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March 11, 2025

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Abstract

The addition of natural fiber in reinforced concrete shows a significant impact in terms of the mechanical properties of the concrete. This research study aims to perform finite element modeling analysis to investigate the behavior of conventional and abaca fiber-reinforced beams under various types of loading. The researchers incorporated the optimal percentage of abaca fiber content in concrete based on the related studies. It was observed that the optimum percentage of abaca fiber composition for the concrete beam is 0.15% and the ideal fiber length is 50 mm. The beams are subjected to Abaqus application to produce 3D mesh models, conduct analysis of the conventional and abaca fiber-reinforced concrete beams, and determine the results of bending moment and deflection. The finite element analysis of the abaca fiber-reinforced concrete yielded a significant value in comparison to traditional concrete beam.

Keywords: abaca fiber reinforced concrete beam, Abaqus, finite element modeling analysis, beam deflection, bending moment

1 Introduction

Increasing demands for improving engineering techniques for strengthening a building's capacity and enhancing structural integrity have been one of the most researched activities in developing environmentally friendly materials. It has produced numerous alternative techniques which greatly impacted on the construction industry. One of which is fiber-reinforced concrete. Adding fiber in concrete improves rigidity, increases plasticity, and reduces deflection. As stated by Tampi (2019), abaca fiber from banana plants is the strongest natural fiber among other existing fibers due to its high tensile strength, high porosity, high resistance to saltwater damage, buoyancy, and length of 2 to 4 meters. Moreover, adding natural fibers to concrete can potentially reduce costs, particularly in construction, operation, and development, without compromising structural reliability and safety (Parandaman & Jayaraman, 2014). Natural fibers have various advantages such as easy accessibility, lightweight, inexpensive, and high tensile strength and rigidity. With that, it became a prominent material in construction to meet the need for sustainable development in the industry.

The main goal of this study is to utilize finite element modeling to investigate the behavior of conventional and abaca fiber-reinforced concrete beams under various loading. Using this method, the researchers will be able to study the properties of abaca fiber in concrete beams. Moreover, this study will focus on the optimal percentage of abaca fiber content in reinforced concrete. All in all, the results of this study will benefit the construction industry, particularly in using and designing an environmentally friendly alternative abaca fiber beam for sustainable building.

2 Methods

This research uses Abaqus software to perform a finite element analysis of a traditional reinforced beam compared to an abaca fiber-reinforced concrete beam.

Phase 1: Structural modeling of traditional singly reinforced concrete beams and abaca fiber reinforced concrete in Abaqus

The researchers have designed an assumption of 450mm x 600mm beam. The properties listed in Table 1 are utilized in this study to comply with the NSCP 2015 requirements for singly reinforced concrete beam design.

Length (l)	6000 mm
Width (b)	450 mm
Height (h)	600 mm
Concrete Compressive Strength (f’c)	28 MPa
Concrete Cover	40 mm
Steel Yield Strength (fy)	420 MPa
Diameter of Reinforcement Bars	25 mm
Diameter of Stirrups	10 mm

Table 1. Beam Properties

This phase also involves the study by Tampi et al. (2019), which states that the optimal fiber-reinforced concrete contains 0.15% abaca fiber composition with 50 mm length yields an improvement for compressive strength by 12.61%, tensile strength by 72.64%, and flexural strength by 98.98% compared to the normal concrete. This step is the crucial part of the phase because it concludes the optimal amount of abaca fiber to be used in this study. Hence, this study considered the least amount of abaca fiber among other studies due to its small increments of percentage and length and complete mechanical properties. Furthermore, the structural modeling and analysis of the beams will proceed using Abaqus. This will produce the 3d mesh of both beams and the results of bending moment and deflection.

