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Chicken Feather Ash (CFA) as a Partial Replacement of Cement in Concrete

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Authors' contributions

This work was carried out in collaboration among all authors. Author VEA designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors VEA and EU managed the analyses of the study. Author JM managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Every day, large quantities of chicken feathers are disposed of as waste at markets where birds are slaughtered and sold for meat. The possibility of using Chicken feather ash (CFA) as a partial replacement of cement in the concrete making was investigated. Water-cement ratio and percentage CFA used for replacement were chosen as variables in the design of the experiment. Compressive strength and workability were chosen as the required responses to observe and analyzed using response surface methodology. Full factorial design was used for the design of experiment, with CFA replacement and water-cement ratio ranging from 2 – 11% and 0.3 – 0.7 % by mass respectively. There were 27 trial mixes and the freshly made concrete mix was tested for workability. Concrete cubes were molded and cured for 7 and 14 days and were crushed to determine the compressive strength. It was found that as the CFA percentage increases, the workability of the concrete increases making it more fluid. The optimum water-cement ratio was observed to range from 0.49 to 0.51 % as the curing age increases. The optimum compressive strength was observed to range from 15.6 to 18.6 N/mm^2 as the curing age increased. However, the allowable range of CFA to be used for concrete making is 3.8 to 6.34 % beyond which compressive strength reduces.

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1. INTRODUCTION

Admixtures are constituents other than aggregate, hydraulic cement, and water that are used as an ingredient of concrete or mortar which is added to the batch during or immediately before mixing. These materials are essential products that can serve as good Pozzolans, which are materials with an amorphous siliceous and aluminous content that react with calcium hydroxide in the presence of water to form cementitious hydration products [1]. Admixtures are added in concrete to improve the quality of concrete some of which include fly ash (FA), silica fume (SF), ground granulated blast furnace slag (GGBS), metakaolin (MK), and rice husk ash (RHA) which possess certain characteristics through which they influence the properties of concrete differently[2]. In general, using admixtures in concrete increases workability, accelerating or retarding setting time, controlling the development of concrete strength, and enhancing durability to deterioration process [3,4].

Admixtures vary widely in chemical composition, they are used to improve the behaviour of concrete under a variety of conditions and they are of two basic types which are mineral and chemical admixtures. Chemical admixtures are used to advance the quality of concrete during mixing, transporting, placing, and also in curing. They help to reduce the cost of construction, modify the properties of hardened concrete, and also ensuring that the quality of the concrete is intact. Chemical admixtures could either be air entrainers, water reducers, set retarders, super plasticizers or set accelerators [5]. Mineral admixtures on the other hand also help make mixtures more economical, they also reduce permeability, increase strength, and also influence other concrete properties. The most important constituents of any mineral admixture are silica and alumina oxides. Mineral admixture influences the nature of the hardened concrete through hydraulic or pozzolanic activity. The benefits of mineral admixtures are associated with the hardened properties of concrete, however, they also influence the properties of wet concrete between the time of mixing and hardening in ways such as water demand, heat of hydration and setting time [2].

Many waste materials are increasingly being investigated to determine the suitability in the concrete making as a partial replacement of cement. Amah et al. [6] reported the use of palm tree leaf ash as a possible partial replacement of cement in concrete making. A 28-day compressive strength of 17.699 N/mm^2 was achieved with up to 5% partial replacement of cement with palm tree leaf ash. Bawankule et al. [7] investigated the use of rice husk ash in concrete making. It was concluded that up to 10 % can be done to achieve the best results. Otoko [8] reported that up to 2% of bagasse ash can be used in concrete making without adversely affecting the properties of the concrete. Corn cob ash was used in partial replacement of cement and it was discovered that The 28 days compressive strength for 5% replacement was 28.78N/mm^2 [9]. Owolabi et al. [10] also carried out similar studies and reported that the optimum compressive strength of 21.44N/mm^2 was obtained at 5% replacement at 28 days of age. Using 15% banana leaf ash and 1.5% Glass Fibre, [11] were able to increase the Compressive, Flexural & Split tensile strength of concrete. Zaid and Ghorpade [12] studied the partial replacement of cement with snail shell ash. The Compressive Strength of the Concrete Cube Specimen shows a 7.50% increase in strength for 5% replacement for 28 days over the control mix of 0% replacement. Further replacement beyond 5% results in the loss of strength. Amin et al. [13] showed that utilization of waste materials in the production of masonry units can be used as an effective way to discard waste which further prevents the rapid depletion of the natural resources. In this study, chicken feather ash (CFA) is being investigated to determine the possibility of use as a partial replacement of cement in concrete making.

