Scientific Research Publishing

Open Journal of Civil Engineering, 2023, 13, 83-102
https://www.scirp.org/journal/ojce
ISSN Online: 2164-3172
ISSN Print: 2164-3164

Factorial Experimental Design to Study the Effects of Layers and Fiber Content on Concrete Flexural Behavior

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How to cite this paper: Odia, D.H. (2023) Factorial Experimental Design to Study the Effects of Layers and Fiber Content on Concrete Flexural Behavior. *Open Journal of Civil Engineering*, **13**, 83-102.
https://doi.org/10.4236/ojce.2023.131006

Received: February 3, 2023
Accepted: March 13, 2023
Published: March 16, 2023

Abstract

Experimentation has come a long in helping researchers achieve breakthroughs in their different scientific areas and engineering happens to be one of those areas with the most impact from experimental advancement. The need for valid experimental results free from biases and confounding conclusions has prompted the development of new experimental techniques that takes consideration of all applicable factor and combinations in providing answers on a research topic, and the Factorial Experimental design credited to Sir Ronald Fisher is one technique yielding highly valid results. This paper uses the factorial design of experiments to research the flexural impact of polyvinyl acetate fiber and layered concrete in construction. The experiment considered two levels of fiber contents and two levels of layers, and prepared samples with all combinations of the variable factors. The samples were tested after 7 days from casting for flexural strength and an advance statistical analysis was performed on the flexural responses of the samples using R-program. The results from the analyses revealed the significance of the variables to the flexural strength of the samples, as well as their interactions. The experiment concluded that based on the number of layers and fiber content used for the experiment, casting concrete in layers does have a significant negative effect on the flexural strength of concrete, and the failure pattern of concrete members under flexural load in evidently influenced by the material composition of the concrete, and that it can be evidently influenced by casting the concrete in layers.

Keywords

Experimental Design, Concrete Flexural Strength, Factorial Design of Experiments, Concrete Fibers, Concrete Layers

1. Introduction

Over the years, men have developed different ways of improving the mechanical properties of materials used for different functions, some materials get heat treatment to improve hardness, some get chemical treatment to prevent decay and corrosion, some are reinforced, and so on. Amongst these material manipulation techniques is layering. It has had application in the wood industry, the fabric industry, the steel industry, and even the automobile industry. Layering techniques on materials has been used to reduce bending, projectile penetration, improve suspension, load resistance, and aesthetics. The process of layering is done in diverse ways for different application. In blades and weapons production in the steel industry, layers of steel are welded together, heated, and beat into thin thicknesses, the beat steel is then cut and layered again, and the process go on for the required number of layers by the design [1]. In the wood industry, layers of thin sheets of wood are laminated tightly together with strong adhesives. The wood sheets are laid so that the wood grains of each layer are perpendicular to the next layer for the entire assembly. This provides stability in different directions which the piece of wood would otherwise be lacking. Application of layering in the wood industry can be found in furniture and in boat building [2]. Layering by lamination, combined with other materials has also been used in the glass industry in producing tougher materials and projectile resistant glasses. It is also used in defense, and with other materials and membranes for bullet proofing [3]. In automobiles, layering has been used in the suspension systems of trucks and heavy vehicles. Layers of curved steel bars of different lengths are stacked on each other and braced together. As a unit, they can effectively manage the downward forces from the vehicular load on them as they provide resistance to bending which is reinforced by the different layers of steel bar members in the suspension unit [4].

Concrete as a building material is very dependable for its compressive strength, but its strength in tension is not very reliable. For this reason, many innovations and resources have gone into improving this mechanical deprivation of concrete. Engineers have come up with difference reinforcement ideas and solutions to improve the flexural capability of concrete. The effect that reinforcement has on concrete is largely dependent on the type of reinforcement used. Steel reinforcement is probably the most used type of reinforcement in the construction industry. It takes the high compressive resistance of concrete and merges it with the high tensile resistance of steel to produce a reinforced concrete that is strong in both compression and tension. Other forms of reinforcement exist to improve specific properties like ductility [5]. The performance of a specific reinforcement does not however depend on the material alone, other factors of the reinforcing media play big roles in achieving the desired effect. Factors like area of contact, nature of bonding, friction resistance, expansivity all act in the tensile resistance of the reinforcing material. An example of this is the use of smooth steel reinforcement bars and ribbed steel reinforcement bars in concrete. With all things being equal for both bar choices, the ribbed bar will provide more contact area for the concrete and more resistance against pull from the concrete [6]. This directly affects the response to flexural forces of the reinforced members [7].

The introduction of fiber as a reinforcing medium for concrete was geared in combating some of the challenges conventional reinforcements face such as susceptibility to corrosion. Since its introduction, different types of fibers have been developed to improve concrete ductility, crack resistance, impact strength, fatigue, shrinkage, and temperature susceptibility [8]. While fibers used for reinforcement comes in different forms, they can be mainly broken down into manmade fibers which are more recent and could be steel fibers, glass fiber, Polyvinyl Alcohol fiber, Polypropylene fiber, and natural fiber which have historically been used for construction in different capacities [9] [10].