Code	Slump (mm)	Density (kg/m^3)	Compressive Strength (MPa)	Tensile Strength (MPa)	Flexural Strength (MPa)
NC-00-000	155	2360.7	26.268	2.109	3.555
FC-25-0,15	95	2290.3	24.490	2.596	4.243
FC-25-0,20	75	2264.8	20.408	2.735	4.688
FC-25-0,25	50	2252.5	19.437	2.831	4.946
FC-37,5-0,15	80	2288.1	21.063	2.767	4.597
FC-37,5-0,20	70	2270.7	18.957	2.608	4.959
FC-37,5-0,25	50	2243.2	15.875	2.842	5.174
FC-50-0,15	85	2292.8	29.580	3.641	7.074
FC-50-0,20	70	2252.1	23.887	2.984	5.855
FC-50-0,25	55	2222.4	20.831	2.872	5.285

Table 2. Abaca Fiber Concrete Properties

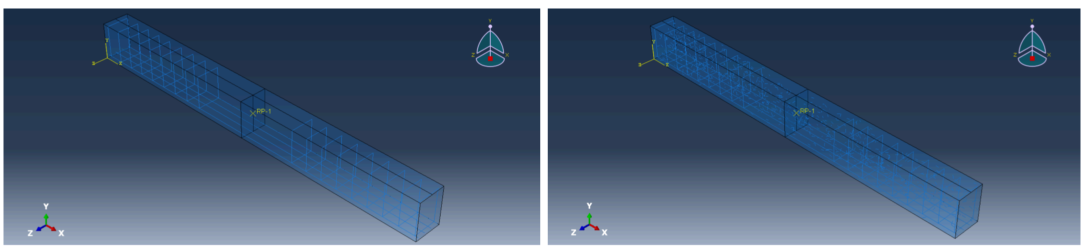

Figure 1. Assembly of beams

The modeling properties of the 3D model of the singly reinforced conventional and abaca fiber concrete beam were based on the first step of this study with consideration of the NSCP 2015 code requirements. The abaca fiber concrete beam was constructed using a Python code to distribute the abaca fiber wires randomly throughout the beam. The dimensional properties of both abaca fiber-reinforced concrete beam and conventional reinforced concrete beam are considered to be the same in order to compare the two.

After the 3D mesh of the singly and abaca fiber-reinforced concrete beam is produced, the model will undergo the Abaqus software for structural analysis. The 3D mesh of the abaca fiber-reinforced concrete beam will need a composite layup to incorporate the abaca fiber in the concrete beam. This determines the results of bending moment and load deflection. This study will utilize hexahedra as its mesh system.

Phase 2: Utilization of Abaqus software

This phase revolves around the application of Abaqus software to conventional and abaca fiber-reinforced concrete beams. The researchers would perform the finite element analysis on this software to produce the beams' bending moment and load deflection.

The Abaqus application does not have a default unit system for the properties. In consideration, the researchers would utilize the use of table guideline below for the unit used throughout the application:

Quantity	SI Unit (mm)
Length	mm
Force	N
Mass	Tonne
Time	s
Stress	MPa (N/mm^2)
Energy	mJ (10^{-3})
Density	tonne/mm^3

Table 3. Unit symbols in Abaqus

For the calculations of Abaqus, values like Mass Density of normal-weight concrete and ASTM A36M steel are also considered which is shown in the table below:

Mass Density of Concrete	2.4 x 10^{-9} tonne/mm^3
Mass Density of Steel	7.85 x 10^{-9} tonne/mm^3

Table 4. Mass Density of Concrete and Steel

The elastic parameters of normal-weight concrete and ASTM A36M steel involve the Young's Modulus and Poisson Ratio. In Abaqus, both of these properties have a linear isotropic elastic property. These values are presented in the table below.

Young's Modulus of Concrete	30 x 10^3 N/mm^2
Poisson Ratio of Concrete	0.2
Young's Modulus of Steel	20 x 10^4 N/mm^2
Poisson Ratio of Steel	0.3

Table 5. Elastic Parameters of Concrete and Steel

The plastic parameters of steel include the Yield Stress and Plastic Strain. The values are shown in the table below.

Yield Stress	460 N/mm^2
Plastic Strain	0

Table 6. Plastic Parameters of Steel

The values for the abaca fiber reinforced concrete beam includes Mass Density and elastic parameters. It is presented in the table below.

Mass Density	1.5 x 10^{-9}
Young's Modulus	41 x 10^3 N/mm^2
Poisson's Ratio	0.21

Table 7. Abaca Fiber Beam Properties

The next step is to create a step after assembling the various parts, such as concrete, steel rebars, stirrups, and abaca fiber wires. The researchers have selected the general static procedure to assign a time period to the analysis. It was also set that the maximum number of increments should be 100000 to analyze up to its limit. The analysis starts with the assigned initial increment size of 0.001 until the maximum size of 1.

