA** and **CCA.**

Property	DPA	CCA
Bulk Density (kg/m^3)	740	970
Specific Gravity	2.3	2.45

DPA
is a material produced from the process of burning palm fronds. It is passing on 90 µm sieve, then the passing is used as shown in **Fig -3a** and **Fig -3b.**

CCA is a material produced from the process of burning corn cob. It is passing on 90 µm sieve, then the passing is used as shown in **Fig -4a** and **Fig -4b**.

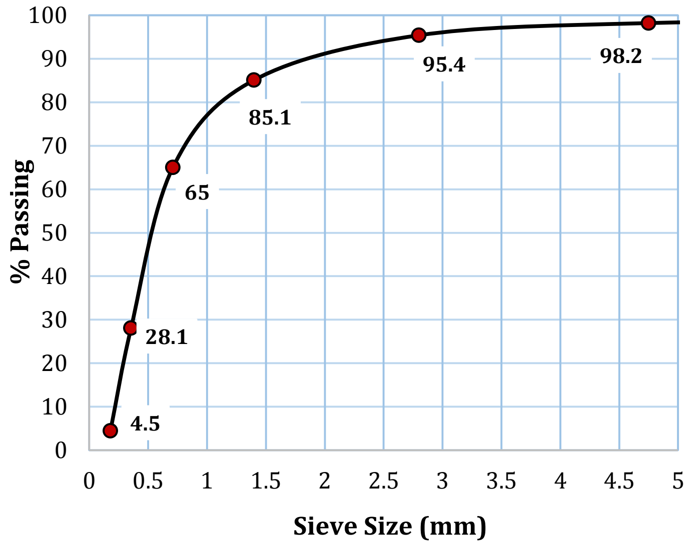


Fig -1: Sieve Analysis of Fine aggregate.

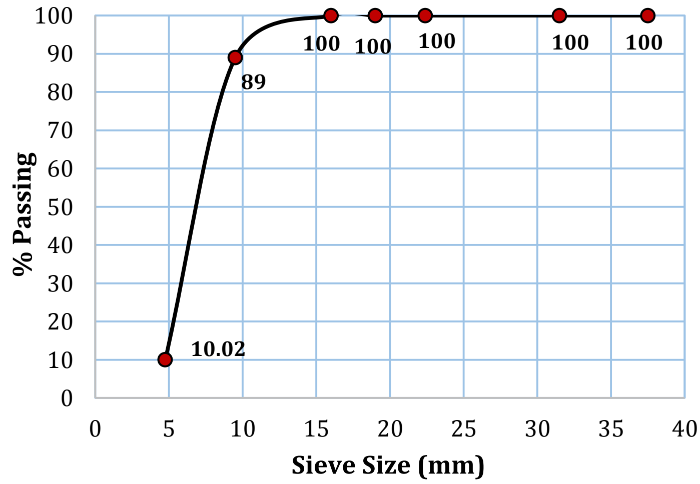


Fig -2: Sieve Analysis of Coarse aggregate.

Table -2: Properties of used aggregate.

Type of Test	Value
Maximum Aggregate Size [mm]	16
Fineness Modulus of Sand	2.24
Specific Gravity of Coarse Aggregate	2.73
Specific Gravity of Fine Aggregate	2.50
Unit Weight of Coarse Aggregate [t\m^3]	1.58
Unit Weight of Fine Aggregate [t\m^3]	1.77

Fig -3a: Date Palm Fronds.

Fig -3b: Date Palm Ash (**DPA**).

Fig -4a: Corn Cob.

3.2 Mix Design

Table -3a, **Table -3b and Table -3c** show contents of 1 m^3 concrete for control mix, cement replacement with **DPA** and cement replacement with **CCA**. Nine classes of concrete were produced to cast series of test specimens divided to three groups. Mixtures are designed using the American code **(ACI 318-2019) [22]** recommendations. Four percentages replacement level (6%, 8%, 10% and 12%) of **DPA** and **CCA** to OPC are used.

Fig -4b: Corn Cob Ash (**CCA**).

Table -3a: Mix Proportions for Control Mixture.

Class	Mix Details	Cement (kg/m^3)	Sand (kg/m^3)	Basalt (kg/m^3)	Water (kg/m^3)	Proportions
Class (1)	**C1 (Control mix)**	411.11	733.85	1005.87	185	1:1.79:2.45 – W/C = 0.45

Table -3b: Mix Proportions for Group 1 (cement replacement with **DPA**).

