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Modelling the Effect of Maize Fuel Ash (MFA) and Plantain Leaf Ash (PLA) on the Heat of Hydration of Concrete

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Abstract

This study modeled the effects of maize fuel Ash (MFA) and plantain leaf Ash (PLA) on the heat of hydration of concrete. The chemical composition tests of the MFA and PLA carried out showed their suitability as pozzolanas based on ASTM C618 (2008). OPC/MFA concrete cubes (0%, 10%, 20% and 30% MFA) and OPC/PLA concrete cubes (0%, 10%, 20% and 30% PLA) were made, cured at various ages, de-moulded and tested for compressive strength. The 28-day compressive strength of the OPC concrete was 22.54N/mm^2 . The OPC/MFA concrete compressive strength of 19.38N/mm^2 was the maximum value at 28 – day testing with M FA content of 10%. OPC/PLA concrete gave the maximum compressive strength of 19.31 M/mm^2 also at 28th day testing with 10% PLA fresh MFA and PLA concretes water – cement ratios of 0.5 were tested for heats of evolution in terms of temperature rise under semi-adiabatic conditions and the results recorded. The compressive strength of concrete produced when maize fuel ash (MFA) is used to replace cement at the replacement level of 10-30% and at the hydration period of 7-28 days ranges from 5.38 – 19.32N/mm^2 as against 11.34 – 22.54N/mm^2 for the control test. Similarly, the compressive strengths of concrete produced when plantain leaf ash (PLA) is used to replace cement at the source replacement level and hydration period ranges from 5.37 – 19.31N/mm^2 as against 11.35 – 53N/mm^2 for the control test. Regression analyses were done on the compressive strengths and heat of hydration results to generate mathematical models. The study revealed that both MFA and PLA were effective supplementary cementing materials, controlling the heat of hydration particularly between the first and second days after casting. The compressive strength analysis indicated that the amount of MFA and curing time significantly influenced strength with higher MFA amounts leading to decreased strength and longer curing times increasing strength. The analysis of heat release showed a negative impact of MFA/PLA on heat release with longer curing times exacerbating this effect. The ANOVA for the heat of hydration for MFA/PLA concrete showed that the regression models were statistically significant (p-value < 0.05).

1. Introduction

Concrete is a composite building material primarily composed of aggregate, cement, and water. It offers remarkable durability, requires minimal maintenance, and is easy to clean. Additionally, concrete is non-combustible and has a slow rate of heat transfer, making it effective in preventing the spread of fire. The hydration of cement is an exothermic process, releasing heat when water is added. During hydration, the compounds in cement react with water to form stable, low-energy states, resulting in the release of heat. The temperature of concrete during hydration is significantly affected by the properties of the materials, the mix design, and environmental conditions. Recently, the use of pozzolanic materials in concrete has gained popularity due to their technological, economic, and ecological benefits. Early field tests using fly ash revealed that concrete containing a substantial percentage of fly ash could significantly reduce the maximum temperature rise during hydration. Other pozzolanic materials, such as slag, silica fume, and rice husk ash, have also been shown to lower the adiabatic heat generated within concrete masses. Research has indicated that the combined effects of materials like pulverized fuel ash and palm oil fuel ash can influence the heat of hydration in various concrete forms. In studies examining these effects, it was found that while the temperature increase due to hydration was significant in control samples, the total temperature rise in mixtures incorporating these materials was considerably lower. Additionally, investigations into mortar formulations that replaced ordinary Portland cement with combinations of palm oil fuel ash and eggshell waste powder demonstrated beneficial effects, particularly in mass mortar applications where thermal cracking from excessive heat rise is a concern.

1.1 History of Concrete

[1] defined concrete as a composite inert material composed of cement, mineral filler (body) or aggregates, and water. The word "concrete" comes from the Latin word "concretus," meaning compact or condensed. During the Roman Empire, Roman concrete was made from quicklime, pozzolana, and an aggregate of pumice. An analysis of mortar from the Great Pyramid showed that it contained 81.5 percent calcium sulphate and only 9.5 percent carbonate. The durability and other characteristics of concrete depend on the properties of its ingredients, the proportions of the mix, the method of compaction, and other controls during placing, compaction, and curing [2] . In 1756, engineer John Smeaton created modern concrete by mixing coarse aggregate (pebbles) and powdered brick with cement. In 1793, he used hydraulic cement to build the Eddystone Lighthouse in Cornwall, England. Another major development occurred in 1824 when English inventor Joseph Aspdin invented Portland cement. He made concrete by burning ground chalk and finely crushed clay in a limekiln until the carbon dioxide evaporated, resulting in strong cement. In 1849, Joseph Monier first invented reinforced concrete. The first rotary kiln was introduced in England in 1886, allowing for the constant production of cement. In 1891, George Bartholomew created the first concrete street in Ohio, USA. Since its modern development, concrete has been widely used as the strongest building material, finding applications in dams, highways, buildings, and various construction projects. As of 2006, about seven billion cubic meters of concrete are produced each year, more than one cubic meter for every person on Earth.

1.2 Portland Cement

Portland cement is a finely ground material with adhesive and cohesive properties, providing a binding medium for concrete ingredients. The invention of Portland cement is attributed to Joseph Aspdin, a builder and bricklayer from Leeds, who patented it on October 21, 1824. The name "Portland" was chosen due to the resemblance of the hardened cement to natural stone found in Portland, England [3]. In Aspdin's process, hard limestone and finely divided clay were mixed and ground into a slurry, then calcined in a furnace similar to a lime kiln until the CO_2 was expelled. The calcined mixture was then ground to a fine powder, possibly at a temperature lower than the clinkering temperature. Later, in 1845, Isaac Charles Johnson improved the process by burning a mixture of clay and chalk to the clinkering stage, producing better cement and establishing factories in 1851. Initially, cement was used only for making mortar, but its use soon extended to concrete production. As the demand for Portland cement in concrete increased, engineers required consistently higher quality materials for major projects. This led to the formation of associations of engineers, consumers, and cement manufacturers to establish standards for cement. The German standard specification for Portland cement was established in 1877, the British standard specification in 1904, and the first ASTM specification was also issued in 1904. Figure 1 shows the production of cement in a rotary kiln.

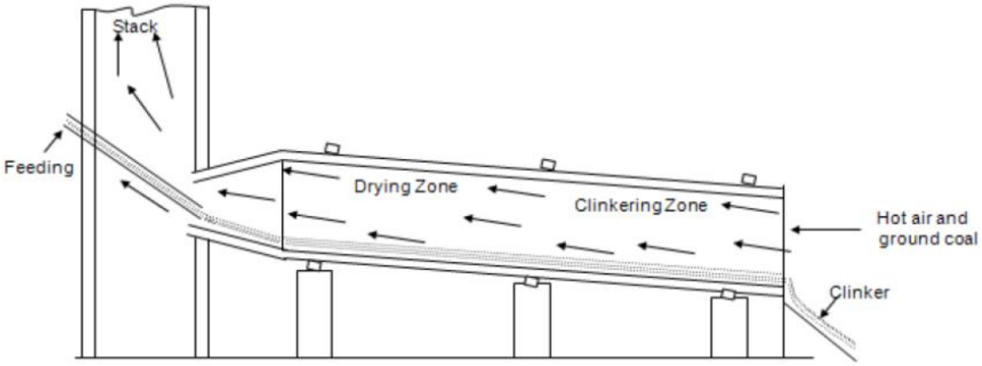

Figure 1: Production of Cement in a Rotary Kiln

1.3 Pozzolans

A pozzolana is an inert siliceous material which, in the presence of water, will combine with lime to produce a cementitious matter with excellent structural properties. The use of pozzolanic materials is as old as that of the art of concrete construction. It was recognized long time ago, that the suitable pozzolans used in appropriate amount, modify certain properties of fresh and hardened mortars and concretes. Ancient Greeks and Romans used certain finely divided siliceous materials which when mixed with lime produced strong cementing material having hydraulic properties and such cementing materials were employed in the construction of aqueducts, arch, bridges etc. One such material was consolidated volcanic ash or tuff found near Pozzuoli (Italy) near Vesuvius. This came to be designated as Pozzolana, a general term covering similar materials of volcanic origin found in other deposits in Italy, France and Spain. Later, the term pozzolan was employed throughout Europe to designate any materials irrespective of its origin which possessed similar properties. Specimens of concrete made by lime and volcanic ash from Mount Vesuvius used in the construction of Caligula Wharf built in the time of Julius Caesar nearly 2000 years ago now exists in a fairly good condition. A number of structures stand today as evidence of the superiority of pozzolanic cement over lime. They also attest to the fact that Greeks and Romans made real advance in the development of cementitious materials. After the development of natural cement during the latter part of the 18th century, the Portland cement in the early 19th century, the practice of using pozzolans declined, but in more recent times, Pozzolans have been extensively used in Europe, USA and Japan, as an ingredient of Portland cement concrete particularly for marine and hydraulic structures.