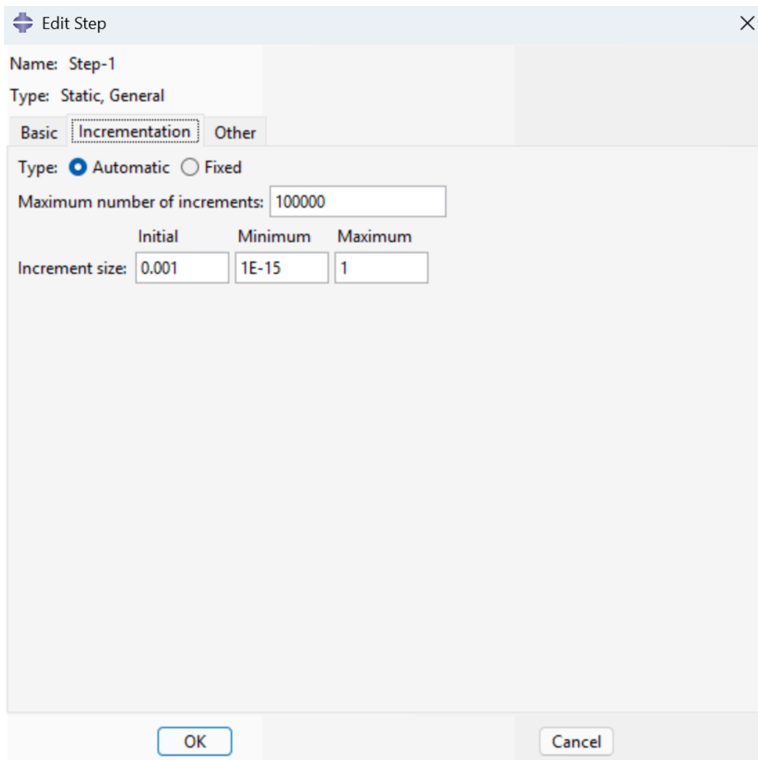

Figure 2. Incrementation under step module

The researchers created a constraint in the interaction module to allow the analysis to run smoothly. The selected constraint type is the embedded region, which restricts all the reinforcements and abaca fiber wires within the host region. This constraint also ensures that the investigation conducted applies to the whole beam.