2. METHODOLOGY

2.1 Sample Collection and Preparation

The samples used for this research are the chicken feather ash, ordinary portland cement, river sand, gravel stone and water. The chicken feathers were collected from Rumuokoro slaughterhouse, Rivers state. They were washed to remove all impurities and then sun-dried for 7 days. The dried feathers were burnt in an open vessel until ash was obtained. The ash was pulverized and sieved to remove larger chunks and then taken to the laboratory for analysis. The river sand and gravel were acquired from a local dealer of river sand and gravel at Choba, Port Harcourt Rivers State. The water used for the concrete mixture was borehole water from the University of Port Harcourt.

2.2 Particle Size Distribution Test

The particle size distribution test helps to properly place the coarse aggregate in its right zone. Sieve analysis helps to determine the aggregate uniformity grading and distribution. The sieve analysis was done according to BS 812 part 103:1 of 1985. Various sizes of sieves were used as specified by the BS code, aggregates were passed through them, and particles left over the sieves were collected and weighed.

2.3 Experimental Design

The experimental method used was developed from the full factorial design experiment of 3 levels which was generated by XL-STAT 2014. There were 27 different trial mixes. Water/cement ratio was varied from 0.3 – 0.7 and partial replacement of cement with admixture in percentages ranged from 2% - 20% by mass. Other materials like sand and gravel were kept constant all through. The design of experiment is shown in Table 1.

Table 1. Design of experiment (Full factorial design with 3 levels)

Experiment	Water Cement ratio(%)	CFA ratio(%)
Exp 1	0.3	2
Exp 2	0.5	2
Exp 3	0.7	2
Exp 4	0.3	11
Exp 5	0.5	11
Exp 6	0.7	11
Exp 7	0.3	20
Exp 8	0.5	20
Exp 9	0.7	20

2.4 Concrete Molding

Concrete cubes were molded in molds with dimension 150 mm by 150 mm by 150 mm and was done adopting 1:2:4 design mix. The concrete was molded in accordance to BS- 1881- Part- 116-83. The partial replacement of cement using admixtures and water/cement ratio was done according to the design of experiment gotten from a response surface model.

2.5 Experimental Tests

2.5.1 Slump test

The essence of slump test was to analyze the concrete mix, by its consistency because the water/cement ratio was being varied. The value of slump varies from concrete to concrete depending on its usage. This was done according to BS EN 12350-2. A truncated steel cone was used to determine the slump of freshly mixed concrete. The cone was 30 cm high, 20 cm base diameter and 10 cm top diameter.

2.5.2 Water absorption test

Water absorption rate of concrete depends on the pores present in the concrete. This test was carried out to determine the rate of absorption of water by the concrete, by measuring the increase in the mass of the concrete after immersing in water during curing time of 7 and 14 days. This was done according to BS 1881-122:2011. The rate of water absorption was measured in percentage as a function of time.

2.5.3 Test for compressive strength

Concrete cubes were molded with different water/cement ratios and different percentages of admixture. The concrete mix was thoroughly done for it to be uniform before filling up the lubricated cast-iron molds. The molded concrete cubes were left for 24 hours to set before curing by full immersion to promote hydration, eliminate shrinkage and absorb heat of hydration until the day of the test. The design of experiment consisted of 9 different experiments. Six cubes were prepared for each experiment, 3 to be cured for 7 days and 3 for 14 days. Before crushing the cubes, they were brought out of the tank, weighed and then air-dried for about 2 hours. The compressive strengths of the cubes were tested in accordance to BS- 1881- Part- 116-83 using a universal testing machine and the results were used to determine the compressive strength of the curing time of each concrete specimen.

2.6 Sieve Analysis

The particle size distribution of the river sand and coarse aggregate were analyzed according to BS 812 part 103:1 of 1985 and the result shown as Figs. 1 and 2 respectively. A total mass of 500 g was used for this analysis for both sand and coarse aggregate. According to BS 410-2 2000 and Fig. 1, the fine aggregate is Zone-2 sand which is medium-fine sand and is good for concrete making. Fig. 2 shows that the coarse aggregate corresponds to 16 mm nominal size aggregate.

3. RESULTS AND DISCUSSION

Diffraction analysis was done on the chicken feather ash and the result is shown in Fig. 3. It can be observed that the chemical constituents detected and their percentages are Sulfur (S) 46.5 %, Carbon (C) 44.6 %, Nitrogen (N_2) 5.6 % and Carbon dioxide (CO_2) 3.2 %.

3.1 Slump Test of Fresh Concrete

The slump test was done on all 9 experiments to determine the workability of the freshly mixed concrete with different mix and admixture proportions. The result for the slump is shown in Figs. 4 and 5. As observed in Fig. 4, the workability of the concrete increased as the admixture percentage was increased. This means that the freshly mixed concrete will become more fluid as the admixture proportion was increased. Fig. 5 shows the effect the increase in water/cement ratio has on the workability. It can be observed that workability increased until an optimum water/cement ratio was achieved at 0.57, beyond which the workability reduces.

3.2 Water Absorption Test

The water absorption test was done every four days until the curing age was complete for both 7 days cubes and 14 days cubes. Figs. 6 and 7 show the rate of water absorption by the concrete at 7 days and 14 days curing respectively. It is observed that the water absorption increased continually for 7 days and up to 14 days.