A lot of research in concrete properties use the traditional testing methods wherein order to test for the contribution of a design factor, samples are prepared and tested, taking account of just that factor alone without consideration for possible contributions and interactions from other design factors and conditions. The research by Mahdi *et al.* [11] which studied the flexural strength of reinforced concrete beams using recycled concrete aggregates could be seen as an example of traditional experimental procedure on concrete mix design. Much like the previous case, the study by Sato *et al.* [12] utilized traditional methods for its experimental design where samples were prepared and tested for each variable factor considered in the mix. This does not negate their findings and conclusions, however, the degree of responses for each of the variable factors would be better defined using a more advance experimental design like the factorial design method. The development of more advance experimental procedures and analyses and seen major improvement the in the way researchers conduct their experiments to reach statistically acceptable results like the series of test mixes used by Ajdukiewicz and Kliszczewicz [13] which covered a range of aggregate combinations between natural, recycled, coarse and fine aggregates, andIgnjatovic *et al.* [14].

Some key benefits associated with using factorial design in experiments is the elimination of biases, the identification of interactions between the variable factors in the mix, and the reduction in number of tests and effort in obtaining the optimum mix for the desired response (in the case of concrete experiments). In cases where a lot of factors are being considered at different combinations and proportions, factorial design would be the best bet to avoid testing each individual factor separately, identifying the interaction between the factors, and reaching more accurate solutions quicker. Khayat *et al.* used factorial experimental design to study key parameters influencing the performance of self-consolidating concrete. With the results of their experiment, they were able to understand the interaction between mix parameters and trade-offs between the parameters that would give the optimized response for their mix [15]. Factorial experimental design still stands as one of the best methods in studying the effects and influence of experimental variables. Vizzari *et al.* [16] used the fractional factorial method in preparing a mix for semi-transparent road surface layer, analyzing the influence and interactions of the different mix components, and taking the optical and mechanical properties of the road as the response variables. The results helped the team develop a mix design having necessary trade-off of materials for the optimum mix design. The experimental design did not just give an optimal mix proportion, it provided information on possible responses resulting for changes of the mix components. It showed which was detrimental to the mix design and what portion of what component inhibits the desired responses of the mix. The application of factorial experimental design has also been applied in Full Depth Reclamation (FDR) by Odia [17] where he investigated and compared the rate and extent of deterioration of FDR pavements rehabilitated with Portland cement and emulsified asphalt. The research evaluated pavement failures associated with freeze-thaw cycles, climatic temperature, water table and rainfall, and proffered a selection guide for FDR stabilizing agents. Other researchers with successful implementation of Factorial method of experiment design in their research include [18] [19] [20].

Having seen how the concept of layering could be used in different industries to improve and compliment the material properties used in various construction. Its possible application in construction industry could revolutionize the construction process. This research investigates that possibility, and does so using the factorial experimental design method in a bid to get the outmost validity for the responses from the test samples.

2. Factorial Design

Credited to Sir Ronald Fisher and based on his argument that with a few samples more relevant information on experimental factors could be generated than they were at the time [21], factorial experimental design can be done as a full factorial or a fractional factorial. Both forms of factorial designs are applicable to multiple numbers of significant factors or variables in the experiments, and the variances of the response are then analyzed to determine the contributions, significance and interactions of the factors [22]. Key elements of a factorial experimental design include the response variables which are the target properties the experiments measures. For this research, the response variable is the flexural strength of the samples. The factors which are the items being investigated in the experiment. This could include all the materials that go into preparing the samples to be tested or specific conditions of interest which are the focus of the experiment. Levels in factorial experimental design refer to the limits at which the factors are tested. An in-depth study of factorial design of experiment could be found in [22].

2.1. Control Variables

For this experiment, an effective investigation of the effect of concrete layers and fibers demands that we test concrete samples at all possible combinations of the variables being studied. Since the goal is purely to investigate how significant the variables are to the response to the concrete and not to find an ideal content that would yield optimum result, two control variables were considered for this experiment: The number of layers and the quantity of fibers used in preparing the mixes. Both factors were set as two levels each.

2.2. Layers

The effect of layering is the major target this experiment is investigating. It is the primary focus, and to effectively determine the flexural performance of concrete, it is necessary to test samples prepared with sufficient number of layer and compare the responses of these samples to the responses of other samples cast monolithically. Two levels chosen for the factor are listed below.

1) Zero (0) layers: This layer factor level indicates a monolithic concrete specimen. Generally, concrete is cast in homogeneity without provision for material separation. This is done to maintain uniformity in the cast concrete, eliminating chances of failure.

2) Five (5) layers: For this factor level, the concrete specimen was cast in parts. The overall quantity of the concrete specimen was calculated, and each materials component was divided into 5 portions. Each portion is separated with single ply absorbent paper towel, this helped emphasized separation between the layers.

2.3. Fiber Content

It will provide valuable informative knowledge to know how samples of the same mix design, with and without fiber reinforcement will response to layering. So, the second experiment factor used considered the effect of fiber reinforcement. The low and high factor levels for the fiber factor are given below. The choice of reinforcement used for the samples will greatly affect the outcome of the response variable and since we are more interested in the effect layers will have on the samples, the ideal choice of fiber reinforcement will be one that does not greatly alter the outcome of the response variable, but one that provide information on how minimal reinforcement will contribute to the effect of the layers [23].