1.4 Waste Material Based

Concrete Currently, some of the agro wastes such as rice husk ash, sugarcane bagasse ash, etc., have been used as an admixture. This is one of the effective ways of reducing their impact on the environment (Sireesha, et al., 2013)

1.5 Maize plant (zea maize)

Figure 2 Maize Plantation

Maize is a tall, determinate annual plant belonging to monocotyledon class and is monoecious with separate male and female flowering organs but on the same plant (Figure 2). Shanks develop in the leaf axis and will mature into female inflorescence (an ear). Depending on the variety, more than one shank may develop on one maize plant but usually only 1-2 may develop into economic ears (cobs). Ears are covered by a number of leaves (husks) and each cob has even number of rows (8-30) of kernels [4]; [5]. Each ovary contains one ovule which will mature into a kernel. One ear of maize contains between 300-1000 kernels [6]. The apical meristem of maize stalk develops into a tassel which consists of central spike and up to 40 lateral branches carrying male flowers. The tassel structure is erected on top of the plant by a strong peduncle. Maize stem has protective epidermis that covers layers of sclerenchyma tissues resulting into strong stalk.

2. Materials and Methods

2.1 Production Maize Fuel Ash (MFA)

Maize Fuel Ash (MFA) is a material produced from the process of burning maize waste (straws and cobs). This material was sourced from Awaka community, in Owerri - North Local Government Area of Imo State in the Eastern Region of Nigeria. The maize waste was sun-dried for days to lower the amount of water in it before incineration. The MFA was produced by heating the raw material in an oven for over 6 hours. In this research, Maize Fuel Ash passing 425 µm sieve is used. 10%, 20% and 30% of Maize Fuel Ash will be incorporated as replacements for OPC.

2.2 Plantain Leaf Ash (PLA)

Plantain Leaf Ash is produced by drying and heating of plantain leaves in an improvised oven for over 6 hours at a temperature below 600 ^{0}C. In this research, PLA passing 425 µm sieve is used.

10%, 20% and 30% of PLA was incorporated as replacement for OPC. The PLA used was obtained from Aronta Mbutu Village in Aboh Mbaise Local Government Area of Imo State.

2.3 Cement

The type of cement selected for this research is ordinary Portland cement (OPC). There are various brands available in the Nigerian building material markets such as Dangote, BUA, Unicem, Elephant Cement, etc. Dangote Falcon, a Portland limestone cement conforming to the Nigerian Cement Standards NIS 444-1: 2003 & EN 197-1:2011 specifications will be used in all the four concrete and mortar mixtures.

2.4 Aggregates

The coarse and fine aggregates used include crushed granite and river sand, respectively from local quarries. The grading of fine aggregates conformed to BS 882 (1992). Sieve analyses of MFA, PLA and sand were carried out with sieve size Nos. 4, 10, 40, 100 and 200. The ratio of 1:2:4 was kept constant in all the concrete mixtures. Moreover, all the concrete and mortar specimens were prepared with a water-cement ratio of 0.55 and potable water was used for mixing and curing the specimens.

2.5 Water

The water used for the study was obtained from a borehole (groundwater). The water was clean and free from any visible impurities. It conformed to BS EN 1008:2002 requirements.

2.6 Specimen Preparation

2.6.1 Maize Fuel Ash (MFA)

Four concrete mixtures were prepared inside the laboratory using neat OPC and four percentage replacement levels (10%, 20% and 30%) of Maize Fuel Ash to OPC. The concrete and mortar constituents were weighed in required proportions and mixed in a concrete mixer.

2.6.2 Plantain Leave Ash (PLA)

Four concrete mixtures were also prepared inside the laboratory using neat OPC and four percentage replacement level (10%, 20% and 30%) of Plantain Leaf Ash to OPC. The concrete and mortar constituents were also weighed in required proportions and mixed in a concrete mixer.

2.7 Tests

2.7.1 Chemical Composition

Chemical analyses to determine the mineralogical composition of MFA and PLA, for silica, Ca, K, Mg, Na, Al, Fe were carried out. Loss on Ignition was done as per standard method.

2.7.2 Workability

Slump test and compacting factor test were conducted on the fresh concrete (MFA and PLA respectively) to determine their ease of mixing, placement and compaction. The slump test was used to test the workability of the concrete. A slump cone mould of diameters 200mm and 100mm, and height 300mm was filled with concrete in three layers of equal volume. Each layer was compacted with 25 strokes of a tamping rod. The slump cone mould was lifted vertically and the change in height of concrete was measured to the nearest millimeter of 1mm (BS 1881: Part 103: 1983; BS 1881: Part 102:1983).

2.8 Compressive Strength Test

2.8.1 Casting and Compaction of Concrete

The oiled plastic molds, free from any foreign material were arranged close to the platform. The concrete was simultaneously filled in the molds approximately 150mm thick for the cubes. Each layer was compacted on compacting table using tamping rod. The surplus on the mold was stripped off and leveled by hand trowel. The specimens (MFA and PLA) were packed neatly to maintain proper hydration of the cement (BS 1881-103:1983 and BS 1881-103:1993).

2.8.2 Curing of Concrete

After casting, placing, compacting and finishing operation, all specimens were covered with a plastic sheet till demolding. The specimens were remolded after 24 hours and immersed in water in a water tank for 28 days. This was done in accordance with BS 1881: Part 111, 1983. Once the desired curing period is completed, the specimens were taken out from the curing tank to prepare them for test program.

2.8.3 Cube Test

The concrete cubes were assessed after the age of 28 days of curing, as per BS 1881: Part 116 (1983) and tested by means of compression testing machine at standard loading rate. The samples were weighed before being put in the compressive test machine. The machine automatically stopped when failure occurred and then displayed the failure load. Two specimen were tested at each age from each mix and their average reading reported.

2.9 Measurement of Heat of Hydration

MFA concrete with a water-cement ratio of 0.50 were selected for testing the heat evolution of fresh concrete in terms of temperature rise under semi-adiabatic conditions. Four mixtures of fresh concrete with 0%, 10%, 15%, 20%, and 30% of MFA were placed in a 450-mm cube with a lining insulator of 50 mm on each side concrete specimen of 350 mm. A Type K thermocouple was embedded in the center of each specimen. When concrete was poured into the box, heat was liberated by the hydration process that subsequently increased the temperature of the concrete mass. This increase in temperature and subsequent drop was monitored with close intervals during the first 24 hours and with lesser frequency afterwards until the temperature dropped close to the initial reading. In this study, the recording of temperature was continued up to 5 days for both mixes. A similar procedure was adopted for PLA concrete.