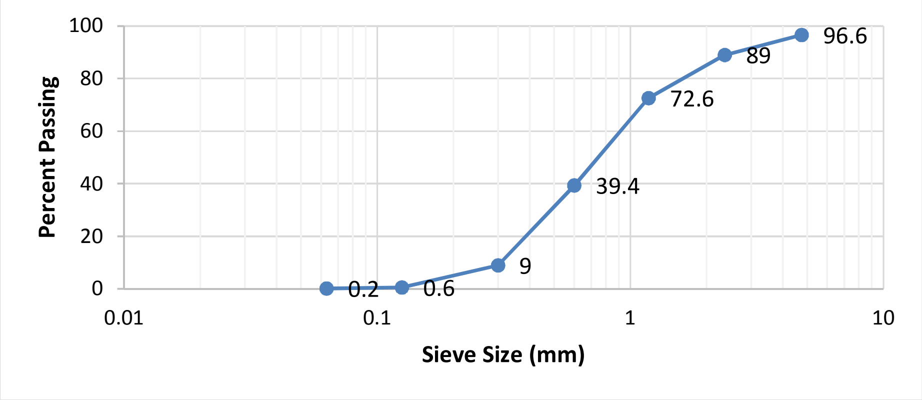


Fig. 1. Sieve analysis chart for fine aggregates

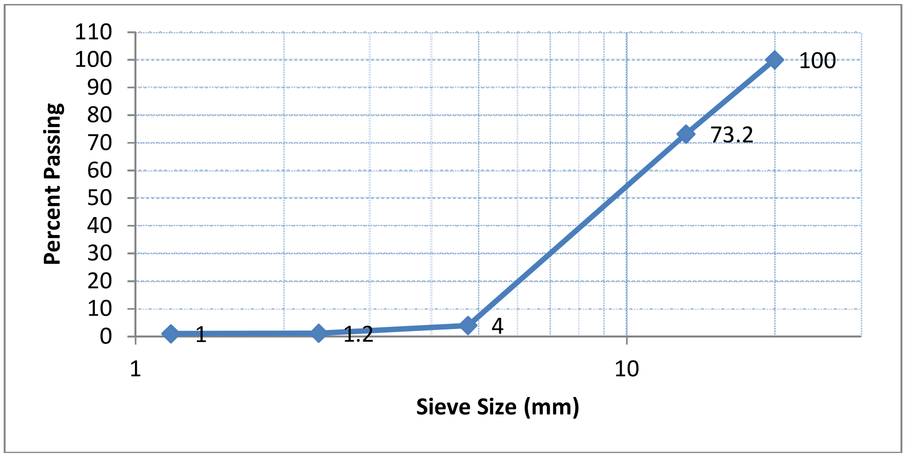


Fig. 2. Sieve analysis chart for coarse aggregates

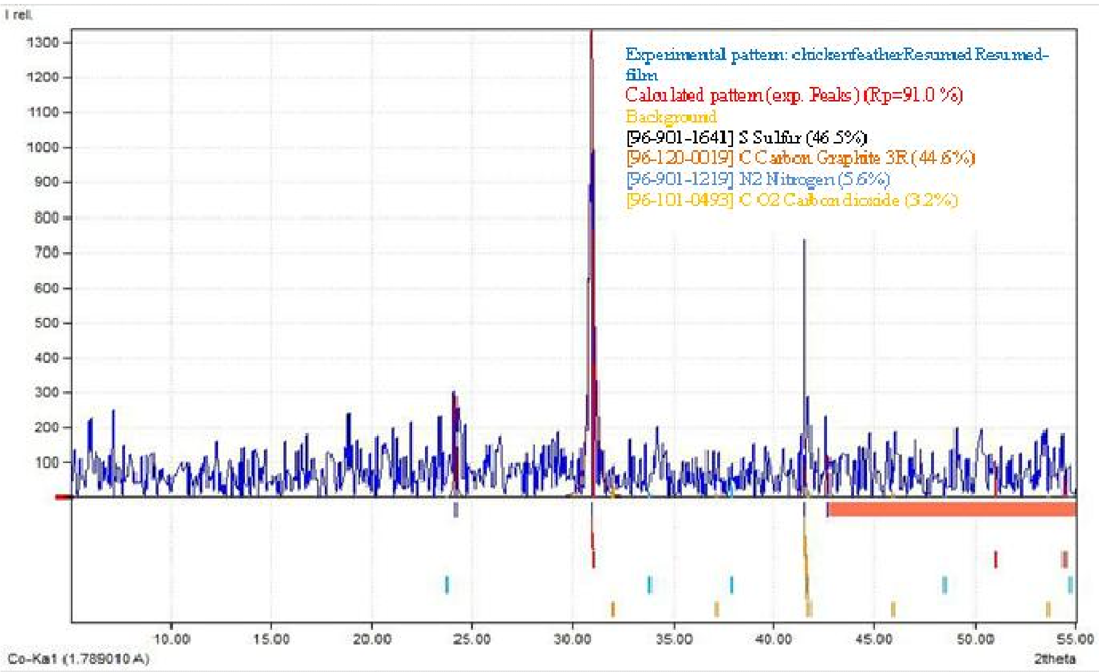


Fig. 3. Diffraction analysis of chicken feather ash

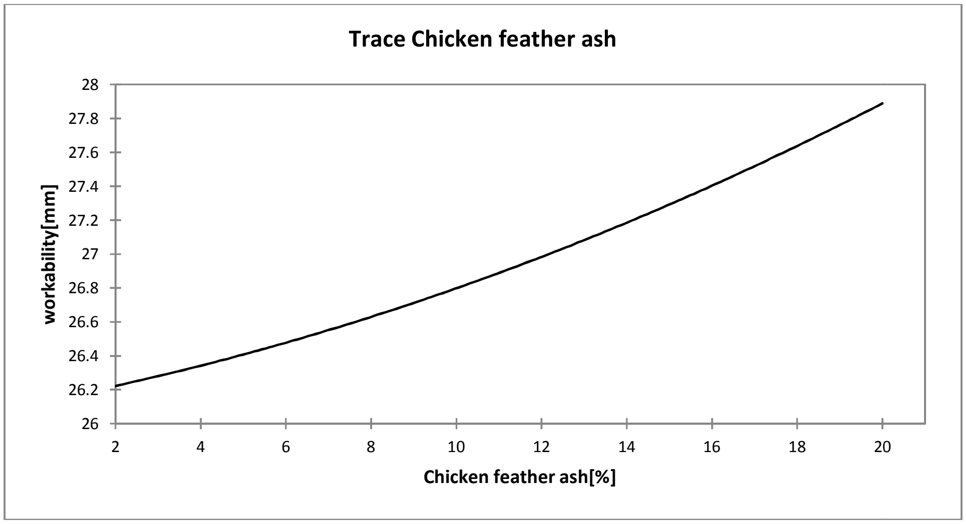


Fig. 4. Workability against chicken feather ash

The total water absorbed during the 7 and 14 days curing period was determined and is presented in Fig. 8. It can be observed in Fig. 8 that experiments 2 and 7 had the highest and least water absorbed respectively during the 7 days curing period. However, during the 14 days curing period experiments 3 and 9 had the highest and least water absorbed respectively during this time.

3.3 Concrete Compressive Strength

After curing for 7 days and 14 days, the concrete cubes were crushed and the results presented in Table 2. The compressive strengths of the cubes were tested in accordance to BS- 1881- Part-116-83 using universal testing machine and the results were used to determine the compressive strength of the curing time of each concrete specimen.