1) Zero (0) fiber content: This level is representative of samples cast without any form of reinforcement.

2) One (1) percent fiber content: This level has a fiber reinforcement of one percent fiber content by mass of the test sample.

2.4. Response Variables

The response variable for this experiment which will be our way of investigating the effect of the design factors is the modulus of rupture (MOR) for the test samples. The peak load is determined by testing the samples using the third-point loading technique (ASTM C78) and the MOR is calculated using the formulae below.

$$f_t = \frac{Pl}{bd^2} \quad (1a)$$

for samples with fracture occurring in the middle-third portion of the beam.

$$f_t = \frac{3Pa}{bd^2} \quad (1b)$$

for sample with fracture occurring outside the middle-third portion of the beam.

f_t is the flexural strength, P is the peak load, a is the distance between the line of fracture to the nearest support, b is the width of the sample, and d is the depth of the sample. The flexural strength of the sample is tested following the specification of the ASTM guide C78.

2.5. Nuisance Factors

As it is with any properly designed experiment, there is anabsolute need to take into consideration the fact that our test results may (if not properly designed for) be affected by unaccounted factors. These unaccounted factors which are referred to as nuisance factors could be known and controllable, they could be unknown and uncontrollable, and they could as well be known and uncontrollable. It is very important to identify these factors and design the experiment with a means of mitigating the influence of these factors on the results of the response variable which we will be investigating. For this experiment, possible identified nuisance factors are listed below.

1) Variation in degree of compaction: As the test samples were manually compacted during preparation, there is the possibility of unequal compaction among the different samples, and this could influence the test results.

2) Room temperature difference: There is the possibility that variation of average room temperature could influence the chemical process and reaction of the samples.

3) Variation in layer thicknesses: The method used in preparing the layered samples could affect the average thicknesses of each layers across the entire surface area of the layered test samples. This could as well influence the test result.

4) Accuracy in quantity measurement: The accuracy in measuring the material quantities for each of the mixes is also a nuisance factor worth considering.

5) Water pH value: It is important that the pH of water used in preparing the samples and water used in curing the samples after casting be accounted for as they could possibly influence the chemical reaction.

6) Cement properties (age and exposure to weather): The age of the cement and its exposure to the atmosphere from the moment it was open is also a nuisance factor that needed consideration.

7) Fatigue: Fatigue is a human factor that greatly influences judgement in ex-

perimentation, and it is a factor that greatly influences the outcome of the experiment.

3. Experimental Design and Process

3.1. Materials Selection

Concrete is a composite building material typically comprising of aggregates and binders. The properties of concrete can be modified with the use of chemical additives or reinforcement. Materials used for this experiment were selected to meet specific requirements that bordered on samples size representation, setting time and reinforcement contribution.

3.2. Binder

Effectively casting the samples in layers meant that the samples had clear separation between the layers, but still maintain a cohesive bond within the overall beam so that it acts as a single unit. This meant that each successive layer had to be cast after the preceding layer had reached its final setting time. The setting time invariably becomes an important consideration for the experiment as each sample for each treatment is required to be cast and tested within a close ranged time interval. To this end, rapid hardening cement was used for all test samples as it hastened the setting time of the layers, enabling more layers to be cast within a significantly short period of time. To emphasize the separation between the layers, single plies of thin paper towel was placed between the layers. The absorbent nature of the paper towel facilitated cohesion as well as separation between the layers without compromising the sample strengths.

3.3. Fine Aggregates

Sharp sand is a fine aggregate option that is widely used in the construction industry and is easy to acquire. Its fine particles are well suited for filling spaces in concrete therefore improving the bonding and structural properties. Sharp sand is the fine aggregate used for this experiment.

3.4. Coarse Aggregates

Various types of coarse aggregates are used in construction, and they range from natural occurring aggregates, industrial waste, specially produced, to construction waste. For this experiment, 3/8-inch stalite was proposed for use, but due to complications resulting from the relationship between the aggregate size and layer thickness, smaller particle size aggregates had to be used. The replacement for the coarse aggregates was stalite with maximum particle passing the number 16 sieve.

3.5. Fiber

Polyvinyl alcohol (PVA) fiber is a material with high tenacity and high modulus of elasticity. When used in concrete, it is very good at controlling crack width [24], and it was used for this experiment.

The image in Figure 1 gives a view of the various materials used for this experiment.

3.6. Test Samples

Test samples used for this experiment as shown in Figure 2(a), and Figure 2(b) are 2 inches by 2 inches in cross section and 12 inches in length with a sample volume approximately equal to 0.03 cubic foot. The mix ratio adopted for this experiment was mix 1:3:6, and materials quantities were calculated and measured by relating the specific gravity for each material, to the sample volume and the mix ratio. A table showing the material quantities is provided in Table 1.

Figure 1. Concrete mix materials.

(a) (b)

Figure 2. Test samples.

Table 1. Sample mix material quantities.