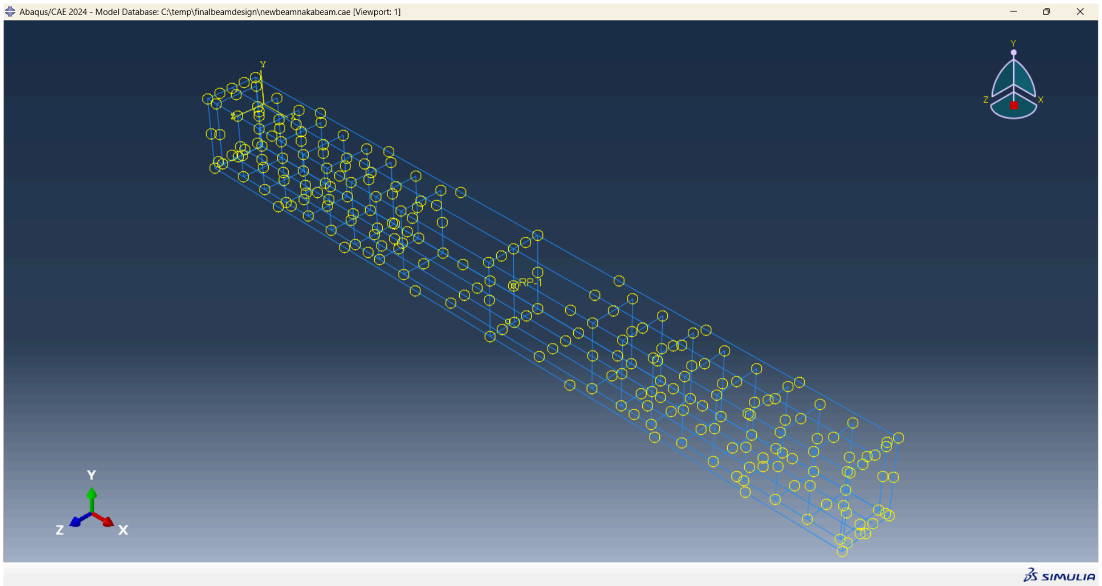

Figure 3. Embedded region under interaction module

The boundary condition set for the singly and abaca fiber-reinforced concrete beam consists of pinned and roller supports. It is placed at the edge of the beam to design it as a simply supported beam with a uniform load. The applied load on top of the beam started at 0 N/mm until 100 N/mm. This is to verify the load deflection of the conventional and abaca fiber beam.

Pinned Support	
U1	0
U2	0
U3	0
Roller Support	
U2	0
U3	0

Table 8. Boundary Condition of the beams

Abaqus's mesh system comprises hexahedra, wedges, and tetrahedra. In this study, the researchers utilized hexahedra as the meshing system of the beam. It is to allow finite elements to analyze simpler shapes. The global seed size for concrete and steel reinforcement is assigned to be 100 and 20, respectively, to ensure precise element analysis of the model. The smaller the size, the more accurate the values are. However, smaller mesh sizes require longer computational time, which is unnecessary for simple shapes. Furthermore, the element type selected for concrete is 3D Stress, while the steel reinforcements and abaca fiber wires are beam and truss.

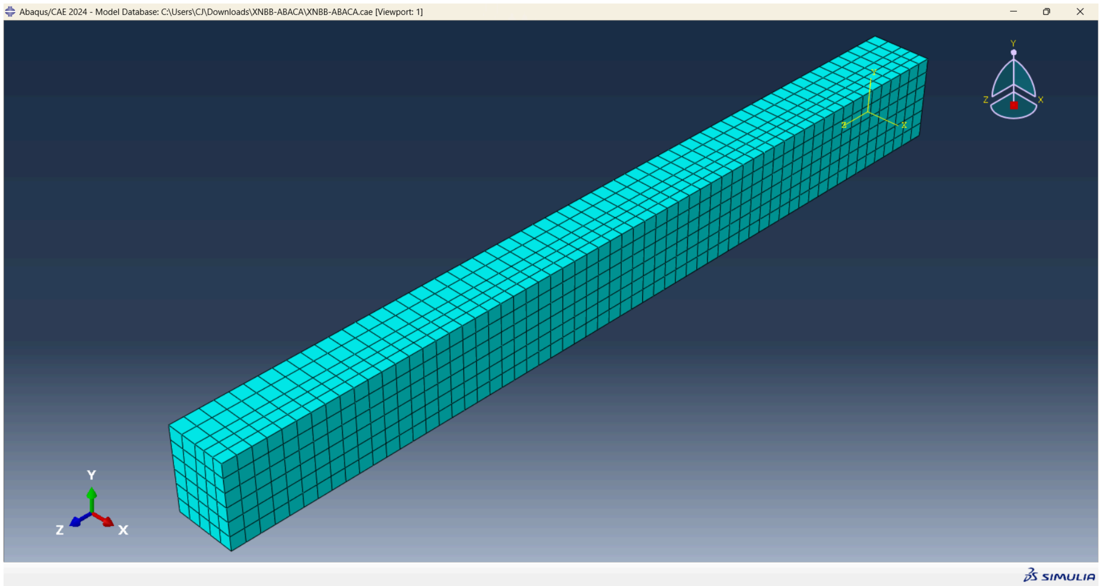

Figure 4. Mesh system of the beam

Phase 3: Analyzation of the results from the Abaqus application

This phase involves analyzing the gathered results from Phase 2, which include the findings of bending moment and load-deflection. The researchers would also provide a summarized comparison between the conventional and abaca-reinforced concrete beams to see the differences based on the different applied loadings. This also includes an analytical computation to ensure that the deflection is accurate.

The researchers would utilize a t-test to compare the significant difference between the results of the finite element analysis, which are generated from the results of the Abaqus application, for the fiber-reinforced concrete and traditional reinforced concrete.