3. Results and Discussion

3.1 Experimental Mix Design

The results of the concrete mix design are shown in Table 1 and 2

Table 1 Concrete Mix Design for compressive strength test (Maize Fuel Ash, MFA)

Constituent Materials	0% MFA (Control)	10 % MFA	20 % MFA	30 % MFA
Cement (kg)	37.0	33.3	29.6	25.9
MFA (kg)	0.0	3.70	7.40	11.1
Fine Aggregate (kg)	74.4	74.4	74.4	74.4
Coarse Aggregates (kg)	148.11	148.11	148.11	148.11
Water/Cement Ratio	0.5	0.5	0.5	0.5
Total Water (kg)	18.5	18.5	18.5	18.5

Table 2 Concrete Mix Design for compressive strength test (Plantain Leave Ash, PLA)

Constituent Materials	0% PLA (Control)	10 % PLA	20 % PLA	30 % PLA
Cement (kg)	37.0	33.3	29.6	25.9
PLA (kg)	0.0	3.70	7.40	11.1
Fine Aggregate (kg)	74.4	74.4	74.4	74.4
Coarse Aggregates (kg)	148.11	148.11	148.11	148.11
Water/Cement Ratio	0.5	0.5	0.5	0.5
Total Water (kg)	18.5	18.5	18.5	18.5

3.2 Chemical Composition of Maize Fuel Ash (MFA)

Table 3 shows the oxide composition of MFA. The results showed that MFA has combined percentage of (SiO2 + Al2O3 + Fe2O3) of 17.47% which is much less than 70%, indicating that the sample is not a good pozzolanic materials in accordance with the requirements in ASTM C618 (2008). The CaO content (45.88%) in MFA also shows that it has some self-cementing properties. MFA also has a high content of K_2O (42.03%) which may be a source of disruption in cement mortar paste.

Table 3 Chemical Composition of Maize Fuel Ash (MFA)

Oxide	Percentage Composition (%)	OPC (BS 12 Ranges)
SiO_2	9.20	17-25
Fe_2O_3	6.10	0.5-6.0
Al_2O_3	2.17	3-8
CaO	45.88	60-67
MgO	1.04	0.1-4.0
SO_3	0.001	1.0-2.0
K_2O	42.03	
PbO	0.02	

3.4 Chemical Composition of Plantain Leaf Ash (PLA)

Table 4 Chemical Composition of Plantain Leaf Ash (PLA)

Oxide	Percentage Composition (%)
SiO_2	47.5
Fe_2O_3	1.55
Al_2O_3	2.58
Na_2O	0.25
K_2O	1.92
CaO	21.30
MgO	0.98
Loss of Ignition (LOI)	5.10

Table 4 shows the oxide composition of PLA. The results showed that PLA has combined percentage of (SiO_2 + Al2O_3 + Fe_2O_3) of 51.63% which is much less than 70%, indicating that the sample is not a good pozzolanic materials in accordance with the requirements in ASTM C618 (2008). The CaO content (21.30%) in PLA also shows that it has some self-cementing properties.

3.3 Compressive strength for Maize Fuel Ash (MFA) Concrete

The compressive strength development in OPC, 10% MFA, 20% MFA and 30% MFA mortar specimens with curing period is shown in Table 5.

Table 5 The Compressive Strength Test Results of Maize Fuel Ash (MFA) Concrete

Amount of Cement (%)	**Amount of MFA (%)**	**Compressive Strength (N/mm^2)**			
		7 Days	14 Days	21 Days	28 Days
100	0	11.34	18.52	20.60	22.54
90	10	8.28	15.10	16.75	19.32
80	20	6.58	12.34	13.61	16.45
70	30	5.38	11.30	11.97	14.36

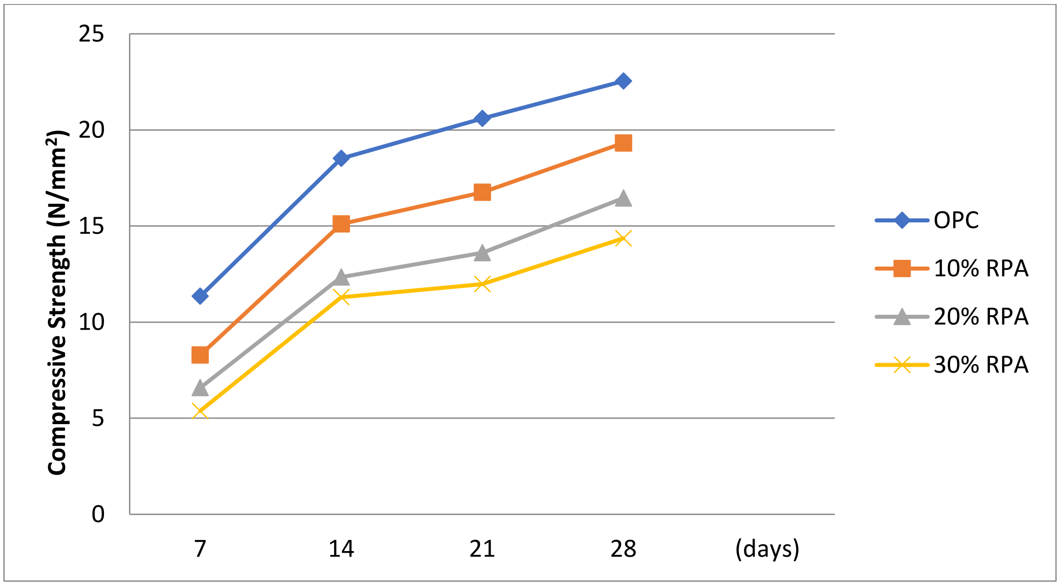

Figure 3 Compressive strength development in all OPC/MFA mortar mixtures.

The highest early strength development was noted in mortar specimens prepared with 100% OPC, followed by 10% MFA, 20% OPC and 30% MFA specimens. The 7-day compressive strength of OPC, 10% MFA, 20% MFA and 30% MFA mortar specimens was 11.34, 8.28, 6.58 and 5.38 N/mm^2, respectively. The 28-day strength development was found to be also highest in 100% OPC specimens and lowest strength was achieved in both 20% and 30% MFA specimens having marginal difference. The 28-day compressive strength of OPC specimens was22.54 N/mm^2 which is about 14.3%, 27% and 36% more than that of10% MFA, 20% MFA and 30% MFA specimens, respectively. Figure 4.1 shows the compressive strength development in all mortar mixtures.

3.4 Compressive strength for Plantain Leaf Ash (PLA) Concrete

The compressive strength development in OPC, 10% PLA, 20% PLA and 30% PLA mortar specimens with curing period is shown in Table 6.

Table 6 The Compressive Strength Test Results for Plantain Leaf Ash (PLA) Concrete

Amount of Cement (%)	**Amount of PLA (%)**	**Design Strength (N/mm^2)**			
		7 Days	14 Days	21 Days	28 Days
100	0	11.35	18.51	20.60	22.53
90	10	8.28	15.11	16.75	19.31
80	20	6.57	12.35	13.62	16.45
70	30	5.37	11.30	11.96	14.35

The highest early strength development was noted in mortar specimens prepared with 100% OPC, followed by 10% PLA, 20% PLA and 30% PLA specimens. The 7-day compressive strength of OPC, 10% PLA, 20% PLA and 30% PLA mortar specimens was 11.34, 8.28, 6.58 and 5.38 N/mm^2, respectively. The 28-day strength development was found to be also highest in 100% OPC specimens and lowest strength was achieved in both 20% and 30% PLA specimens having marginal difference. The 28-day compressive strength of OPC specimens was 22.54 N/mm^2 which is about 14.3%, 27% and 36% more than that of 10% PLA, 20% PA and 30% PLA specimens, respectively.