Quantity	Sp. Gravity	Samples Without Fiber			Samples with Fiber		
		vol (cft)	mass (lb)	mass per layer (lb)	vol (cft)	mass (lb)	mass per layer (lb)
Cement	2.98	0.0033	0.6140	0.1228	0.0033	0.6062	0.1212
Sand	1.81	0.0066	0.7458	0.1492	0.0065	0.7364	0.1473
Stalite	1.6	0.0132	1.3186	0.2637	0.0130	1.3020	0.2604
Water	1	0.0069	0.4298	0.0860	0.0068	0.6062	0.1212
Fiber	1.3	NA	NA	NA	0.0004	0.0328	0.0066
Total		0.0300	3.1082	0.6216	0.0300	3.2837	0.6567

The quantities for the treatment with fiber content duffers from that without fiber due to the fiber content in it. The major impact of using fiber is however in the water-cement ratio. Without fiber, a water-cement ratio of 0.7 is used. However, PVA is a hydrophilic material and thus, more water is required to mix the concrete. The water-cement ratio had to be increased to 1.0 for the sample treatment with fiber to get good mixing properties and similar consistency for both treatment levels.

3.7. Preparation and Testing

This experiment was designed with the consideration of the identified nuisance factors. The known and controllable nuisances were catered for using the replications of the test prepared at different days as blocks, the unknown and uncontrollable nuisance factors are catered for by randomization. Randomization of the treatment combinations are limited within the blocks, providing a restriction on randomization. The random function in excel was used in generating an order of four numbers with which the tests were run. Table 2 give the test order for the experiment.

For this experiment, hypothesis testing will be used to reach a statistical inference on the sample responses based on a one-way ANOVA test. The hypotheses, on the mean flexural strength of the mixes are taken as:

- Null hypothesis – The mean responses between two factor levels are statistically the same (H_o: $\mu_1 = \mu_2$).
- Alternative hypothesis –The mean responses between two factors levels are not statistically the same (H_1: $\mu_1 \neq \mu_2$).

The treatments consisted of paired levels for each factor andthese treatment combinations are denoted and interpreted as:

- nL-nF: treatment with zero layers and zero fiber content.
- nL-F: Treatment with zero layers and 1 percent fiber content.
- L-nF: Treatment with 5 layers and zero fiber content
- L-F: Treatment with 5 layers and 1 percent fiber content.

Table 2. Randomized test order.

Test Order	Block 1	Block 2	Block 3	Block 4
1	nL-nF	L-nF	nL-F	L-F
2	L-F	nL-F	L-nF	nL-F
3	L-nF	L-F	nL-nF	L-nF
4	nL-F	nL-nF	L-F	nL-nF

Each of these treatment combinations will be replicated 4 times for this experiment, and the replicates will be taken as blocks. Within each block, the order in which the mixes are prepared and tested are randomized with the help or MS excel and the randomly selected mix order combinations are assigned test order numbers.

The samples were prepared following the order in Table 2. Sample without layers were prepared by pouring sample mixes into concrete molds and rodding the mix in three parts. For the layered samples, concrete materials for each layer were prepared separately, poured, and rodded. The layers were left to set (initial setting) before the mix for the next layer was. After casting each layer, thin sheets of paper towel were placed between the layers to establish separation between the layers. The samples were left to set in their molds for 24 hours before de-molding, after which they were transferred to a curing bath. The samples were left to cure for 6 days after casting at a temperature of 75°F and immediately tested while still in their wet condition. Figure 3 shows the test samples being prepared for testing.

Samples were tested for peak flexural resistance using the four-point bending test, and in the same order in which they were prepared according to the specifications of ASTM C78. The modulus of rupture for each of the samples were then calculated using equations 1a and 1b. The results of the test for the samples are provided in Table 3.

4. Experimental Results

The tests and calculations for the MOR were performed, and the results and presented in Table 4.

4.1. Analysis

Analyses of the results from the tests were done using the statistical analysis tool R. The tool has the necessary components to reach statistical decisions and provide graphical representations of the results and inferences to reach comprehensible conclusions. The analysis of the responses as performed on R and the deduction from the analysis could be broken into sections of significance as they relate to understanding the effects of the factors and their contributions to the overall flexural strengths of the samples.