3 Results and Discussions

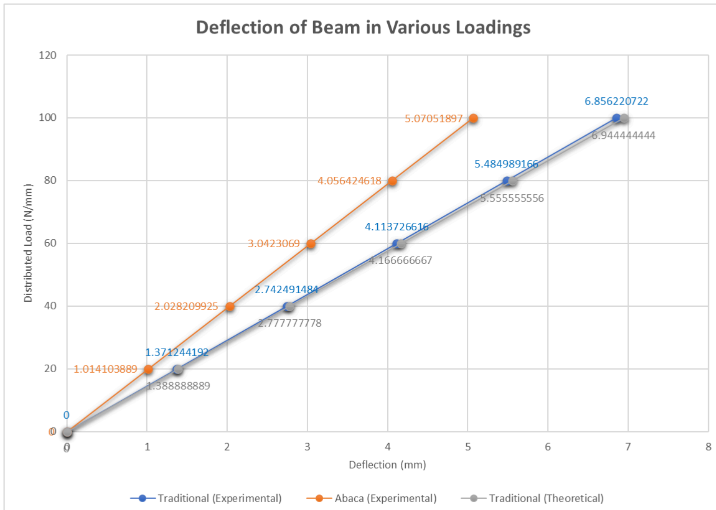

Figure 5. Deflection of Beam in Various Loadings with Abaca Fiber-Reinforced and Traditional (Experimental and Theoretical)

In Figure 5, it can be seen that the Abaca Fiber-Reinforced Concrete Beam has reduced values in comparison to Traditional Concrete Beams in terms of deflection under increasing distributed load with a decrease of approximately 1.428 mm for the 80N/mm loading of the beam design. In average, there is a 26.04% decrease for the values of the abaca deflection in relation to the traditional experimental value of deflection for the beam.

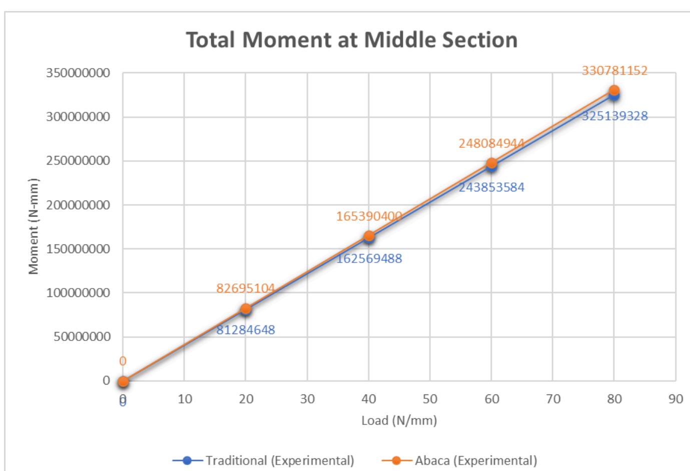

Figure 6. Bending Moment of the Abaca Fiber Concrete Beam in comparison to Traditional Concrete Beam

In comparison to the decrease of bending in Abaca fiber-reinforced concrete, the bending moment of the beam at the middle section increases for the Abaca fiber-reinforced concrete in comparison to the traditional reinforced concrete beam. At load 80 N/mm, the difference of the bending moment of the beam is estimated to be 5, 650, 000 N-mm having a percentage of 1.74% difference to the moment of the traditional reinforced concrete beam.

Data Analysis

	Theoretical	*Experimental*
Theoretical	1	
Experimental	1	1

Table 9. Correlation matrix for Theoretical and Experimental Traditional Reinforced Concrete Beam

The table above shows a positive correlation between the theoretical and experimental values, which means that as one value increases, the other value increases proportionally. The experimental data closely follows the theoretical predictions, with only negligible differences. This suggests that the experimental deflections are reliable and that the behavior of the Traditional Reinforced Concrete Beam aligns well with the theoretical model.