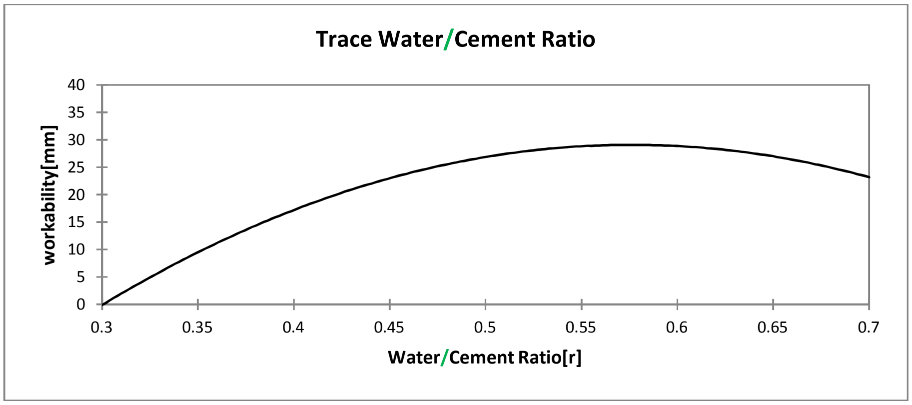


Fig. 5. Workability against water/cement ratio

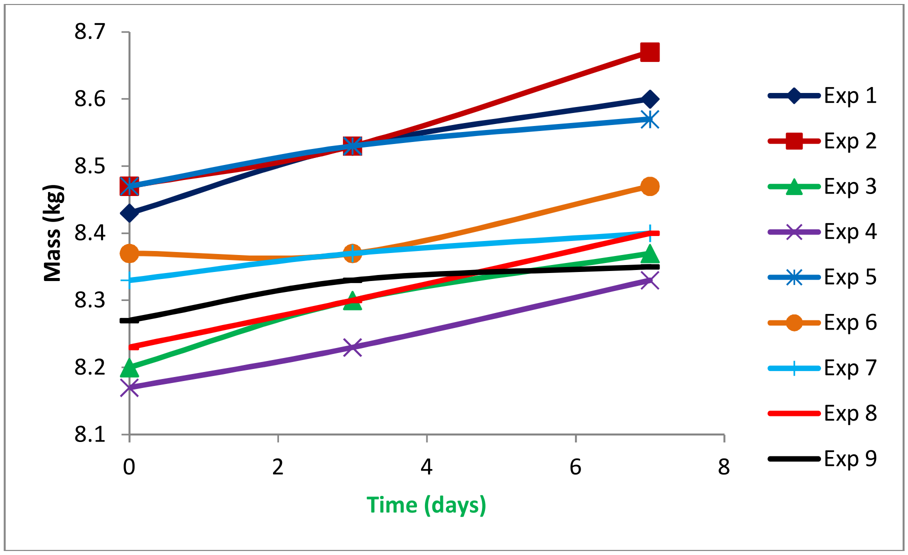


Fig. 6. 7 days water absorption rate

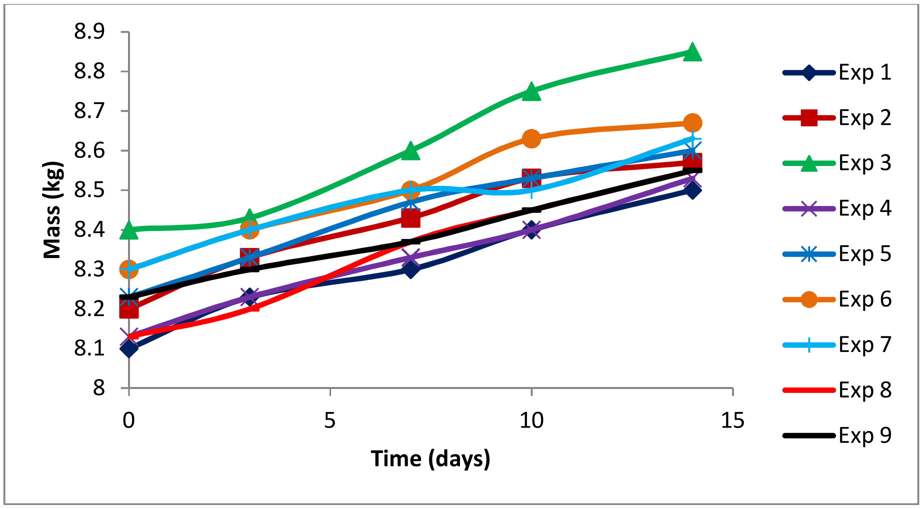


Fig. 7. 14 days water absorption rate

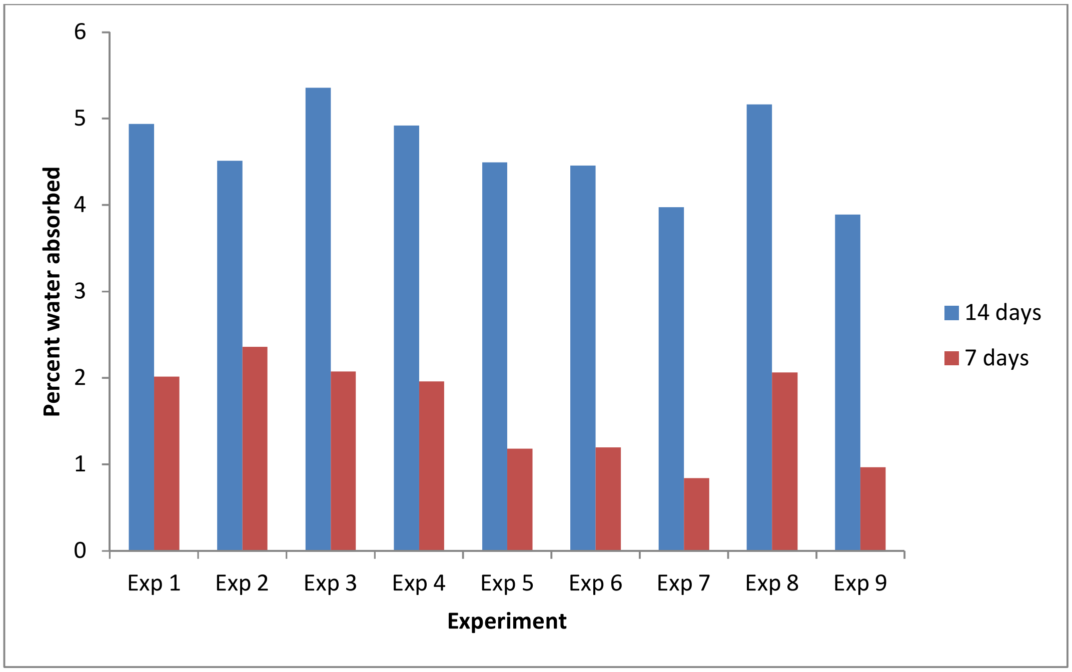


Fig. 8. Percentage of water absorbed after 7 and 14 days curing

Table 2. Compressive strengths of cured concrete cubes

Experiment	Water/ Cement ratio	Admixture ratio	7 days Compressive strength (N/mm^2)	14 days Compressive strength (N/mm^2)
Exp 1	0.3	2	12.2	13.1
Exp 2	0.5	2	13.6	17.23
Exp 3	0.7	2	13.9	17.78
Exp 4	0.3	11	11.2	15,17
Exp 5	0.5	11	14.7	16.54
Exp 6	0.7	11	12.2	16.29
Exp 7	0.3	20	11.2	14.8
Exp 8	0.5	20	13.6	16.09
Exp 9	0.7	20	6.3	10.4