Class	Mix Details	Cement (kg/m^3)	Sand (kg/m^3)	Basalt (kg/m^3)	Water (kg/m^3)	DPA (kg/m^3)
Class (2)	**DPA6 (6% DPA)**	386.44	733.85	1005.87	185	24.67
Class (3)	**DPA8 (8% DPA)**	378.22	733.85	1005.87	185	32.89
Class (4)	**DPA10 (10% DPA)**	370	733.85	1005.87	185	41.11
Class (5)	**DPA12 (12% DPA)**	361.78	733.85	1005.87	185	49.33

Table -3c: Mix Proportions for Group 2 (cement replacement with **CCA**).

Class	Mix Details	Cement (kg/m^3)	Sand (kg/m^3)	Basalt (kg/m^3)	Water (kg/m^3)	CCA (kg/m^3)
Class (6)	**CCA6 (6% CCA)**	386.44	733.85	1005.87	185	24.67
Class (7)	**CCA8 (8% CCA)**	378.22	733.85	1005.87	185	32.89
Class (8)	**CCA10(10% CCA)**	370	733.85	1005.87	185	41.11
Class (9)	**CCA12(12% CCA)**	361.78	733.85	1005.87	185	49.33

3.3 Test Specimens

For each mixture nine cubes were cast to test concrete compression strength at 28, 60 and 90 days and nine beams specimens were cast to test concrete flexural strength at 28, 60 and 90 days. The experimental program of this study involved testing of 81 cubes (100 mm*100 mm*100 mm) as shown in **Fig -5a** and **Fig -5b** and 81 beams (100 mm*100 mm*500 mm) as shown in **Fig -6a** and **Fig -6b**.

After casting, placing, compacting and finishing operation, all specimens were covered with a plastic sheet till demoulding. Thereafter, specimens were cured by submerging them into fresh water tank. Once the desired curing period is completed, specimens were taken out from the curing tank to perform test program.

Fig -5a: Cubes (100 mm *100 mm*100mm) during casting.

Fig -5b: Cubes (100 mm *100 mm*100mm) during curing.

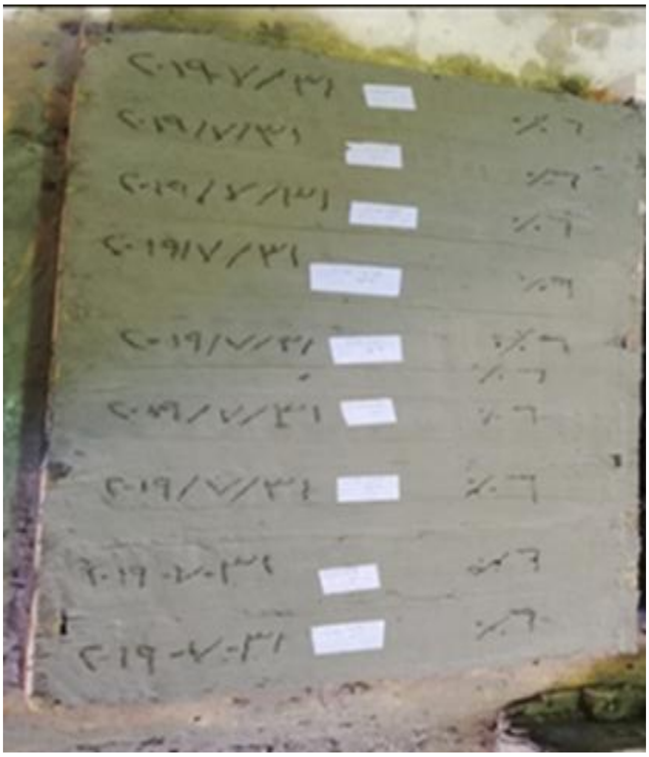


Fig -6a: Beams (100 mm *100 mm*500mm) during casting.

Fig -6b: Beams (100 mm *100 mm*500mm) during curing.

3.4 TESTS

3.4.1 Fresh Concrete Tests

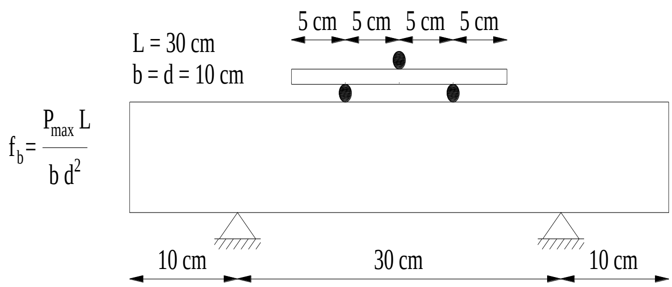
3.4.1.1 Slump Test

For measure the consistency of each fresh mix and compare between conventional mixes and others include agricultural waste, slump test has performed. Tools for slump test essentially consist of a metallic mould on the form of a cone having internal dimensions of 20 cm diameter bottom, 10 cm diameter top and 30 cm in height. The mould is placed on a smooth, horizontal and non-absorbent surface. The fresh test sample of concrete is taken from the pan mixer immediately after mixing and is placed into the cone mould at three layers. Each layer is compacted 25 times by a standard tamping rod. Slump is measured immediately by determining the vertical distance between the height of the mould and that of highest point of the specimen being tested as shown in **Fig -7**.