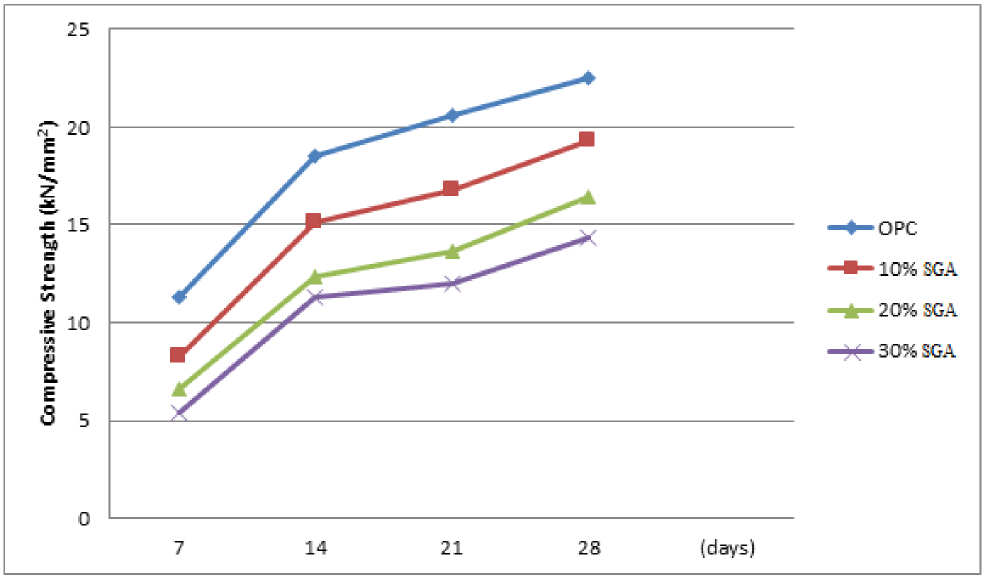

Figure 4 Compressive strength development in all OPC/PLA mortar mixtures

3.5. Heat of Hydration of Maize Fuel Ash (MFA)

The results of the various amount of heat evolved from concrete prepared from OPC, 10% MFA, 20% MFA and 30% MFA mortar specimens is shown in table 4.7. The results of variation of the temperature versus time were recorded for the different concrete types and presented in Table 7. The development of temperature due to heat liberation was also obtained in the mid depth of MFA concrete during hydration process for the concrete samples and the results are showed in Figure 3. It has been observed that during the initial stage, the temperature rise due to heat of hydration of all the specimens was approximately equal. However, as testing time increased the influence of ash replacement on heat of hydration was observed. The specimens containing 10% MFA, 20% MFA and 30% MFA demonstrated lower heat rise as compared to the OPC concrete. 10% MFA, 20% MFA and 30% MFA concrete could successfully reduce the total temperature rise compared to the OPC concrete. Also, the time at which the peak temperatures occurred increased compared to the OPC concrete is shown in Figure 3. Although the initial temperature of the whole concrete types was approximately same, more heat was considerably obtained from OPC concrete during the first day of experiment, particularly in the first 15 hours after casting. A peak temperature of 45.5^{0}C was observed for OPC concrete at 15 hours, while the peak temperature of 42.3,42.1^{0}C and 41.3^{0}C were observed for 10% MFA, 20% MFA and 30% MFA concrete at 23, 25 and 25.5 hours, respectively (Table 8).

Table 6 Values of heat released from OPC and the various MFA concretes

Time (hours)	**Temperature (^{0}C)**			
	OPC	**10% MFA**	**20% MFA**	**30% MFA**
0	30.8	30.6	30.5	30.3
5	35.3	33.2	32.5	31.8

10	42.4	40.9	38.5	38.0
15	45.3	42.3	40.7	39.6
20	43.9	41.9	41.5	41.1
25	42.7	42.4	42.0	41.0
30	41.0	40.7	40.5	41.2
35	37.9	37.6	37.5	37.5
40	35.4	34.8	34.3	34.2
45	35.8	35.7	35.2	34.9
50	35.3	34.5	34.2	33.1
55	34.1	34.4	34.7	34.5
60	33.0	31.9	31.5	31.3
65	32.5	31.0	30.7	30.7
70	31.8	31.3	30.9	30.7
75	32.0	31.7	31.5	30.5
80	31.5	30.4	29.0	28.6
85	31.1	30.1	28.6	28.2
90	29.6	28.9	28.3	28.3
95	29.3	28.5	28.0	27.6
100	29.2	28.2	28.0	27.7
105	29.2	28.1	28.1	27.7
110	29.1	28.1	28.3	27.5
115	29.2	28.0	28.1	27.4
120	29.2	27.9	28.2	27.6

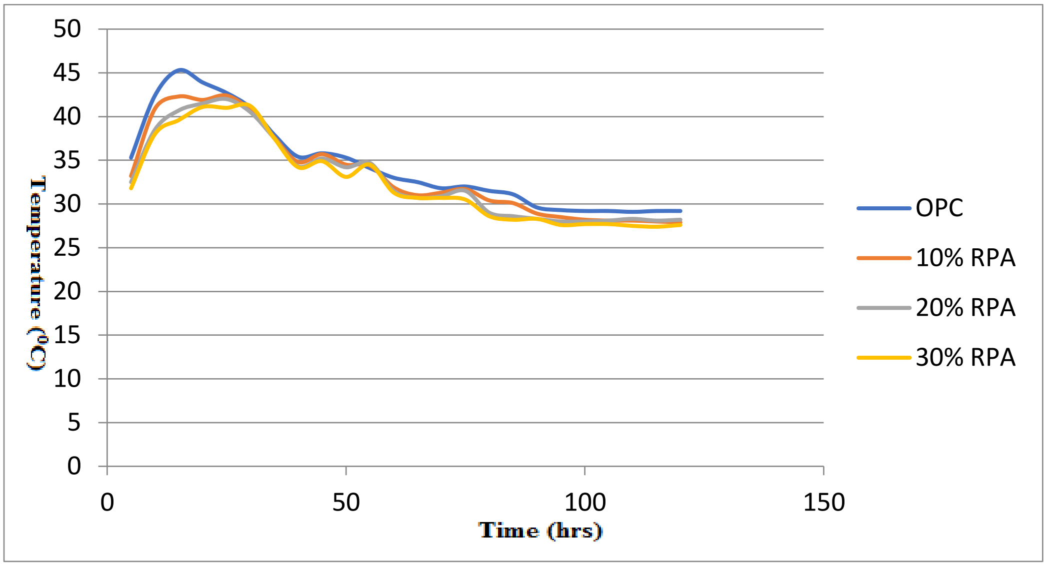

Figure 1 Development of heat of hydration in OPC/MFA Concrete

Table 7 Characteristic of Heat of Hydration of OPC and MFA Concrete

Properties	**OPC**	**10%MFA**	**20%MFA**	**30%MFA**
Initial Temperature (^{0}C)	31.6	31.4	31.5	31.3
Peak Temperature (^{0}C)	45.5	42.3	42.1	41.3
Time since mixing to peak temperature (hr)	17	23	24	26.1

3.6. Heat of Hydration of Plantain Leaf Ash (PLA)

The results of the various amount of heat evolved from concrete prepared from OPC, 10% PLA, 20% PLA and 30% PLA mortar specimens is shown in Table 9.

The results of variation of the temperature versus time were recorded for the different concrete types and presented in Figure 4. The development of temperature due to heat liberation was also obtained in the mid depth of PLA concrete during hydration process for the concrete samples and the results are showed in Figure 3. It has been observed that during the initial stage, the temperature rise due to heat of hydration of all the specimens was approximately equal. However, as testing time increased the influence of ash replacement on heat of hydration was observed. The specimens containing 10% PLA, 20% PLA and 30% PLA demonstrated lower heat rise as compared to the OPC concrete. 10% PLA, 20% PLA and 30% PLA concrete could successfully reduce the total temperature rise compared to the OPC concrete. Also, the t
me at which the peak temperatures occurred increased compared to the OPC concrete (Figure 4).