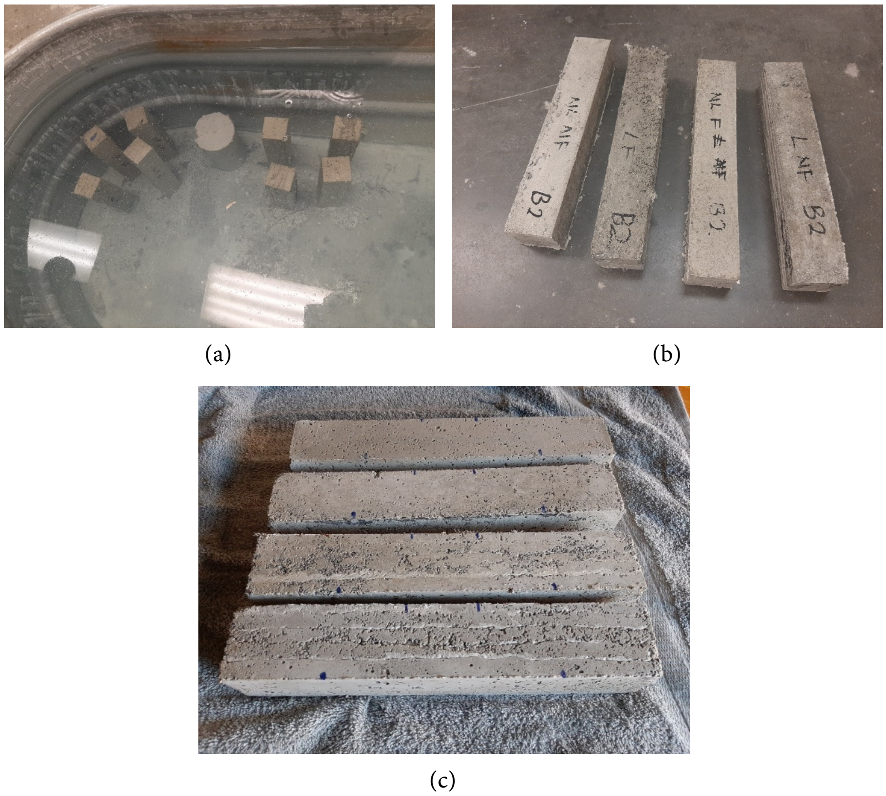

Figure 3. Test sample preparation.

Table 3. MOR results for the test samples.

Sample Treatment	Block 1	Block 2	Block 3	Block 4
nL-nF	452.6	469.3	463.2	448.6
nL-F	340.8	340.6	349.2	394.1
L-nF	303.0	344.4	210.6	372.5
L-F	251.8	332.3	387.3	347.3

L: Five layers; F: One percent fiber content; nL: Zero layers; nF: Zero percent fiber content.

Table 4. Test results for statistical analysis.

Factor		Sample	Modulus of Rupture (psi)			
A	B	Treatment	Block 1	Block 2	Block 3	Block 4
−1	−1	nL-nF	452.6	469.3	463.2	448.6
−1	1	nL-F	340.8	340.6	349.2	394.1
1	−1	L-nF	303.0	344.4	210.6	372.5
1	1	L-F	251.8	332.3	387.3	347.3

A: Number of layers; B: Fiber content.

4.2. ANOVA

The treatment means were calculated to be 458.420, 356.175, 307.634 and 329.693 for nL-nF, nL-F, L-nF and L-F respectively. The effects of the changes in the factor levels (increasing the layer numbers and fiber content) and the interaction between the factors showed that increasing the number of layers of concrete in the samples had the most effect on the flexural strength of the samples with a value of −88.632. The negativity in the value indicates that as the factor level increases, that is from zero to five, the flexural strength of the samples reduces. The same is the effect in increasing the fiber content in the samples at −40.096 though not in the same magnitude as the layer content. The interactions between the design factors turned out to have a positive effect on the flexural strength of the samples with a magnitude of 62.150. Learning the effects and magnitude of the factors and their interaction is however not enough. The significance of these effects would need to be determined before conclusions on the experiment would be made, and for that, the 2^2 factorial design statistical analysis would be utilized.

From the results of the 2^2 factorial analyses presented in **Table 5**, it can be determined with a 95% confidence level that changes in the number on layers in the concrete samples has a statistically significantly large negative effect on the flexural strength on concrete with a P-value of 0.003, therefore, we can reject the null hypothesis that there is no difference in the factor levels for the layer content. While increase in the fiber content have some negative effect on the flexural strength, the effect with a P-value of 0.116 is not statistically significant to the changes in the concrete flexural strength and so we cannot reject the null hypothesis for the fiber content. The interaction between layer content and the fiber content was seen to have a positive effect on the flexural strength of the concrete samples and with a P-value of 0.022, we can reject the null hypothesis, and say with a 95% confidence level that interactions between layer content and fiber content in concrete is statistically significant to the flexural strength of the concrete samples. A summary of the analyses result is provided in **Table 5**.

4.3. Visualization and Plots

The interaction plot between layers and fiber as represented in the **Figure 4**

Table 5. Summary of statistical analyses results.

Factors	Factor Effects	Degree of Freedom	Sum of Squares	Mean Squares	F-Value	P-Value
Layers	−88.632	1	31422.7	31422.7	13.991	0.003
Fiber	−40.096	1	6430.7	6430.7	2.863	0.116
Interaction	62.150	1	15450.3	15450.3	6.879	0.022
Residuals		12	26951.5	2246.0		

NB: This experiment takes P-values less than 0.05 as statistically significant.