Fig -7: Slump Test.

3.4.1.2 Compaction Factor Test

Value of workability is estimated by the compaction factor apparatus as shown in **Fig -8**. The compaction factor can be determined by filling the upper cone with fresh concrete and allow concrete sample to fall in the lower cone by opening the upper cone's door. At last, the sample is allowed to fall again in the cylinder and is weighted with the sample (partially compacted). After that, the cylinder is filled with fully compacted sample and is weighted (fully). Finally, compacted factor (C.F) is determined (partially weighted / fully weighted).



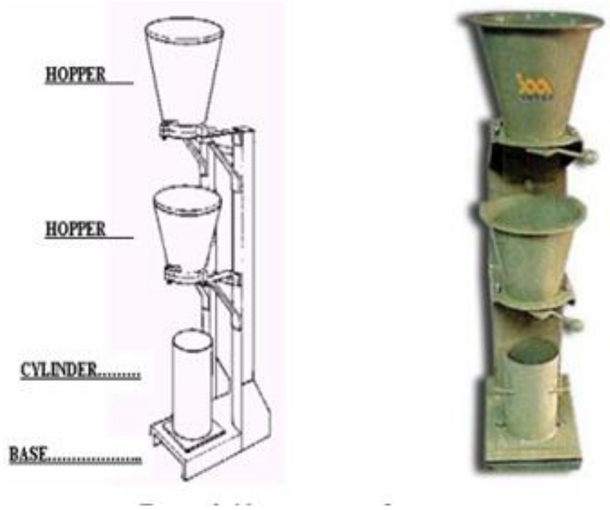


Fig -8: Compacting factor apparatus.

3.4.2 Hardened Concrete Tests

Tests of hardened concrete play an important role in controlling and confirming its quality. Tests help to achieve higher efficiency of the material used and greater assurance of the performance of the concrete with regard to both strength and durability.

3.4.2.1 Compression Strength Test

For compressive strength test, prepared 9 cubes specimens, for each mix, of dimensions 100 mm * 100 mm * 100 mm were caste. After 24 hours specimens were demoulded and were transferred to curing tank where they were allowed to cure for 28, 60 and 90 days. These specimens were tested in compression testing machine as shown in **Fig -9.** In each category, for each mix 3 cubes, their average value is reported by using following form:
Compressive strength = Load / Area (kg/cm^2).

3.4.2.2 Flexural Strength Test

For Flexural strength test, prepared 9 beams specimens for each mix of dimensions 100 mm * 100 mm * 500 mm were caste. Samples were demoulded, after 24 hours from casting kept in a pure water tank for 28, 60 and 90 days to cure. Specimens were tested in machine as shown in **Fig -10** and tested for flexural strength. In each category, for each mix 3 beams, their average value is reported by using following form: Flexural Strength (Kg/cm^2).

Fig -9: Cube (100 mm *100 mm*100mm) during compressive strength test.

Fig -10: Beam (100 mm *100 mm*500mm) during flexural strength test.

4. EXPERIMENTAL RESULTS AND DISCUSSION

4.1 Fresh Concrete Properties

4.1.1 Slump Test Results

Results of slump test for cement replacement with **DPA** mixes is shown in **Fig -11**. Slump of **DPA** mixes is decreasing as the **DPA** content increases.

Fig -12 shows slump values for cement replacement with **CCA** mixes. Also, slump of **CCA** mixes is decreasing as the **CCA** content increases.

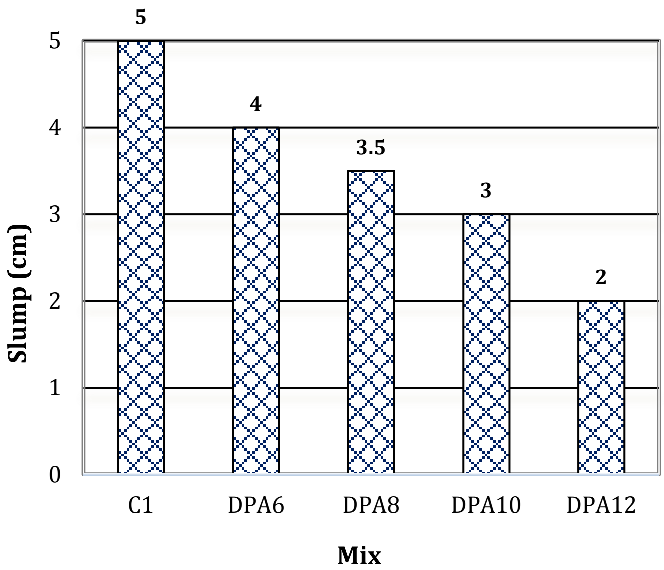


Fig -11: Slump Test for **DPA** Replacement.