Table 8 Values of heat released from OPC and the various PLA concretes

Time (hours)	**Temperature (^{0}C)**			
	OPC	**10% PLA**	**20% PLA**	**30% PLA**
5	35.2	32.2	32.5	31.7
10	42.2	40.5	37.3	37
15	45.3	41.3	40.2	39

20	43.7	41.5	40.5	40.3
25	42.8	42.2	42	41.2
30	41.2	40.3	40.3	41
35	37.7	37.8	37.3	37.5
40	35.6	35.1	34	34.2
45	35.9	35.7	34.8	34.9
50	35.4	34.1	34.2	33.1
55	34.3	33.8	34.8	34.5
60	33.1	32.2	31.7	31.2
65	32.4	31.1	30.3	30.7
70	31.8	31.3	30.6	30.5
75	32.2	31.9	31.3	30.2
80	31.3	30.6	29.1	28.6
85	31.3	30.1	28.4	28.2
90	29.3	28.5	28.2	28.5
95	29.3	28.1	28.2	27.5
100	29.2	28	28.1	27.8
105	29.2	28	28.1	27.8
110	29.1	28	28.2	27.5
115	29.1	28	28.1	27.5
120	29.1	27.5	28.1	27.7
5	35.2	32.2	32.5	31.7

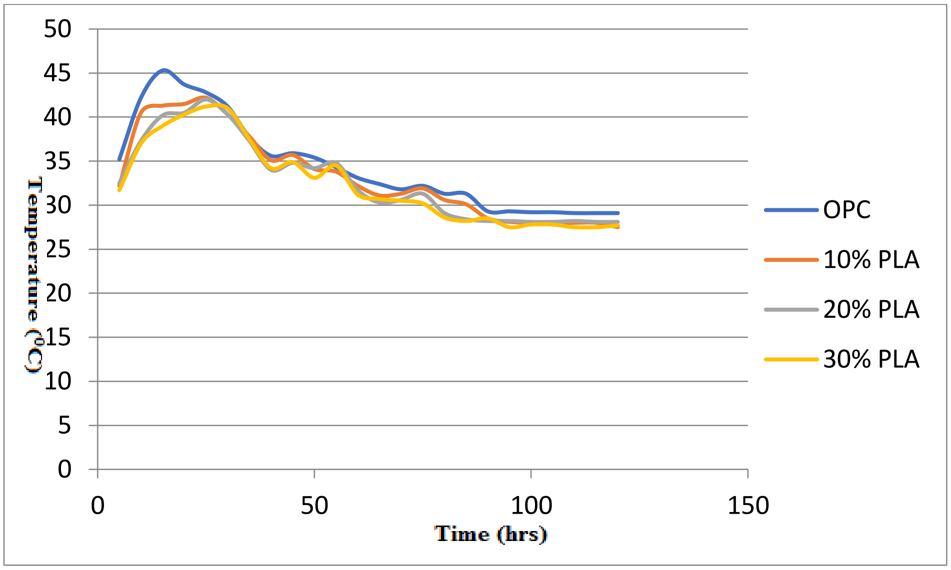

Figure 4.2 Development of heat of hydration

Although the initial temperature of the whole concrete types was approximately same, more heat was considerably obtained from OPC concrete during the first day of experiment, particularly in the first 15 hours after casting. A peak temperature of 45.3^{0}Cwas observed for OPC concrete at15 hours, while the peak temperature of 42.3,42.0^{0}C and 41.1^{0}C were observed for 10% PLA, 20% PLA and 30% PLA concrete at 23, 25 and 26.5 hours, respectively (Table 10).

Table 9 Characteristic of heat of hydration of OPC and PLA concrete

Properties	OPC	10%PLA	20%PLA	30%PLA
Initial Temperature (^{0}C)	30.8	30.6	30.5	30.3
Peak Temperature (^{0}C)	45.3	42.3	42.0	41.1
Time since mixing to peak temperature (hr)	15	23	25	26.5

3.7 MFA Reinforced Concrete Regression Model Analysis

3.7.1 Response Surface Regression: Design Strength versus Amount of cement, Amount of MFA

Figure 5 shows the effect of the variables against the compressive strength of the MFA reinforced cement.

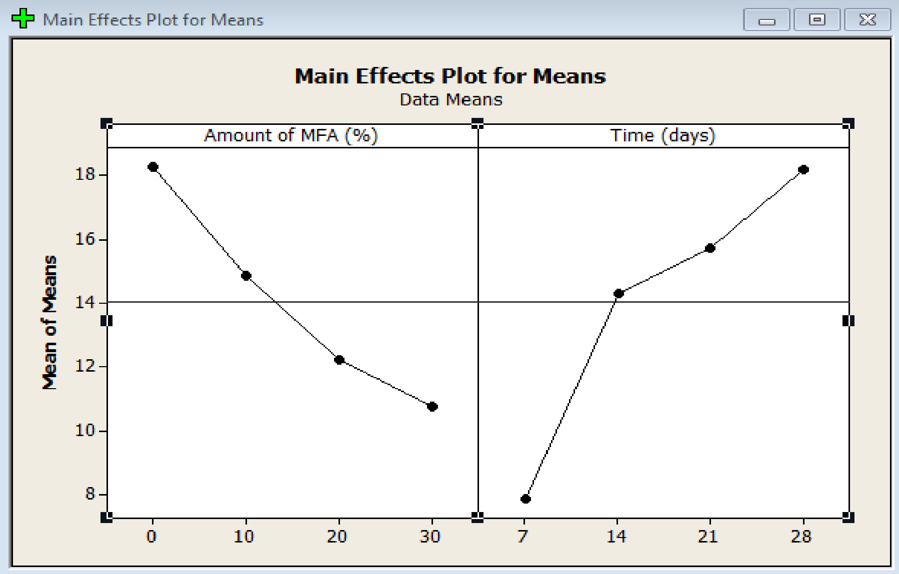

Figure 3 Effect of the variables against the compressive strength of the MFA reinforced cement

3.7.2 Response Surface Regression: compressive Strength versus Amount of MFA, Time (days)

The analysis was done using coded units on Table 10.

Table 10 Estimated Regression Coefficients for Compressive Strength (N/mm^2)

Term	Coef	SE Coef	T	P
Constant	14.6806	0.4604	31.883	0.000
Amount of MFA (%)	-3.7665	0.3042	-12.383	0.000
Time (days)	4.8353	0.3042	15.897	0.000
Amount of MFA (%)*Amount of MFA (%)	1.0659	0.5101	2.090	0.063
Time (days)*Time (days)	-2.2416	0.5101	-4.394	0.001
Amount of MFA (%)*Time (days)	-0.6322	0.4081	-1.549	0.152

S = 0.906838; PRESS = 18.4973; R-Sq = 97.74%; R-Sq(pred) = 94.91%; R-Sq(adj) = 96.61%

The estimated regression coefficients for the compressive strength of OPC/Maize Fuel Ash (MFA) concrete at various curing periods (Time in days) show that the amounts of MFA and curing time have a significant impact on the compressive strength of the concrete. Therefore, the estimated regression coefficients provide strong evidence that the amount of MFA and curing time have a significant impact on the compressive strength of MFA reinforced concrete.

Table 11 Analysis of Variance for Design Strength (N/mm^2)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	355.367	355.367	71.073	86.43	0.000
Linear	2	333.921	333.921	166.961	203.03	0.000
Amount of MFA (%)	1	126.102	126.102	126.102	153.34	0.000
Time (days)	1	207.819	207.819	207.819	252.71	0.000
Square	2	19.471	19.471	9.736	11.84	0.002
Amount of MFA (%)*Amount of MFA (%)	1	3.591	3.591	3.591	4.37	0.063
Time (days)*Time (days)	1	15.880	15.880	15.880	19.31	0.001
Interaction	1	1.974	1.974	1.974	2.40	0.152
Amount of MFA (%)*Time (days)	1	1.974	1.974	1.974	2.40	0.152
Residual Error	10	8.224	8.224	0.822		
Total	15	363.590				

The Analysis of Variance (ANOVA) table (Table 11) for the compressive strength of Maize Fuel Ash (MFA) reinforced concrete at various curing periods (Time in days) shows that the model is statistically significant and that the amounts of MFA and curing time have a significant impact on the compressive strength of the concrete.

Table 7 Estimated Regression Coefficients for Design Strength (N/mm^2) using Data in uncode units

Term	Coefficient
Constant	4.17400
Amount of MFA (%)	-0.322975
Time (days)	1.23232
Amount of MFA (%)*Amount of MFA (%)	0.00473750
Time (days)*Time (days)	-0.0203316
Amount of MFA (%)*Time (days)	-0.00401429

Mathematically, the compressive strength of OPC/MFA reinforced concrete can be predicted via the following:

$$\text{Compressive strength} = 4.17400 - 0.322975A + 1.23232B + 0.00473750A^2 - 0.0203316B^2 - 0.00401429AB \quad (1)$$

Equation (1) shows how the compressive strength of the material containing MFA can be predicted from the independent variables (A = Amount of MFA (%), B = curing time).