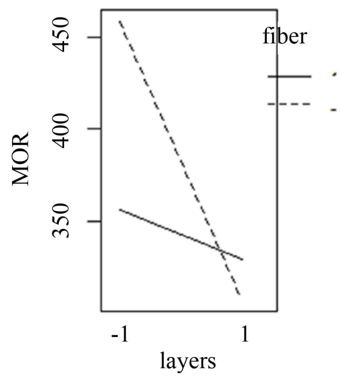

Figure 4. Interaction plot between sample layers and fiber content.

shows the crossing of paths of the two factors as their levels change, indicating the presence of an interaction. It can be interpreted that at both fiber contents, increasing the number of layers in the concrete samples results in a lower flexural strength whereas for the fiber content, at zero sample layers, the flexural strength is higher for lower fiber content while at higher sample layers, higher fiber content yielded higher flexural strength. Other important plots from the analysis results are the Residual vs Fitted plot and the Normal Q-Q plot. Since the residuals indicate how much deviations exists between regression line and the responses and the actual values of the responses, a plot of the residual vs fitted values is useful in showing if there has been a healthy and unpredictable distribution in errors across the test samples and if the results from the test have been subjected to unaccounted nuisance factors affecting the outcome of the experiment. The residual plot from the experiment in **Figure 5** is seen to have data points scattered above and below the regression line. The Normal Q-Q plots fits the individual results from the test on a hypothetical line of best fit. An acceptable Q-Q plot would have the plotted responses following a trajectory close to the theoretical line, and excessive deviations from the line is an indication of biases which could call for a rerun of the experiment. Looking at both the Residual vs fitted plot and the Normal Q-Q plots in **Figure 5** and **Figure 6** respectively, we can conclude that they appear to be satisfactory, and that there are no reasons to suspect that there are any problems with the validity of the experimental conclusions.

4.4. Failure Characteristics

An interesting observation from the test samples were the failure patterns associated with the treatment combinations as the samples were subjected to flexural load under a 4-point bending test. At peak loads, samples treated without layers and without fibers had "catastrophic" failure that can be seen in **Figure 7** with complete separation along the fracture line shown in **Figure 8**. Samples treated with one percent fiber content had a more gradual failure process and less catastrophic fracture pattern as is shown in **Figure 9** where the strain gradually

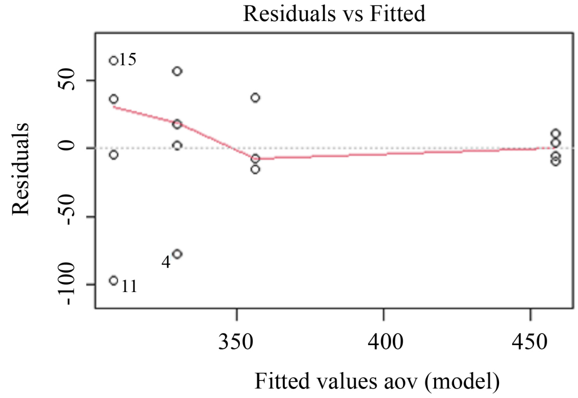

Figure 5. Residual vs fitted value plot.

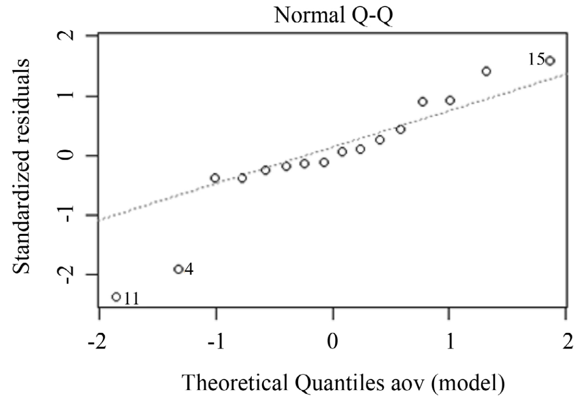

Figure 6. Normal Q-Q plot.

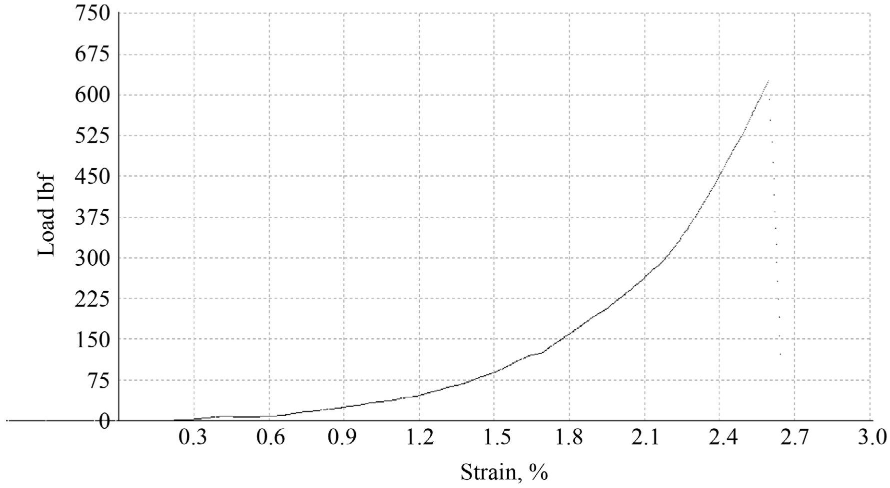

Figure 7. Stress-strain curve for nL-nF.

decrease beyond the peak load. **Figure 10** shows an image of the sample after failure. It can be inferred that even though the overall strength of the samples gets reduced, the presence of fiber in the concrete mix acts to hold elements of the samples together providing some tensile resistance along the bottom tension

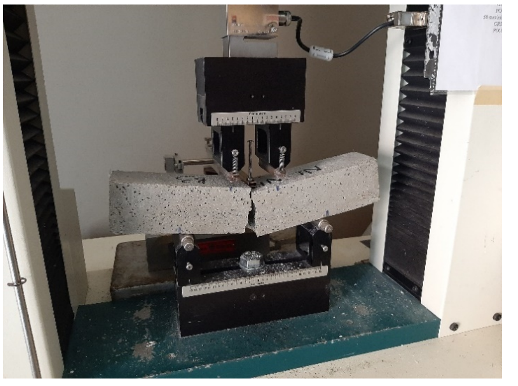

Figure 8. Failure pattern of nL-nF samples.