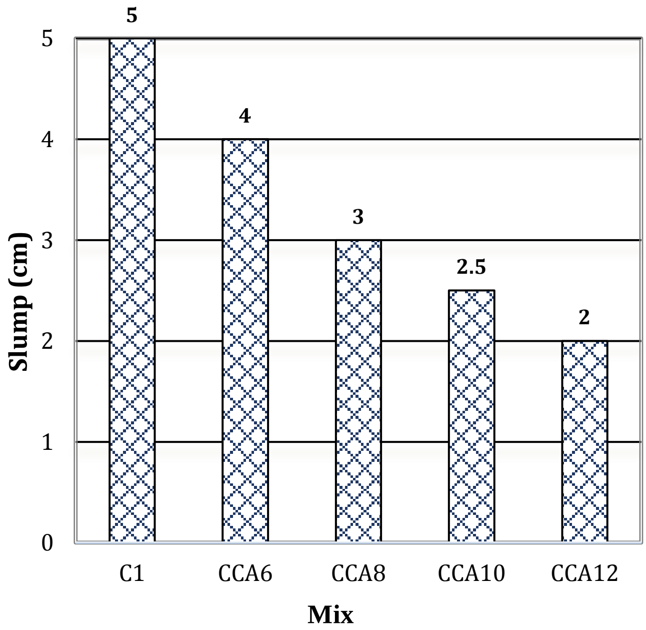


Fig -12: Slump Test for **DPA** Replacement.

4.1.2 Compaction Factor Test Results

Fig -13 and **Fig -14** demonstrate variation of Compacting factor for cement replacement with **DPA** and **CCA**, respectively. It was observed that, Compacting factor for **DPA** and **CCA** mixes is decreased with the increase of replacement ratio.

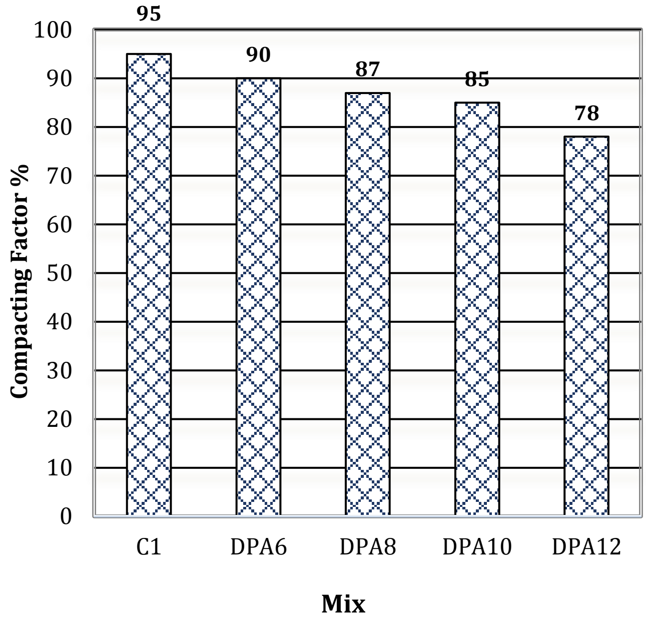


Fig -13: Compaction Factor for **CCA** Replacement.

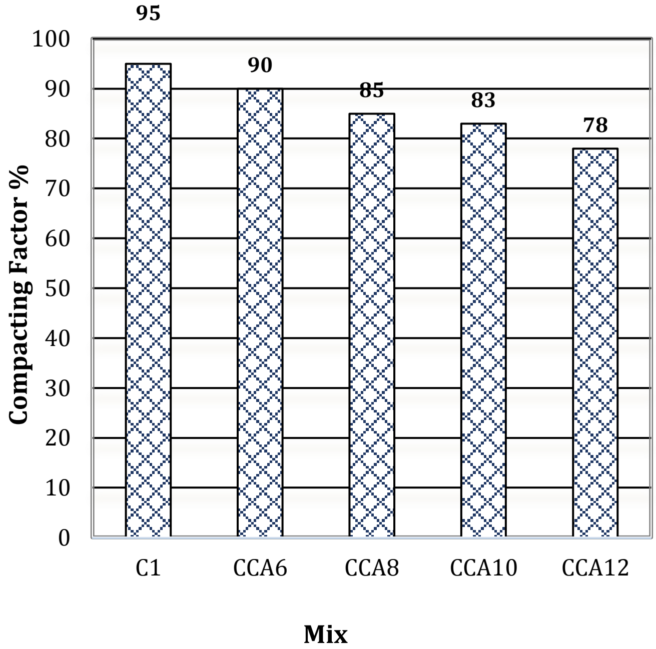


Fig -14: Compaction Factor for **CCA** Replacement.