Table 13 Predicted Response for New Design Points Using Model for Design Strength (N/mm^2)

Point	Fit	SE Fit	95% CI	95% PI
1	11.8040	0.711160	(10.2194, 13.3886)	(9.2362, 14.3718)
2	8.7670	0.524871	(7.5975, 9.9365)	(6.4324, 11.1016)
3	6.6775	0.524871	(5.5080, 7.8470)	(4.3429, 9.0121)
4	5.5355	0.711160	(3.9509, 7.1201)	(2.9677, 8.1033)
5	17.4415	0.524871	(16.2720, 18.6110)	(15.1069, 19.7761)
6	14.1235	0.420484	(13.1866, 15.0604)	(11.8963, 16.3507)
7	11.7530	0.420484	(10.8161, 12.6899)	(9.5258, 13.9802)
8	10.3300	0.524871	(9.1605, 11.4995)	(7.9954, 12.6646)
9	21.0865	0.524871	(19.9170, 22.2560)	(18.7519, 23.4211)
10	17.4875	0.420484	(16.5506, 18.4244)	(15.2603, 19.7147)
11	14.8360	0.420484	(13.8991, 15.7729)	(12.6088, 17.0632)
12	13.1320	0.524871	(11.9625, 14.3015)	(10.7974, 15.4666)
13	22.7390	0.711160	(21.1544, 24.3236)	(20.1712, 25.3068)
14	18.8590	0.524871	(17.6895, 20.0285)	(16.5244, 21.1936)
15	15.9265	0.524871	(14.7570, 17.0960)	(13.5919, 18.2611)
16	13.9415	0.711160	(12.3569, 15.5261)	(11.3737, 16.5093)

Table 14 and Table 15 show the predicted values obtained from the regression model, and it was seen that the predicted values are 95 % certain to be within the lowest and highest possible values (i.e. 95% Confidence interval and Prediction interval) as shown in Table 1. The model predictions gave a correlation factor (R) of 0.988, with R sq. ($R^2 = 0.977$) which implies that the model predictions are 98% accurate

Table 8 Comparison between the Actual Compressive Strength Value and The Model Predicted Value

Amount of cement (%)	Amount of MFA (%)	Time (days)	Design Strength (Actual Value)	Design Strength (Predicted Value)
100	0	7	11.34	11.804
90	10	7	8.28	8.767
80	20	7	6.58	6.6775
70	30	7	5.38	5.5355
100	0	14	18.52	17.4415
90	10	14	15.1	14.1235
80	20	14	12.34	11.753
70	30	14	11.3	10.33
100	0	21	20.6	21.0865
90	10	21	16.75	17.4875
80	20	21	13.61	14.836
70	30	21	11.97	13.132
100	0	28	22.54	22.739
90	10	28	19.32	18.859
80	20	28	16.45	15.9265
70	30	28	14.36	13.9415

R = 0.988626494

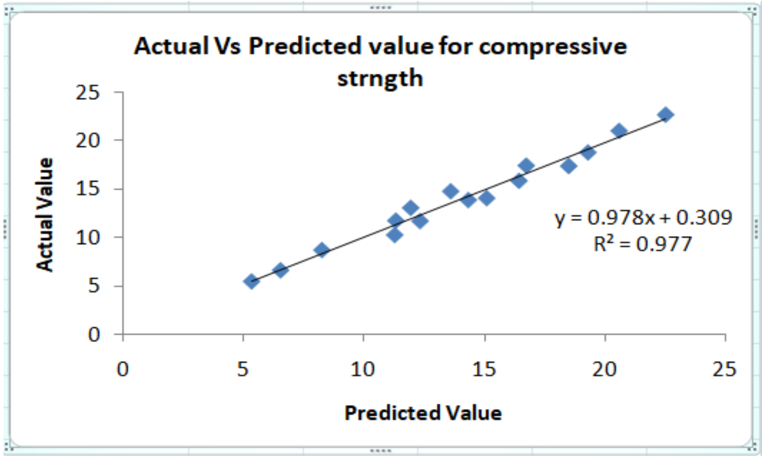

Figure 4 Actual vs Predicted value for the compressive strength

From Figure 6, we saw that there was a perfect correlation between the actual values and the predicted values, which signifies that there is a very good agreement with the model predictions and experimental value.

3.9.2 Response Surface Regression: Amount of heat released (ºC) versus Amount of MFA (%), Time (Hrs)

The analysis was done using coded units in Table 16.

Table 9 Estimated Regression Coefficients for TEMP ºC

Term	Coef	SE Coef	T	P
Constant	33.7084	0.5962	56.542	0.000
Amount of MFA (%)	-0.9246	0.4093	-2.259	0.026
Time (Hrs)	-6.3021	0.5077	-12.413	0.000
Amount of MFA (%)*Amount of MFA (%)	0.2452	0.6864	0.357	0.722
Time (Hrs)*Time (Hrs)	-1.7825	0.9469	-1.883	0.063
Amount of MFA (%)*Time (Hrs)	0.2862	0.6811	0.420	0.675

S = 3.05085; PRESS = 1043.09; R-Sq = 63.43%; R-Sq(pred) = 56.40%; R-Sq(adj) = 61.48%

The estimated regression coefficients for the amount of heat released in (Temp ºC) when reinforcing concrete with Maize fuel ash (MFA) at various curing periods (Time in days) show that the amount of MFA has a significant negative impact on the amount of heat released, while curing time has a significant negative impact on the amount of heat released. The coefficient for the amount of MFA is negative, indicating that an increase in the amount of MFA leads to a decrease in the amount of heat released. This is because MFA is a slower reacting material than cement, and it releases less heat during hydration.

Table 10 Analysis of Variance for Heat Released (ºC)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	1517.51	1517.51	303.50	32.61	0.000
Linear	2	1481.69	1481.69	740.84	79.59	0.000
Amount of MFA (%)	1	47.49	47.49	47.49	5.10	0.026
Time (Hrs)	1	1434.20	1434.20	1434.20	154.09	0.000
Square	2	34.18	34.18	17.09	1.84	0.165
Amount of MFA (%)*Amount of MFA (%)	1	1.19	1.19	1.19	0.13	0.722
Time (Hrs)*Time (Hrs)	1	32.99	32.99	32.99	3.54	0.063
Interaction	1	1.64	1.64	1.64	0.18	0.675
Amount of MFA (%)*Time (Hrs)	1	1.64	1.64	1.64	0.18	0.675
Residual Error	94	874.92	874.92	9.31		
Total	99	2392.43				

This means that the effect of the amount of MFA on the amount of heat released is not dependent on the curing time. In summary, the ANOVA table provides strong evidence that the amount of MFA and curing time have a significant impact on the amount of heat released in concrete reinforced with MFA. The model is statistically significant, and the amount of MFA and curing time are both individually significant. The interaction terms between the amount of MFA and curing time are not statistically significant. This information can be used to design concrete mixes with the desired heat release characteristics for different applications. For example, if a concrete mix with a low heat release is required, then the amount of MFA should be increased and the curing time should be decreased.