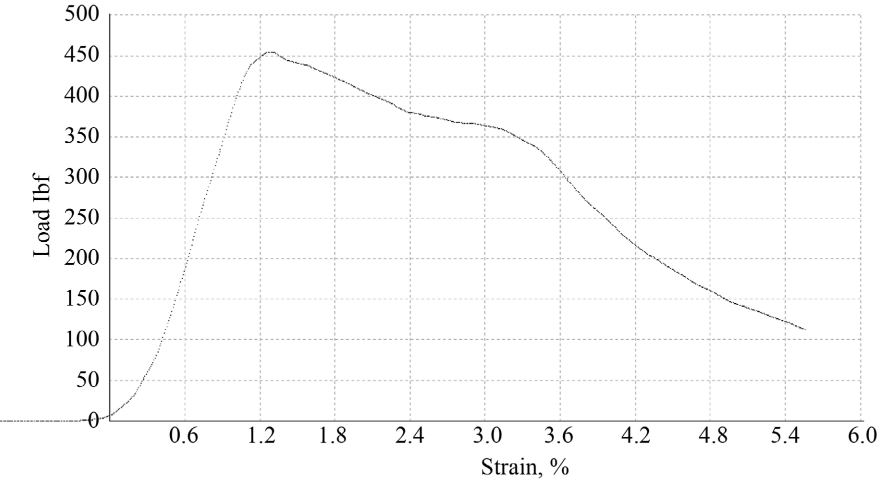

Figure 9. Stress-strain curve for nL-F.

Figure 10. Failure pattern of nL-F samples.

zone of the concrete samples, reducing the amount of separation between the fracture line in the samples. The presence of PVA fibers in the compression zone of the samples however contributes no compression resistance to the concrete samples, thereby compromising the ability of the concrete to resist flexural deformation, and ultimately failing under lower flexural loading conditions than samples without fiber content.

Unlike the unlayered samples, failure in layered samples without fiber content (L-nF) had a different fracture pattern. The fracture lines originating at the bottom layers only went through a maximum of three layers with some of the sample having fracture in just two layers. This could be accredited to the difference in tensile and compression resistance of concrete, and since the top layers are always in compression when subjected to bending, and the bottom layers are in tension, and coupled with the inferiority of concrete tensile resistance compared to the compressive resistance, it is only logical that the bottom layers subjected to tension would fail. And since the layers are separated by a thin membrane, with less concrete mass to resist the localized compression and tension in the lowest layers, failure is expected to happen with lighter flexural load than unlayered concrete, In **Figure 11**, the stress-strain curve shows a sharp drop in load at failure point. However, the drop is cushioned out as load drops, and it could be inferred that the cushioning is due to the unfractured layers of concrete acting to provide some support to the beam even after failure has occurred. In the case of layered samples treated with fiber, the failure characteristics were rather-similar to those of unlayered samples treated with fiber. It would seem that the presence of fiber in the lower layers of the samples limiting the amount of separation in the tension-prone layers creates a sort of load transference across the layers enabling the samples to execute more resistance to separation during failure as fracture proceeds through the layers. **Figure 12** shows the stress-strain curve for L-Fsamples with a longer post-failure strain response to reduction in stress. For this reason, the fracture in these sample are more pronounce that fracture in layered samples with no fiber content.

Figure 13 shows an image of a layered sample with no fiber content under peak load, while **Figure 14** shows an image of a layered sample with fiber content and **Figure 15** shows an image of the failure pattern of all treatments with nL-F, L-nF, L-F and nL-nF from left to right.

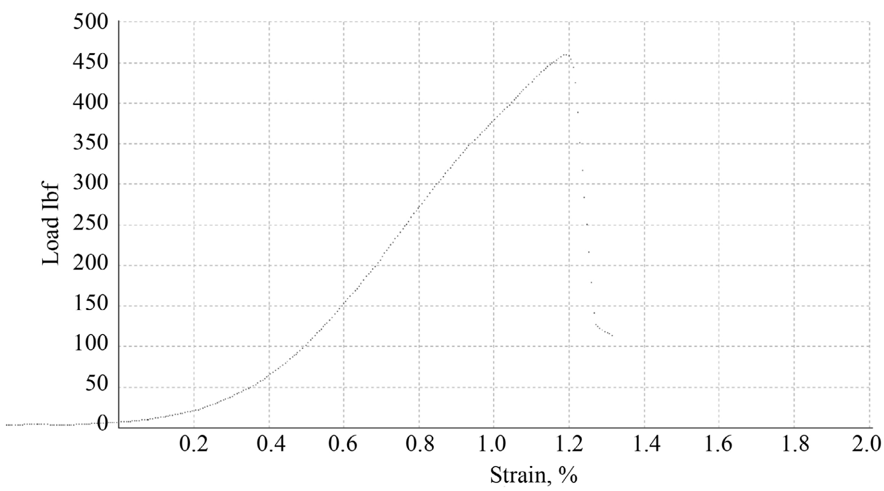

Figure 11. Stress-strain curve for L-nF.