4.2 Hardened Concrete Properties

4.2.1 Compression Strength Test Results

Table -4: Compressive Strength Variation at 28, 60 and 90 days for Control Mixture, **DPA** and **CCA** replacement mixes

Mix Details	Class	Mix	Mixture ID	Compressive Strength (Kg/cm²)		
				28 days	60 days	90 days
Control Mixture	Class (1)	C1	Plain Concrete	330	355	365
Group (1) Palm Date Ash (DPA)	Class (2)	PDA6	6% DPA	304	316	346
	Class (3)	**DPA8**	**8% DPA**	**335**	**362**	**370**
	Class (4)	DPA10	10% DPA	312	334	341
	Class (5)	DPA12	12% DPA	300	310	326
Group (2) Corn Cob Ash (CCA)	**Class (6)**	**CCA6**	**6% CCA**	**300**	**315**	**367**
	Class (7)	CCA8	8% CCA	295	309	358
	Class (8)	CCA10	10% CCA	290	303	351
	Class (9)	CCA12	12% CCA	287	300	328

Table -4 and **Fig -15** show Compressive strength variation with **DPA** cement replacement. The results show that with increasing curing time, compressive strength increases. Also, optimum **DPA** cement replacement for all concrete ages is **8%.**

Also, **Table -4** and **Fig -16** demonstrate Compressive strength variation with **CCA** cement replacement. The results indicate that, Cement replacement with **CCA** reduce concrete strength for all replacement ratios, except at age of 90 days with **CCA** replacement ratio 6%.

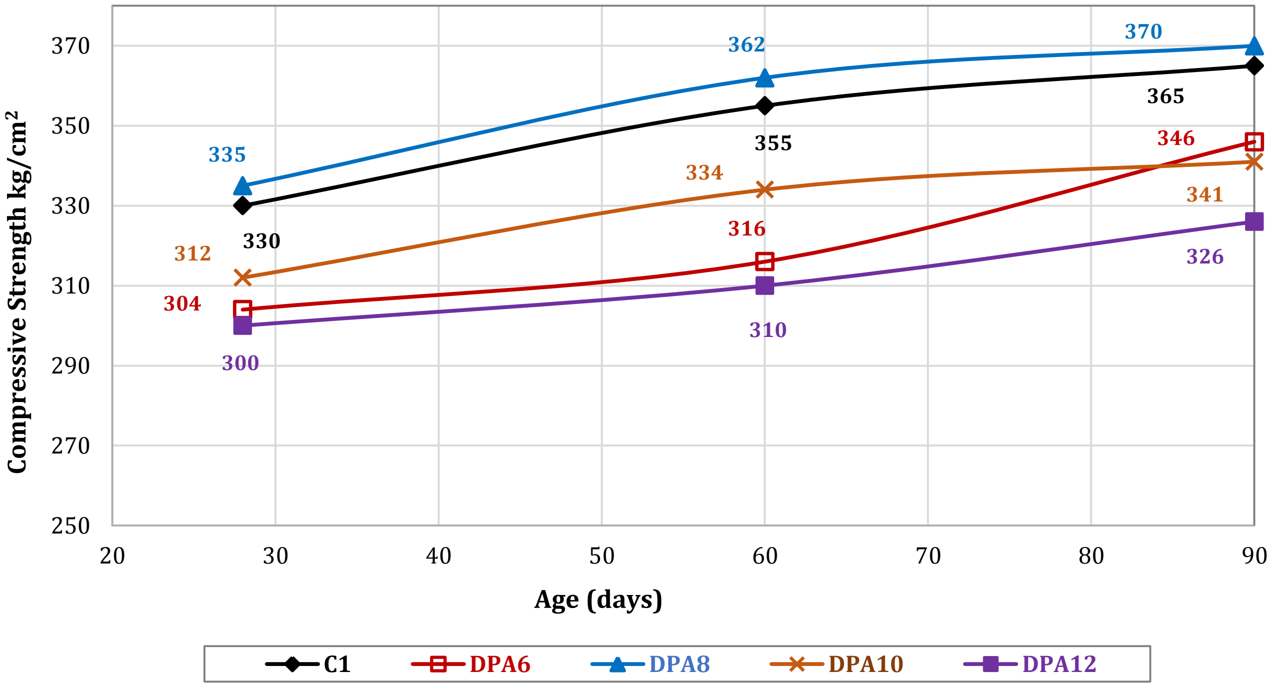


Fig -15: Compressive Strength Variation for **DPA** Replacement and Control Mix (C1) at different ages.