Table 4.11 Estimated Regression Coefficients for TEMP °C using data in uncoded units

Term	Coef
Constant	39.6840
Amount of MFA (%)	-0.113420
Time (Hrs)	-0.0503866
Amount of MFA (%)*Amount of MFA (%)	0.00109000
Time (Hrs)*Time (Hrs)	-4.95151E-04
Amount of MFA (%)*Time (Hrs)	0.000318000

The estimated regression coefficients for the amount of heat released in (Temp °C) when reinforcing concrete with Maize fuel ash (MFA) at various curing periods (Time in days) can be interpreted as follows (Table 4.18):

Mathematically, the estimated regression coefficients for the amount of heat released in (Temp °C) when mixing concrete with Maize fuel ash (MFA) at various curing periods (Time in days) can be represented as:

$$\text{Amount of heat released} = 39.6840 - 0.113420A - 0.0503866B + 0.00109A^2 - 0.00049515B^2 + 0.000318AB \quad (2)$$

Where

A = Amount of MFA (%),

B= Time

4.9.3 Regression Model Analysis for OPC/PLA Concrete Response Surface Regression: Compressive Strength versus Amount of PLA, Time (days)

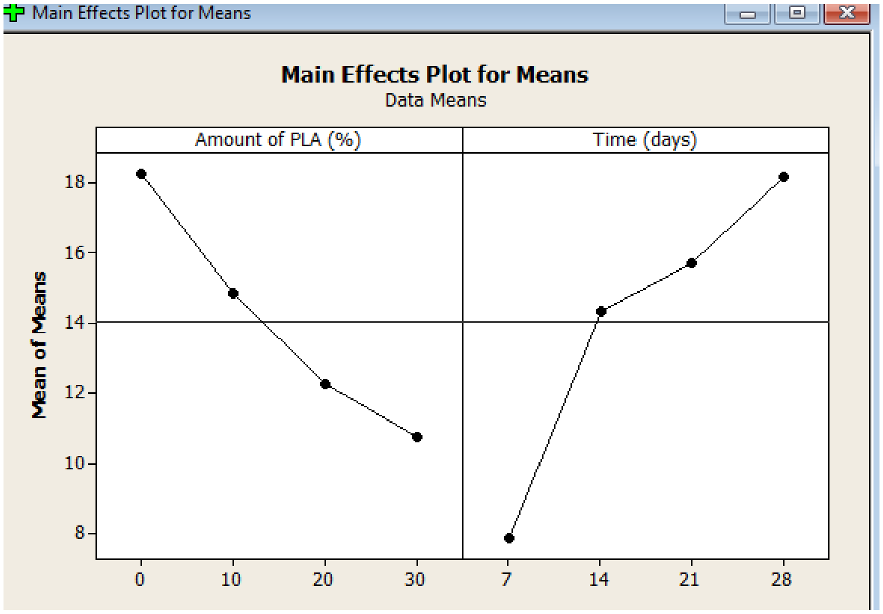

Figure 5 Effect of the variables against the compressive strength of PLA reinforced cement

Table 19 Estimated Regression Coefficients for compressive Strength (N/mm^2)

Term	Coef	SE Coef	T	P
Constant	14.6866	0.4602	31.913	0.000
Amount of PLA (%)	-3.7684	0.3040	-12.396	0.000
Time (days)	4.8326	0.3040	15.897	0.000
Amount of PLA (%)*Amount of PLA (%)	1.0589	0.5098	2.077	0.065
Time (days)*Time (days)	-2.2486	0.5098	-4.411	0.001
Amount of PLA (%)*Time (days)	-0.6280	0.4079	-1.540	0.155

S = 0.906350; PRESS = 18.4226; R-Sq = 97.74%; R-Sq(pred) = 94.93% ; R-Sq(adj) = 96.61%
The estimated regression coefficients for the compressive strength of Plantain leaf ash (PLA) reinforced concrete at various curing periods (Time in days) show that:
Overall, the regression coefficients provide valuable insights into the relationship between the amount of PLA, curing time, and the compressive strength of PLA reinforced concrete. This information can be used to optimize the design and performance of PLA reinforced concrete structures.

Table 12 Analysis of Variance for Compressive Strength (N/mm^2)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	355.293	355.293	71.059	86.50	0.000
Linear	2	333.821	333.821	166.911	203.19	0.000
Amount of PLA (%)	1	126.228	126.228	126.228	153.66	0.000
Time (days)	1	207.593	207.593	207.593	252.71	0.000
Square	2	19.524	19.524	9.762	11.88	0.002
Amount of PLA (%)*Amount of PLA (%)	1	3.544	3.544	3.544	4.31	0.065
Time (days)*Time (days)	1	15.980	15.980	15.980	19.45	0.001
Interaction	1	1.947	1.947	1.947	2.37	0.155
Amount of PLA (%)*Time (days)	1	1.947	1.947	1.947	2.37	0.155
Residual Error	10	8.215	8.215	0.821		
Total	15	363.507				

The Analysis of Variance (ANOVA) (Table 20) for the compressive strength of Plantain leaf ash (PLA) reinforced concrete at various curing periods (Time in days) shows that the regression model is statistically significant (p-value < 0.05).

Table 13 Estimated Regression Coefficients for Design Strength (N/mm^2) using data in uncoded units

Term	**Coefficient**
Constant	4.16675
Amount of PLA (%)	-0.322638
Time (days)	1.23390
Amount of PLA (%)*Amount of PLA (%)	0.00470625
Time (days)*Time (days)	-0.0203954
Amount of PLA (%)*Time (days)	-0.00398714

The constant term represents the expected compressive strength of PLA reinforced concrete with no PLA and a curing time of zero days. The coefficient for the amount of PLA term is negative, indicating that the compressive strength decreases with increasing PLA content. The coefficient for the time term is positive, indicating that the compressive strength increases with curing time. The interaction term between PLA and curing time is negative, indicating that the effect of PLA on compressive strength is greater at longer curing times. Thus the regression coefficients for PLA reinforced concrete can be represented mathematically as:

$$\text{Compressive Strength} = 4.16675 - 0.322638A + 1.23390B + 0.0047063A^2 - 0.020395B^2 - 0.000398714AB \quad (3)$$

Where A = Amount of PLA (%), B= Time

Table 14 Predicted Response (OPC/PLA Concrete) for New Design Points Using Model for Design Strength (N/mm^2)

Point	Fit	SE Fit	95% CI	95% PI
1	11.8047	0.710777	(10.2209, 13.3884)	(9.2383, 14.3710)
2	8.7698	0.524588	(7.6009, 9.9387)	(6.4365, 11.1031)
3	6.6762	0.524588	(5.5073, 7.8451)	(4.3429, 9.0095)
4	5.5238	0.710777	(3.9401, 7.1076)	(2.9575, 8.0902)
5	17.4438	0.524588	(16.2749, 18.6127)	(15.1105, 19.7771)
6	14.1299	0.420257	(13.1935, 15.0662)	(11.9038, 16.3559)
7	11.7571	0.420257	(10.8208, 12.6935)	(9.5311, 13.9832)
8	10.3257	0.524588	(9.1568, 11.4946)	(7.9924, 12.6590)
9	21.0842	0.524588	(19.9153, 22.2531)	(18.7509, 23.4175)
10	17.4912	0.420257	(16.5548, 18.4275)	(15.2651, 19.7172)
11	14.8394	0.420257	(13.9030, 15.7757)	(12.6133, 17.0654)
12	13.1288	0.524588	(11.9599, 14.2977)	(10.7955, 15.4621)
13	22.7259	0.710777	(21.1421, 24.3096)	(20.1595, 25.2922)
14	18.8537	0.524588	(17.6848, 20.0226)	(16.5204, 21.1870)
15	15.9228	0.524588	(14.7539, 17.0917)	(13.5895, 18.2561)
16	13.9331	0.710777	(12.3494, 15.5169)	(11.3668, 16.4995)

Overall, the regression coefficients provide valuable insights into the relationship between the amount of PLA, curing time, and the compressive strength of PLA reinforced concrete. This information can be used to optimize the design and performance of PLA reinforced concrete structures.

Table 15 Comparison between the Actual compressive strength value and the model predicted Value

Amount of cement (%)	Amount of PLA (%)	Time (days)	Design Strength (Actual Value)	Design Strength (Predicted Value)
100	0	7	11.35	11.8047
90	10	7	8.28	8.7698
80	20	7	6.57	6.6762
70	30	7	5.37	5.5238
100	0	14	18.51	17.4438
90	10	14	15.11	14.1299
80	20	14	12.35	11.7571
70	30	14	11.3	10.3257
100	0	21	20.6	21.0842
90	10	21	16.75	17.4912
80	20	21	13.62	14.8394
70	30	21	11.96	13.1288
100	0	28	22.53	22.7529
90	10	28	19.31	18.8537
80	20	28	16.45	15.9228
70	30	28	14.35	13.9331

R = 0.988620429

Table 22 and Table 23 show the predicted values obtained from the regression model, and it was seen that the predicted values are 95 % certain to be within the lowest and highest possible values (i.e. 95% Confidence interval and Prediction interval) as shown in Table 23.