Trace plots were made to establish the relationship between the compressive strength, the water/cement ratio and the admixture proportion. Figs. 9 and10 show the 7 and 14 days compressive strength relationship with water/cement ratio and admixture proportion respectively.

As seen in Figs. 9 and 10, which is the plot of compressive strength against water/cement ratio, at 7 days a parabolic curve is observed and the optimum strength of 14.57N/mm^2 is attained at a water/cement ratio of 0.49%. Compressive strength was optimum at 15.13N/mm^2 with an admixture ratio of 3.8%. At 14 days it is observed that optimum strength of 17.36 N/mm^2 is attained at a water/cement ratio of 0.51%. Compressive strength was optimum at 17.7 N/mm^2 with an admixture ratio of 6.34%. Fig. 11 and 12 shows the interaction between these parameters in a 3-D plot. When water/cement ratio and CFA are at the optimum, compressive strength is observed to range from 15.6 to 16.8 N/mm^2 at 7 days and 17.4 to 18.6 N/mm^2 at 14 days. From the result of the average compressive strength of concrete for 7 and 14 days of curing, we can deduce that the concrete strength met the minimum required standard for 7 and 14 days of curing which is 65% and 90% of 15 N/mm^2 the minimum standard 28days of curing strength.

The interaction between compressive strength with varying CFA and water/cement ratio is represented mathematically as Equation (1).

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_1^2 + \beta_4 x_2^2 + \beta_{12} x_1 x_2 \quad (1)$$

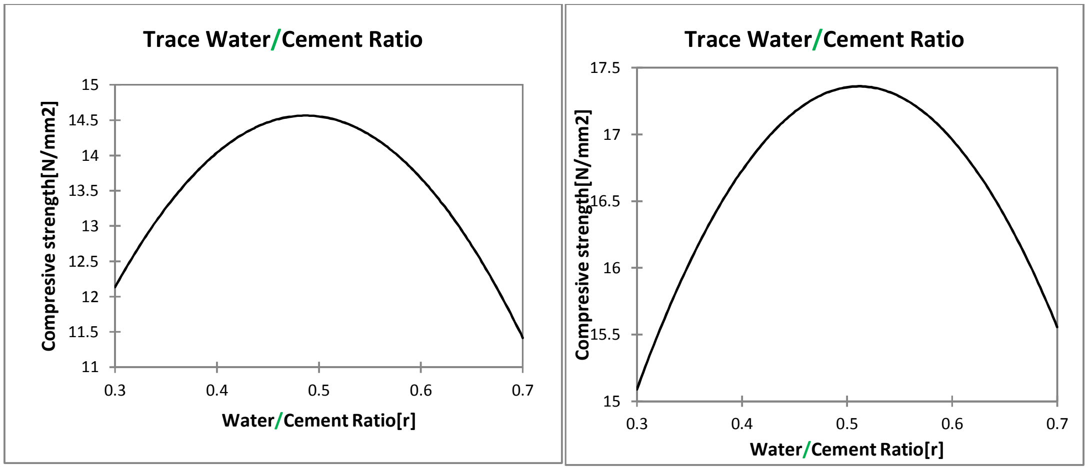
β_0 = constant which represents the mean of the response
βi = constants which estimates the main effects of the factors X_I on the response
βij = two factor interactions
Y = compressive strength
x_1 = water/cement ratio
x_2 = admixture

Equation (1) is calibrated by regression analysis and presented as Equation (2) and (3) which represent 7 and 14 days compressive strength models respectively.

$$Y = 14.55333 - 1.45333{*}x_2 - 0.36000{*}x_1 - 0.91000{*}x_2^2 - 2.78000{*}x_1^2 - 1.64000{*}x_1 x_2 \quad (2)$$