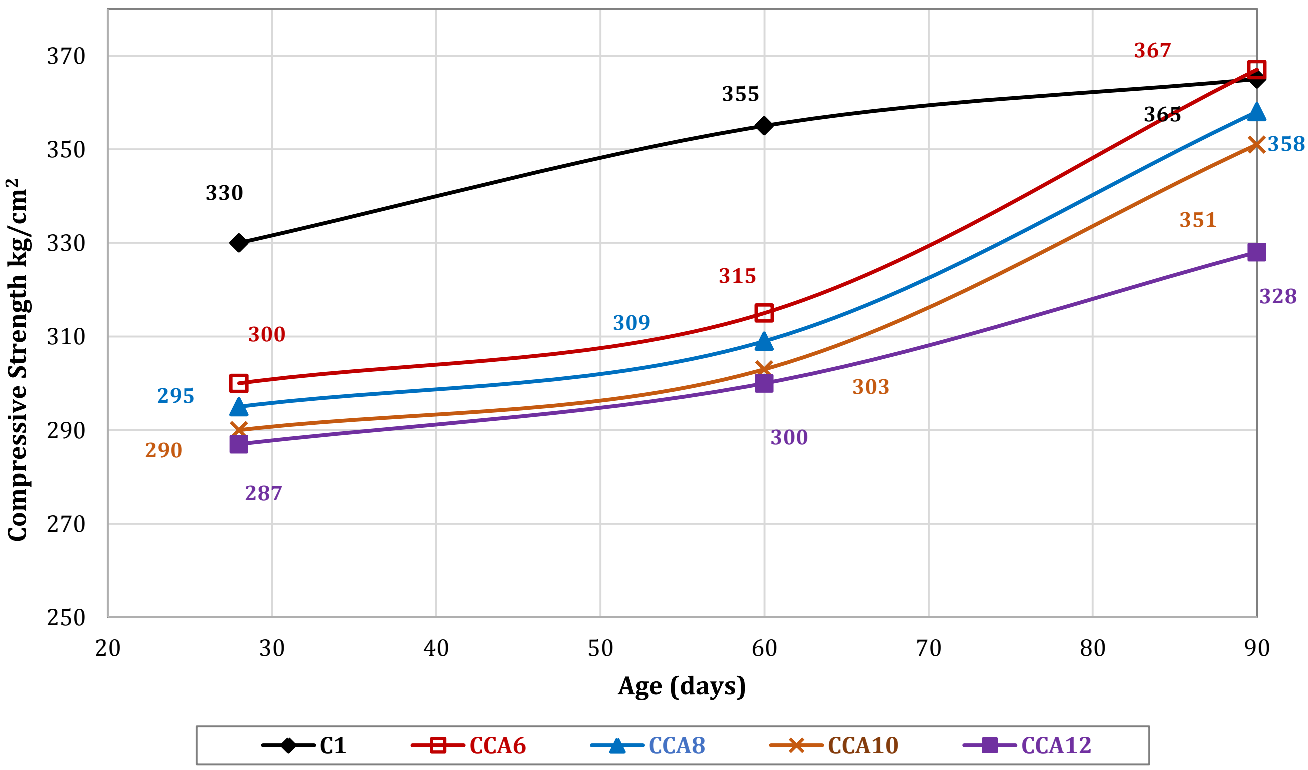


Fig -16: Compressive Strength Variation for **CCA** Replacement and Control Mix (C1) at different ages.

4.2.2 Flexural Strength Test Results

From **Table -5** and **Fig -17**, it is clear that flexural strength increased with the increase of concrete age. Also, optimum **DPA** cement replacement percent is **8%** at all ages.

The results of flexural strength variation for **CCA** replacement is shown in **Table -5** and **Fig -18**.

Also, flexural strength increases with the increase of concrete age. **CCA** cement replacement reduce flexural strength for all replacement ratios, except at age of 90 days with **CCA** replacement ratio 6%.

Table -5: Flexural Strength at 28, 60 and 90 days for Control Mixture, **DPA** and **CCA** replacement.

Mix Details	Class	Mix	Mixture ID	Flexural Strength (Kg/cm^2)		
				28 days	60 days	90 days
Control Mixture	Class(1)	C1	Plain Concrete	62	68	70
Group (1) Palm Date Ash (DPA)	Class(2)	PDA6	6% DPA	57	61	69
	Class(3)	**DPA8**	**8% DPA**	**66**	**70**	**74**
	Class(4)	DPA10	10% DPA	60	67	68
	Class(5)	DPA12	12% DPA	56	60	62
Group (2) Corn Cob Ash (CCA)	**Class(6)**	**CCA6**	**6% CCA**	**54**	**61**	**72**
	Class(7)	CCA8	8% CCA	53	59	69
	Class(8)	CCA10	10% CCA	53	56	68
	Class(9)	CCA12	12% CCA	49	55	62