The model predictions gave a correlation factor (R) of 0.988, with Rsq ($R^2 = 0.977$) which implies that the model predictions are 98% accurate. From Figure 8, there is a perfect correlation between the actual values and the predicted values, which signifies that there is a very good agreement with the model predictions and experimental results.

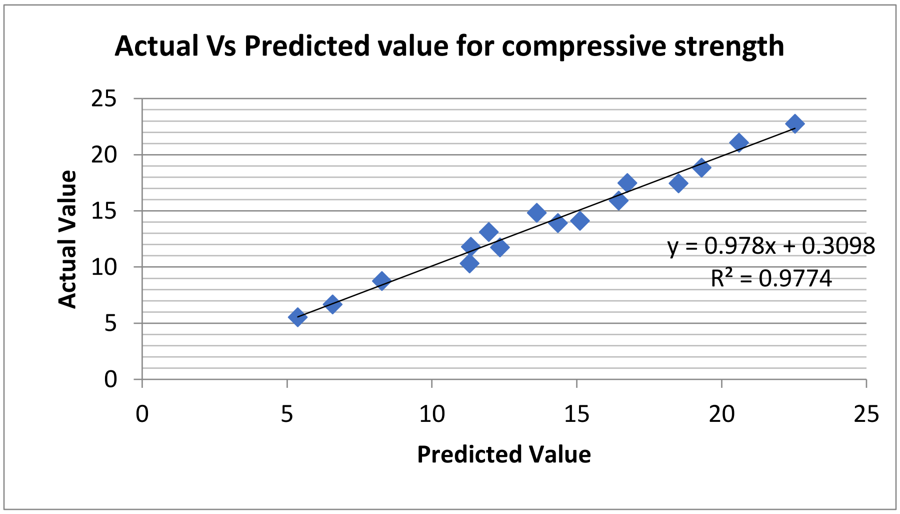

Figure 6 Actual Vs Predicted value for compressive strength of OPC/PLA Concrete

3.9.4 Response Surface Regression: Heat released (ºC) versus Amount of PLA (%), Time (Hrs)

The analysis was done using coded units in Table 24.

Table 16 Estimated Regression Coefficients for TEMP ºC

Term	Coef	SE Coef	T	P
Constant	32.0859	0.5128	62.570	0.000
Amount of PLA (%)	-0.9810	0.3521	-2.786	0.006
Time (Hrs)	-6.4860	0.4367	-14.852	0.000
Amount of PLA (%)*Amount of PLA (%)	0.5107	0.5904	0.865	0.389
Time (Hrs)*Time (Hrs)	2.2744	0.8144	2.793	0.006
Amount of PLA (%)*Time (Hrs)	0.4273	0.5859	0.729	0.468

S = 2.62421; PRESS = 796.186; R-Sq = 71.64%; R-Sq(pred) = 65.12%; R-Sq(adj) = 70.13%

In conclusion, the regression coefficients provide valuable insights into the relationship between the amount of PLA, curing time, and the amount of heat released in PLA reinforced concrete. This information can be used to optimize the design and performance of PLA reinforced concrete structures.

Table 17 Analysis of Variance for Amount of heat released (TEMP ºC)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	1635.11	1635.11	327.02	47.49	0.000
Linear	2	1572.59	1572.59	786.30	114.18	0.000
Amount of PLA (%)	1	53.46	53.46	53.46	7.76	0.006
Time (Hrs)	1	1519.13	1519.13	1519.13	220.60	0.000
Square	2	58.86	58.86	29.43	4.27	0.017
Amount of PLA (%)*Amount of PLA (%)	1	5.15	5.15	5.15	0.75	0.389
Time (Hrs)*Time (Hrs)	1	53.70	53.70	53.70	7.80	0.006
Interaction	1	3.66	3.66	3.66	0.53	0.468
Amount of PLA (%)*Time (Hrs)	1	3.66	3.66	3.66	0.53	0.468
Residual Error	94	647.33	647.33	6.89		
Total	99	2282.44				

The Analysis of Variance (ANOVA) (Table 25) for the amount of heat released in (Temp ºC) when reinforcing concrete with Plantain leaf ash (PLA) at various curing periods (Time in days) shows that the regression model is statistically significant (p-value < 0.05). This means that the model explains a significant proportion of the variation in the heat release data. The F-statistic of 47.49

for the regression model is highly significant (p-value < 0.001). This indicates that the model is a good fit for the data and can be used to predict the amount of heat released in concrete reinforced with PLA at various curing periods. The ANOVA table also shows that all of the individual terms in the model are statistically significant (p-value < 0.05), except for the interaction term between PLA and time. This means that the amount of PLA, curing time, and the square of the curing time all have a significant impact on the amount of heat released in PLA reinforced concrete, but the interaction between PLA and time does not. The R-squared value of 0.7164 indicates that the model explains a large proportion of the variation in the heat release data. The adjusted R-squared value of 0.7013 is also high, indicating that the model is not overfitting the data. Invariably, the ANOVA table shows that the regression model is statistically significant and provides a good fit for the data. All of the individual terms in the model are statistically significant, except for the interaction term between PLA and time, indicating that they all have a significant impact on the amount of heat released in PLA reinforced concrete.

Table 18 Estimated Regression Coefficients for Amount of heat released (TEMP ^oC)

Term	**Coefficient**
Constant	43.7363
Amount of PLA (%)	-0.164360
Time (Hrs)	-0.197352
Amount of PLA (%)*Amount of PLA (%)	0.00227000
Time (Hrs)*Time (Hrs)	0.000631773
Amount of PLA (%)*Time (Hrs)	0.000474769

The constant term represents the expected amount of heat released in PLA reinforced concrete with no PLA and a curing time of zero hours. The coefficient for the amount of PLA term is negative, indicating that the amount of heat released decreases with increasing PLA content. The coefficient for the time term is negative, indicating that the amount of heat released decreases with curing time. The interaction term between PLA and curing time is negative, indicating that the effect of PLA on heat release is greater at longer curing times. The regression coefficients provide valuable insights into the relationship between the amount of PLA, curing time, and the amount of heat released in PLA reinforced concrete. Mathematically, the estimated regression coefficients for the amount of heat released in (Temp °C) when reinforcing concrete with PLA at various curing periods (Time in days) can be represented as:

$$\text{Amount of heat released} = 43.7363 - 0.164360A - 0.197352B + 0.00227000A^2 + 0.000631773B^2 + 0.000474769AB \quad (4)$$

Where

A = Amount of PLA (%),

B = Time

4. Conclusion

The study investigated how Maize Fuel Ash (MFA) and Plantain Leaf Ash (PLA) affect the heat of hydration and compressive strength of concrete. Eight concrete mixes were tested: a control mix with 100% Ordinary Portland Cement (OPC), and mixes with 10%, 20%, and 30% MFA or PLA.

Key findings include:

i.) **Compressive Strength**: Increasing MFA reduces compressive strength, while longer curing times improve it. The negative interaction between MFA and curing time suggests that higher MFA content exacerbates strength reduction over longer curing periods. All coefficients related to compressive strength were statistically significant ($p < 0.05$).

ii.) **Heat of Hydration**: MFA significantly reduces the amount of heat released. Both MFA content and curing time negatively impact heat release, with the model explaining a moderate amount of variation ($R^2 = 63.43\%$, adjusted $R^2 = 61.48\%$).

iii.) **PLA Effects**: The regression models for PLA-reinforced concrete showed that both compressive strength and heat release were well-explained by the models, with highly significant ANOVA results (F-statistic of 86.50 for compressive strength and 47.49 for heat release, both $p < 0.001$).

Overall, the study demonstrates that MFA and PLA significantly influence concrete's performance, with the models showing good predictive power for both compressive strength and heat release.

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