

Behaviour Analysis of Strengthened-RC Beam with Natural Fiber Reinforced Polymer (NFRP) based on Abaca Fiber by Using Finite Element Method

Taufiq Saidi¹, Muttaqin Hasan¹, Zahra Amalia^{1*}, Muhammad Iqbal¹

¹Civil Engineering Department, Universitas Syiah Kuala, Banda Aceh, Indonesia

*Corresponding author : zahra.amalia@unsyiah.ac.id

Received : June 18, 2022

Received in revised from September 3, 2022

Accepted : September 4, 2022

Online : September 5, 2022

Abstract- Synthetic fiber reinforced polymer (FRP) as an alternative composite material has been widely used for strengthening and repairing reinforced concrete structures. However, applying synthetic FRP materials is expensive and may be unsafe for the environment. Therefore, natural fiber reinforced polymer (NFRP) is the best alternative FRP, especially in increasing the shear strength of reinforced concrete beams. It has good tensile strength and also is environmentally friendly. Technological developments in the field of computing make modeling various aspects easier. One of them is modeling reinforced concrete (RC) beams. In this study, the ATENA V534 software was used to evaluate the results of the research and testing behavior of reinforced concrete beams. Behavior is evaluated in the form of load and deflection, the pattern of cracks and failure, and stress and strain of reinforcements. The numerical results obtained in ATENA V534 showed good agreement with experimental results. The maximum load of the four beams, namely BN, BSTV1, BSTV2, and BSTD1, based on the finite element method analysis results using ATENA V534 are 25,89 tons, 27,53 tons, 28,14 tons, and 26,92 tons, respectively. In contrast, the maximum load obtained from experimental results are 26,79 tons, 29,40 tons, 29,45 tons, and 27,14, respectively. The difference in crack angle in the beam between ATENA V534 and the experimental result is around 2°. The results of numerical analysis using ATENA V534 show a lower maximum load value, higher stiffness, and lower deflection at maximum load compared to experimental results on all reinforced concrete beams analyzed in this study.

Keywords: *ATENA V534, NFRP based on abaca fiber, Shear strengthening of RC Beam.*

Introduction

Shear reinforcement in reinforced concrete beams is important in designing reinforced concrete (RC) beams. Indonesia is a country that is vulnerable to natural disasters such as earthquakes, which can occur at any time without being predicted. This reinforcement is expected to minimize the structure's risk of failure and strength degradation. Thus, the infrastructure will be safer (Ozbakkaloglu *et al.*, 2013; Saidi *et al.*, 2020a).

One method of shear strengthening in reinforced concrete beams is the jacketing method using Fiber Reinforced Polymer (FRP). FRP is a composite material consisting of a polymer resin matrix reinforced with glass, carbon, or aramid fibers. FRP has been applied in various countries, such as strengthening bridge pillars and building columns (Tang, 2003; Nanni, 2003; Oller *et al.*, 2019). However, the use of FRP with synthetic fibers has several drawbacks, including the manufacturing process, which is not environmentally friendly and has waste material that is very difficult to decompose. In addition, the production cost of synthetic FRP is too expensive (Burgoyne, 2009; Alam & Riyami, 2018; Codispoti *et al.*, 2015; Cheung *et al.*, 2009). Using natural fibers as a composite material in building structures can be an alternative. Using natural fibers in composite materials can reduce the environmental impact because the manufacturing process is environmentally friendly (Rodiawan *et al.*, 2017; Jeyapragash *et al.*, 2010). In addition, natural fiber has several advantages, including abundance, light mass; low economic production costs; and being renewable (Nopriantina & Astuti, 2013; Widyaningsih *et al.*, 2016; Tong *et al.*, 2017; Saheb & Jog, 1999). The study of (Jirawattanasomkul *et al.*, 2020) found that severely

shear-damaged RC beams can fully rehabilitate to their original shear strength when they are effectively repaired and strengthened with proper layers of jute fabric-reinforced polymer. One natural fiber studied and used as a Natural Fiber Reinforced Polymer (NFRP) composite material is abaca fiber. Abaca fiber is obtained from the trunk of the abaca banana tree, which has a tensile strength of up to 970 MPa.

Similarly, it takes 140,686 pounds of energy per inch² to make the fiber break (Arisno, 2009). Meanwhile, technological developments in computing have made modeling various aspects easier. The modeling structures tested in the laboratory can be easily modeled visually using supporting software. In this study, the software used to model the reinforced concrete beam structure was ATENA V534 (Cervenka & Jan 2016).

Based on the above background, this study aims to examine the behavior of reinforced concrete beams reinforced by NFRP made of abaca fiber against shear capacity using ATENA V534 and assisted by GiD 13.0.1 as software to carry out pre-processing procedures. The results from the modeling will then be compared with research carried out experimentally in the laboratory by Saidi *et al.* (2020a) and Saidi *et al.* (2020b). The behavior that will be evaluated is in the form of failure patterns of reinforced concrete beams and abaca fiber NFRP, stress-strain, load and deflection, and internal forces resulting from each material in the form of concrete, reinforcing steel, and abaca fiber NFRP.