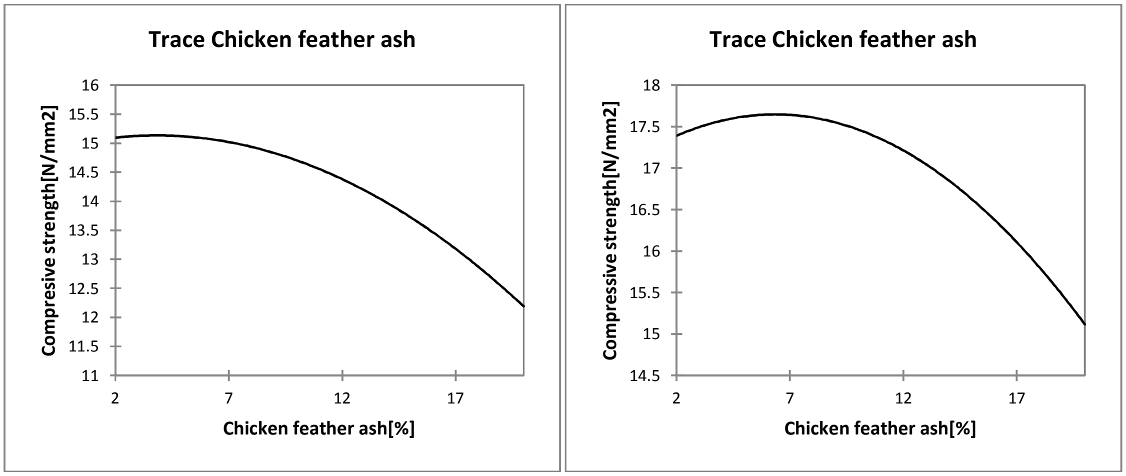
$$Y = 17.35333 - 1.13667{*}x_2 + 0.23333{*}x_1 - 1.10000{*}x_1^2 + 2.03000{*}x_2^2 - 2.27000{*}x_1 x_2 \quad (3)$$

Compressive strength and predicted compressive strength was plotted and shown as Figs. 13 and 14. The 7 and 14 days coefficient of determination "R^2" obtained was 0.83 and 0.93 respectively. These were tested at 5 % level of significance and the null hypothesis was rejected. Therefore, Equation (2) and (3) can be used to predict 7 and 14 days compressive strength.



(a) (b)

Fig. 9. Compressive strength against water/cement ratio for (a) 7 days (b) 14 days



(a) (b)