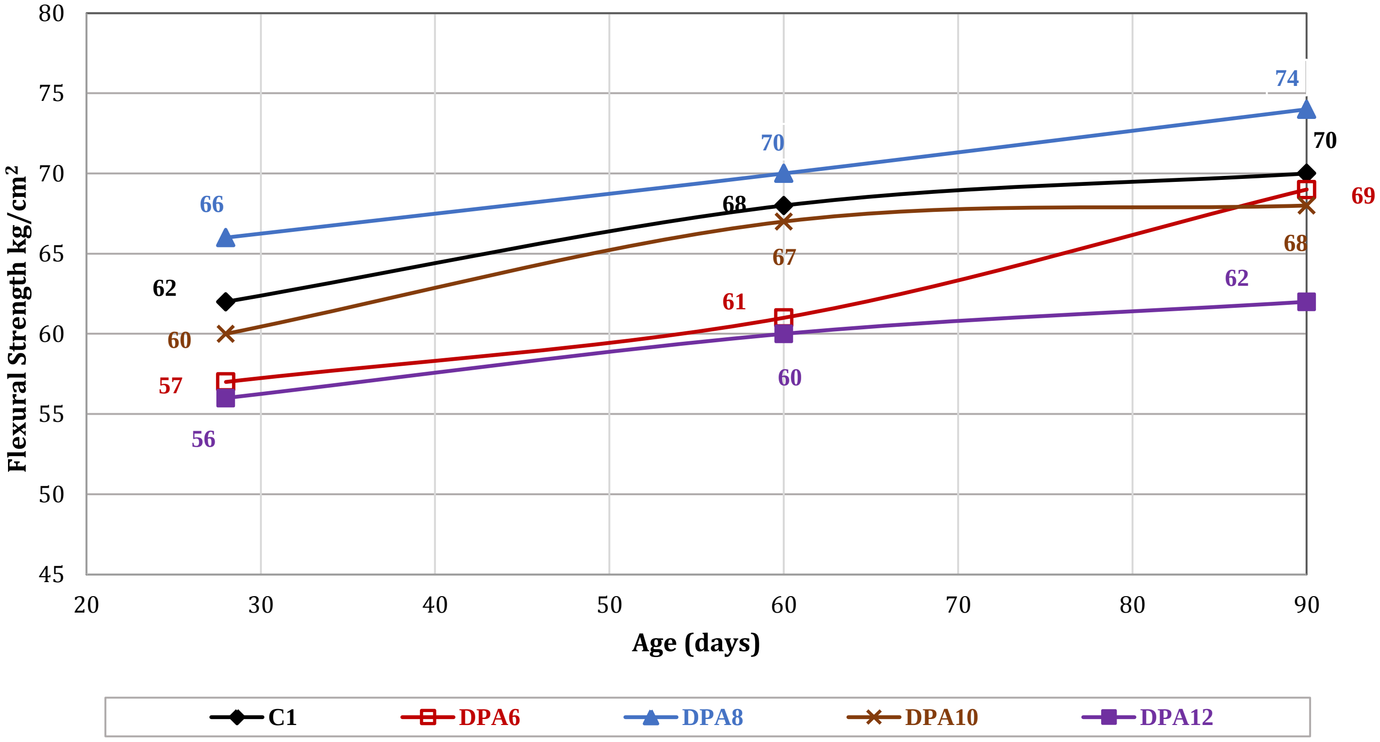


Fig -17: Comparison between Flexural Strength for **DPA** Replacement and Control Mixture (C1) at different ages.