Materials and Methods

Test Specimen

In this study, the finite element method was analyzed on reinforced concrete beams reinforced with abaca fiber NFRP. Saidi *et al.* (2020a) tested reinforced concrete beams with NFRP reinforcement consisting of 3 test objects in the form of BN (standard beam), BSTV1 (1 layer vertical strip beam NFRP), and BSTV2 (2 layers vertical strip beam NFRP) with object dimensions test is 150 mm x 300 mm x 2200 mm and the parameter is the number of layers. Meanwhile, Saidi *et al.* (2020b) conducted tests with similar test objects with the configuration parameters for affixing NFRP to reinforced concrete beams with a total of 3 reinforced concrete beams. The test objects are BN (normal beam), BSTV1 (1 layer NFRP vertical strip beam), and BSTD1 (1 layer NFRP diagonal strip beam).

Based on the research above, the test objects used in this analysis from the research of Saidi *et al.* (2020a) and Saidi *et al.* (2020b) are reinforced concrete beams with various variations of reinforcement using NFRP made from abaca fiber. The beam test object used is 150 mm x 300 mm x 2200 mm. The reinforcing steel used as flexural reinforcement is 2-D12.8 reinforcement as compression reinforcement, while 2-D15.8 and 2-D18.8 reinforcement as tensile reinforcement. While the shear-reinforcement used is 5,9-150 reinforcement for the side reinforced with abaca fiber NFRP and 5,9-50 reinforcement for the side that is not reinforced with abaca fiber NFRP. Reinforced concrete beam specimens are tested by placing the beam on a pedestal with a theoretical distance between supports of 2000 mm. Loading is done by giving two concentrated loads of the same size and having a distance between loads of 600 mm.

Table 1. Specimen of RC Beam

No.	Specimen	Fiber width (mm)	Placement configuration	Thickness	Number of specimens	Source
1	BN	-	-	-	1	Saidi et.al. (2020a)
2	BSTV1		90°	1 layer (1.1 mm)	1	Saidi et.al. (2020a)
3	BSTV2	50	90°	2 layers (2.2 mm)	1	Saidi et.al. (2020a)
4	BSTD1		135°	1 layer (1.1 mm)	1	Saidi et.al. (2020b)

Note: BN = normal beam; BSTV1 = beam strengthened by 1 layer vertical NFRP; BSTV2 = beam strengthened by 2 layers vertical NFRP; dan BSTD1 = beam strengthened by 1 layer diagonal NFRP.