Fig. 10. Compressive strength against admixture ratio for (a) 7 days (b) 14 days

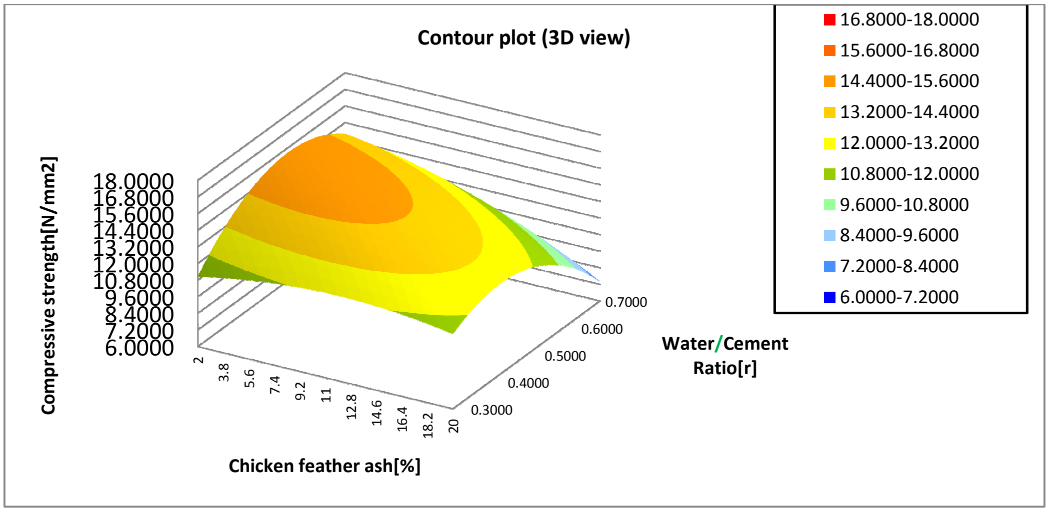


Fig. 11. 7 days compressive strength at varying CFA and water/cement ratio

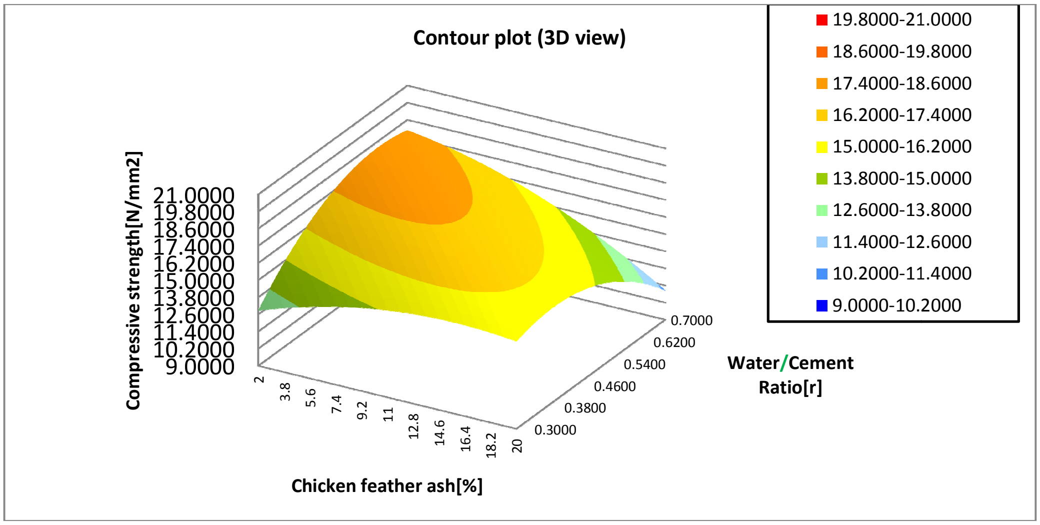


Fig. 12. 14 days Compressive strength at varying CFA and water/cement ratio

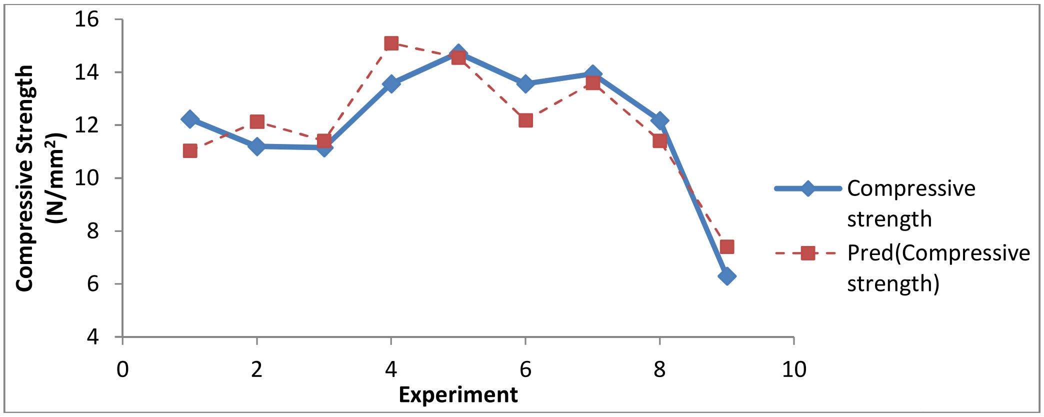


Fig. 13. Modeled 7 days compressive strength

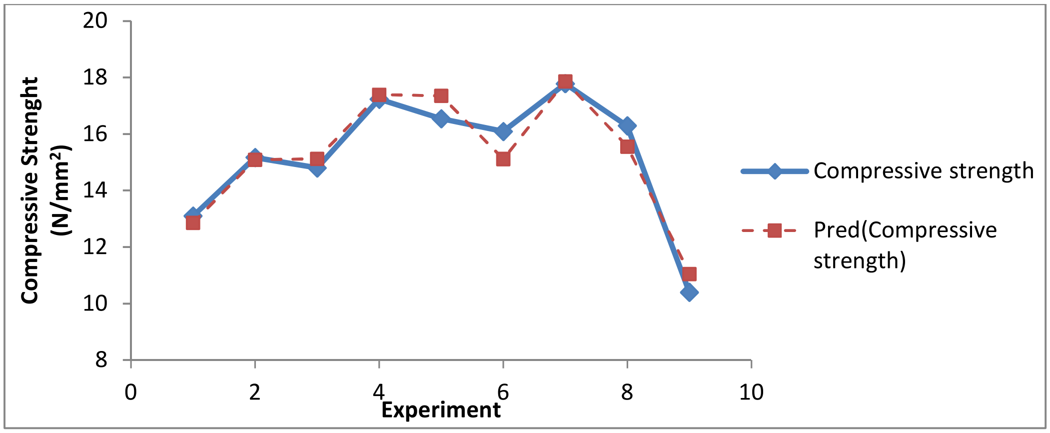


Fig. 14. Modeled 14 days compressive strength

4. CONCLUSION

The workability of the freshly mixed concrete was observed to improve with increasing percentage replacement of cement with CFA. However, an optimum water/cement ratio was determined to be 0.57 for maximum workability. The optimum strength of 14.57 N/mm^2 and 15.13 N/mm^2 is attained at a water/cement ratio of 0.49% and an admixture ratio of 3.8% respectively for 7 days curing. The optimum strength of 17.36 N/mm^2 and 17.7 N/mm^2 is attained at a water/cement ratio of 0.51% and an admixture ratio of 6.34% respectively for 14 days curing. When water/cement ratio and CFA are at an optimum, compressive strength is observed to range from 15.6 to 16.8 N/mm^2 and 17.4 to 18.6 N/mm^2 for 7 days and 14 days curing respectively. The compressive strength models derived had R^2 values of 0.83 and 0.93 and can be used for predictions when CFA is used for partial replacement of cement. These results indicate that the admixture can be used in concrete making with up to 6 % replacement of cement with CFA.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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