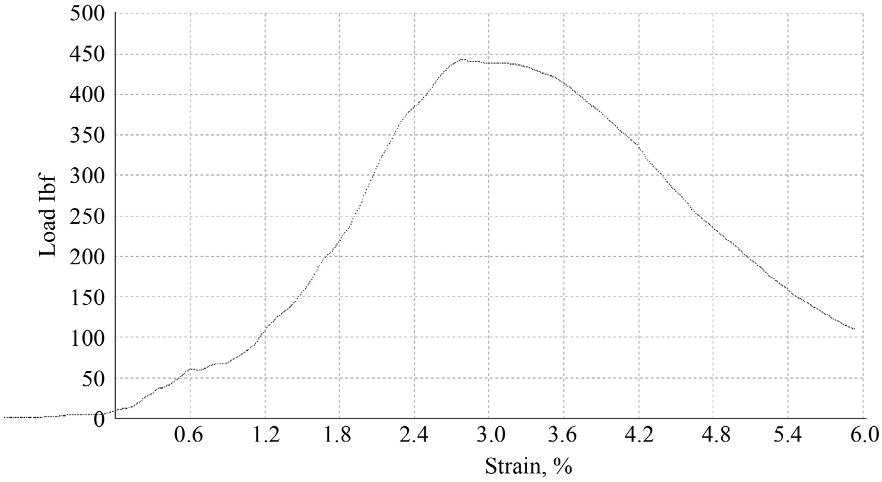

Figure 12. Stress-strain curve for L-F.

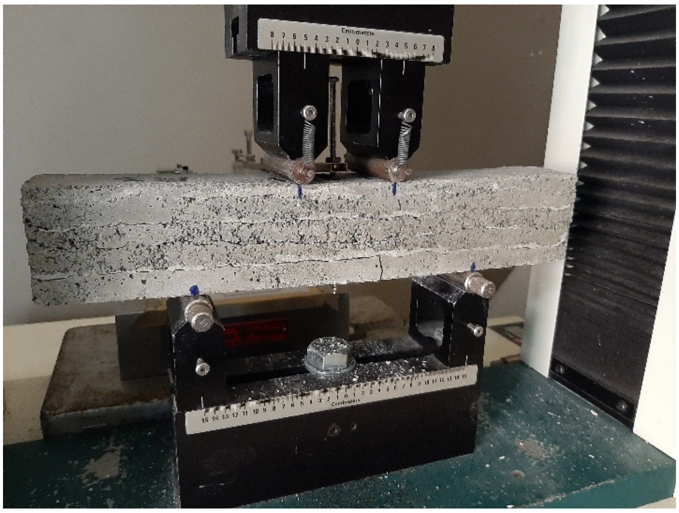

Figure 13. Failure pattern of L-nF samples.

Figure 14. Failure pattern of L-F samples.

Figure 15. Failure and fracture patterns of all treatment types.

5. Conclusions

This experiment used factorial experimental design to investigate if casting concrete in layers had any impact in improving its response to flexural deformation and failure like in other materials like wood and investigated if the addition of polyvinyl acetate fiber could improve the response of concrete to flexural loading. The findings from the tests conducted provided conclusive evidence that while layering of materials worked to improve the flexural resistance of materials like wood and steel, is failed to do same for concrete. One takeaway from the experiments is that the nature of failure experienced form the layered concrete is one that deserves further research as it still provided some form of support for the test beams even in failure while the unlayered samples experienced irredeemable structural fractures. Coupled with the effect of fiber in some of the test samples, further research would be helpful in investigating a modified form of layered concrete which will reinforce only the tension zone of the concrete with fiber and leave the compression zone unreinforced. I would believe that while this will help maintain the integrity of the concrete compressive strength in the tension zone, the fiber content in the tension zone would help improve its tensile resistance, and the layers would possible help ensure a "safe fail" in loading.

When performing experiments, the validity of the results is more important than the results itself, and a properly designed experiment does not only give valid results, it also covers all possible combinations of the factors of interest, reduces the possibility of confounding variables, limits the number of significant repetitions, and save resources in the forms of time, money and labor. The benefits of a properly designed 2^k factorial experiment are clear in the tests described in this paper. The validity of the results was proven, the significance of the effects of the factors were discovered the interactions between the factors was also discovered and the tests were conducted, and advanced statistical conclusions reached using a few test samples and saving a lot of time. With the information derived from this experiment, the study can be advanced with the inclusion of other fiber materials like steel fibers, and reinforcement could be applied only to layers with weakest in tension resistance. This would raise the number of factors for the experiment, and the number of test samples need. However, with increasing factors, the overall number of test samples can be halved using a different version of the factorial design called the fractional factorial design method.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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