	Experimental	*Abaca-Fiber*
Mean	3.42811203	2.535260717
Variance	6.581094609	3.599427072
Observations	6	6
Pearson Correlation	1	
Hypothesized Mean	0	
df	5	
t Stat	3.273268021	
P(T<=t) one-tail	0.011059237	
t Critical one-tail	2.015048373	
P(T<=t) two-tail	0.022118475	
t Critical two-tail	2.570581836	

Table 10. T-test results for the analysis of the comparison of Traditional RCB and Abaca Fiber RCB deflections in various loadings

The data for Table 10 represents the paired t-test results for the deflection comparison between Traditional and Abaca Fiber-reinforced concrete. The Pearson correlation, having a value of 1, shows that there is a perfect positive correlation between the deflection of the two beams. Since the p-values of the t-test results are both less than 0.05, this indicates that the Abaca Fiber RCB and Traditional RCB have a statistically significant difference between their deflections under various loadings. Furthermore, rejecting the null hypothesis and accepting the alternative hypothesis indicates that Abaca Fiber-Reinforced Concrete Beams exhibit significantly lower deflection compared to Traditional Reinforced Concrete Beams under various uniformly distributed loads.

	Abaca	Traditional
Mean	165390320	162569409.6
Variance	1.70962E+16	1.6518E+16
Observations	5	5
Pearson Correlation	1	
Hypothesized Mean Difference	0	
df	4	
t Stat	2.828427125	
P(T<=t) one-tail	0.023710328	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.047420656	
t Critical two-tail	2.776445105	

Table 11. T-test results for the analysis of the comparison of Traditional RCB and Abaca Fiber RCB bending moment at middle section

Under Table 11, which shows the T-test results for the comparison of the bending moment at the middle section of the beams, reveals that the bending moment for both beams has a statistically significant difference. Since the p-values of the t-test are lower than 0.05, we could reject the null hypothesis and accept that the Abaca Fiber-Reinforced Concrete Beams exhibit significantly a higher bending moment capacity compared to Traditional Reinforced Concrete Beams under various uniformly distributed loads. This shows that the Abaca-Fiber beam may perform marginally better in handling bending forces compared to Traditional RCB.

4 Conclusions

Based on the analysis and results of the finite element analysis in Abaqus, the following conclusions were formulated:

- In addressing the modelling of conventional and abaca fiber reinforced concrete beams, the researchers used a simply supported beam with a uniformly distributed load applied along the length of the beam. The beam properties used are in accordance with NSCP 2015 standards for singly reinforced concrete beams in consideration of a Dead Load and Live Load of 20 kN/m and 35 kN/m respectively. For the 3D model, both beams' dimensional properties are considered to be the same, but for the abaca fiber concrete beam, abaca fiber wires were distributed throughout the beam using a Python code. The abaca fiber beam will also utilize a composite layup and embedded region tool to incorporate the abaca fiber in said concrete beam and both beams also utilized hexahedra as their mesh system. The amount of abaca fiber considered is 0.15% which is in accordance with the study by Tampi et. al (2019), which states that the optimal fiber-reinforced concrete contains 0.15% which yields an improvement in compressive, tensile, and flexural strength compared to normal concrete.
- Based on the results of the FEM analysis on Abaqus, the theoretical and experimental data for the deflection in conventional concrete shows a linear relationship wherein as the distributed load increases, deflection proportionally rises as well. The same can be said for the total bending moment on conventional beams, which rises as distributed load increases. At 80 N/mm, the theoretical max deflection is 5.556 mm, while the experimental deflection is 5.494 mm, which has a relative error of 1.12%. With the same load, the bending moment reaches 325,139,328 N/mm. In contrast, the addition of abaca fiber in concrete beams reduces the deflection of the beam by 1.431 mm compared to conventional concrete beams at

80 N/mm loading. The bending moment also increases to 330,781,152 N/mm at the same load applied.

- Based on the study's results, the bending moment at 80 N/mm uniform load of the abaca fiber concrete beam at the middle section shows an increase of 1.74% compared to the normal concrete beam. Additionally, the deflection for abaca fiber concrete beam yields a lower value than the normal concrete beam, considering the same load applied. The abaca fiber beam gives an average of 26.04% decrease in deflection at 80 N/mm applied uniform load. The reduction in deflection is aligned with studies from Beltran (2016) & Tampi et al. (2019) that show that adding fiber contributes to the flexural resistance of the beam when applied by the equivalent load and that abaca fiber reinforced beams gives a higher moment capacity than normal beams when load is applied. Thus, the bending moment value and deflection obtained from our study is comparable to the aforementioned research study.

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