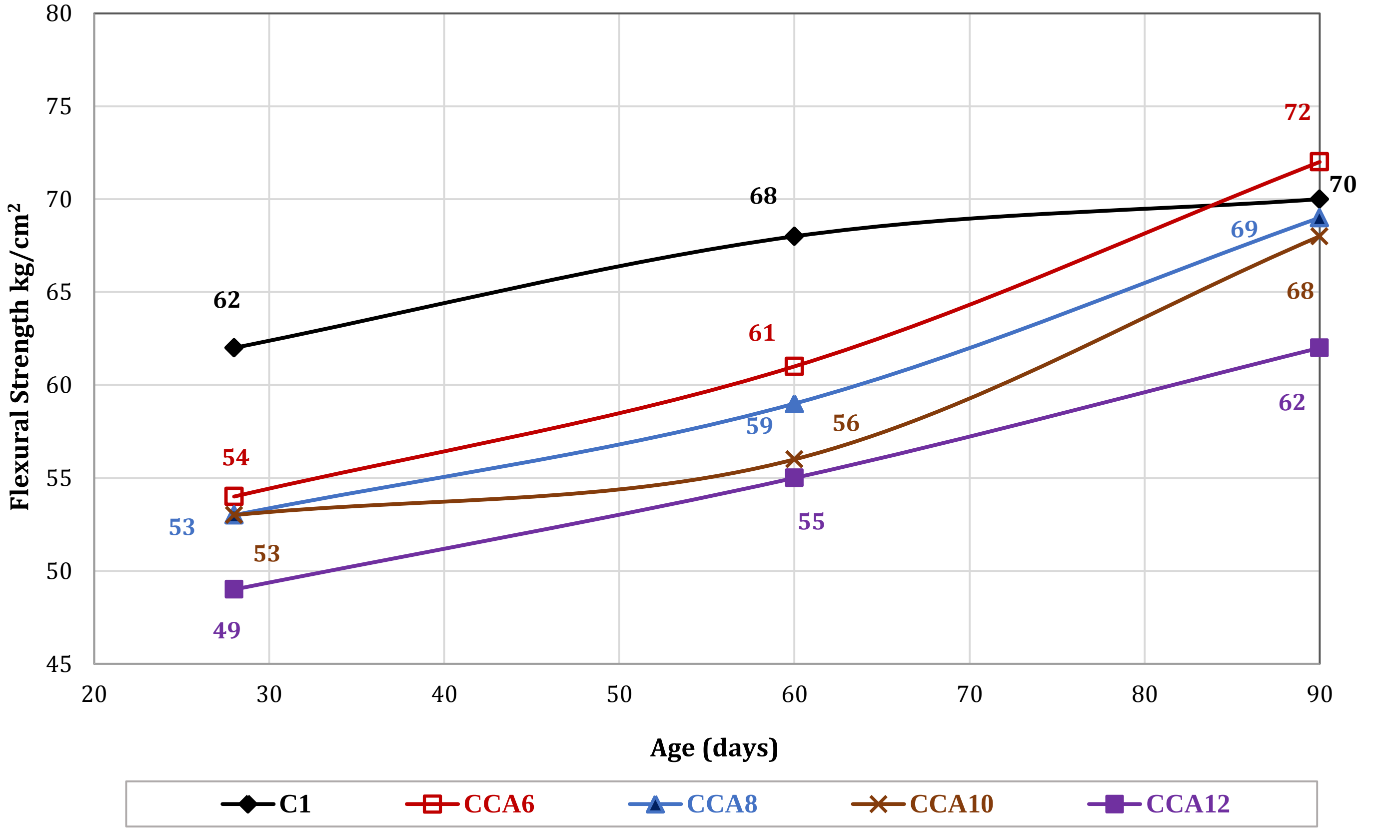


Fig -18: Comparison between Flexural Strength for **CCA** Replacement and Control Mixture (C1) at different ages.

5. CONCLUSIONS

The following conclusions could be drawn from the experimental data presented in the reported study:

1. The waste material date palm ash (**DPA**) and corn cob ash (**CCA**) are introduced as a competent binder in enhancing concrete properties.
2. The slump of test samples ranged between (2 cm to 5 cm).
3. The slump decreased with increasing proportion of date palm ash and corn cob ash.
4. The Compaction factor of test samples ranged from 95% to 78%.
5. The compacting factor decreased with increasing content of date palm ash (**DPA**) and corn cob ash (**CCA**).
6. Compressive strength for all samples increased with the increase of concrete age
7. Compressive strength for **8% DPA** replacement increased by 8.06% and 10.45% of that 28 days value at 60 and 90 days, respectively.
8. Optimum **DPA** cement replacement ratio is 8%.
9. Compressive strength of 8% **DPA** samples at 28 days, 60 days and 90 days increased by 1.52%, 1.97% and 1.37% of that control mix, respectively.
10. Compressive strength for **CCA** samples is smaller than that of control mix (without replacement) except for 6% replacement at 90 days.
11. Compressive strength of 6% **CCA** at 28 days and 60 days is smaller than that control mix by 9.09% and 11.27%, respectively. At 90 days, compressive strength of 6% CCA is larger than the control mix by 0.55%.
12. Flexural strength of **8% DPA** samples at 28 days, 60 days and 90 days increased by 6.45%, 2.94% and 5.71% of that control mix, respectively.
13. Flexural strength of **6% CCA** samples at 28 days and 60 days smaller than that of control mix by 12.90% and 10.29 %, respectively. At 90 days, flexural strength of 6% CCA is larger than the control mix by 2.86%.
14. Effect of **CCA** cement replacement on strength enhancement is more pronounced at later ages (more than 90 days).
15. To reduce the CO2 emission into the atmosphere and minimizing the cost of construction without compromising the service life of the structures. We recommend using **DPA** and **CCA** as a cement replacement material with the given optimum values.

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