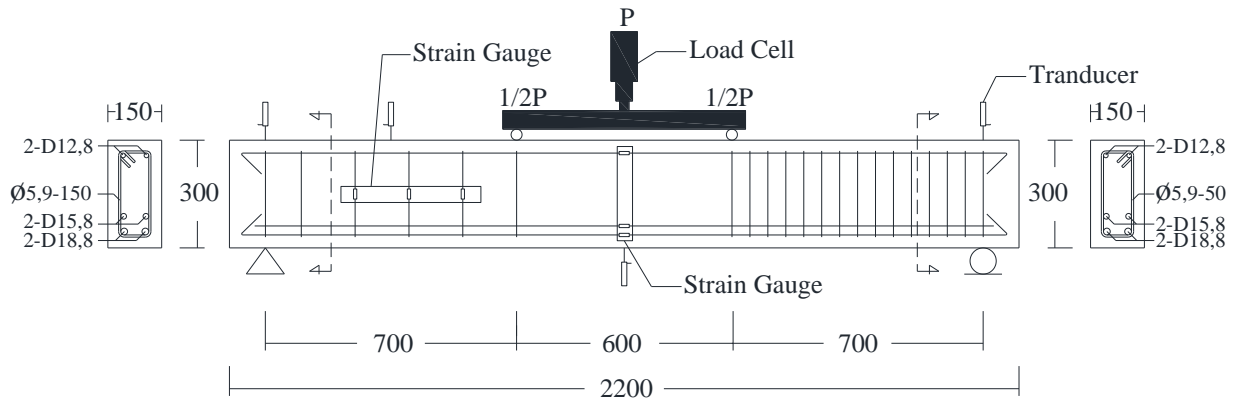


Figure 1. Detail of BN

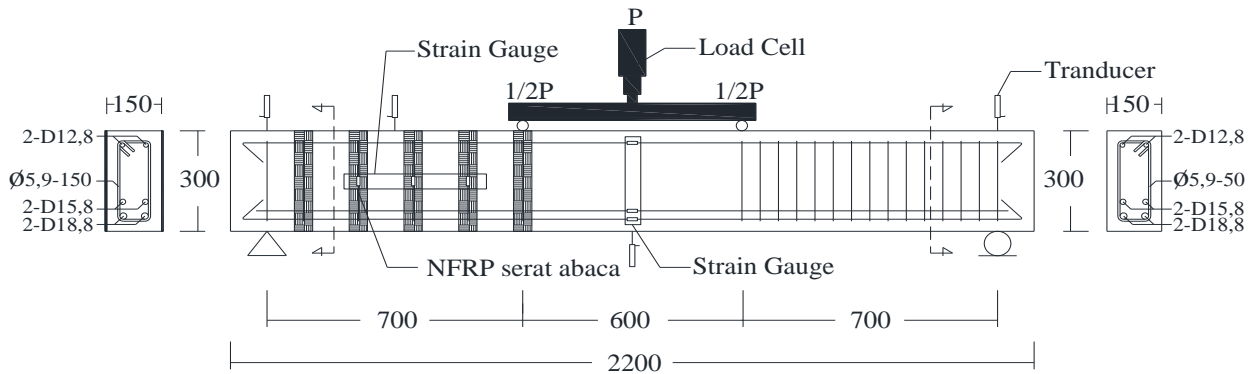


Figure 2. Detail of BSTV1 and BSTV2

Modeling of RC beam by Finite Element Method

The concrete material used is the constitutive model CC3DNonLinCementitious2 with model parameters that can be seen in Table 2 and data on concrete material in Table 3. Reinforcement steel is modeled discretely. The material used is the CCRReinforcement model, with the constitutive model shown in Figure 4 and the steel material data in Table 4. Meanwhile, the NFRP material is modeled as CCCCombinedMaterial with the constitutive model parameters shown in Table 5 and the steel material data in Table 6.

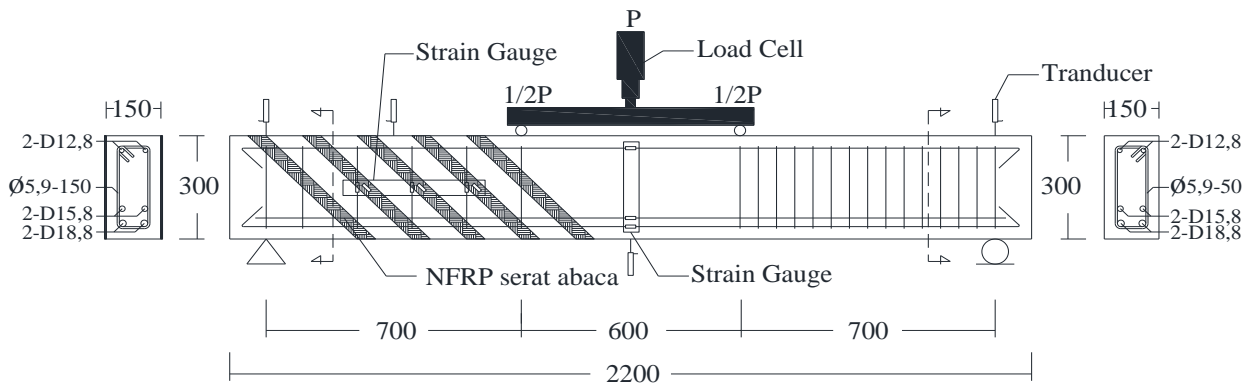


Figure 3. Detail of BSTD1

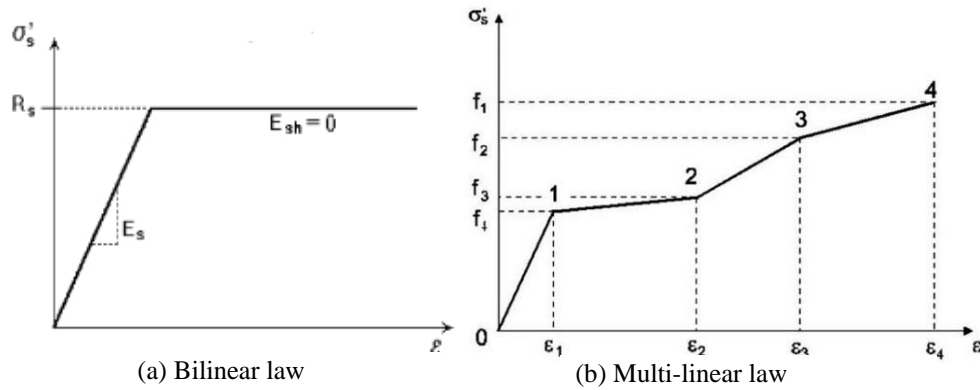


Figure 4. Constitutive model of reinforcement (Cervenka *et al.*, 2016)

Table 2. Concrete Constitutive Law Model Parameters

Parameter	Equation
Compressive strength	$f'_c = -0,85 f'_{cu}$
Tensile strength (Dipohusodo, 1999)	$f_t = 9\% - 15\%$
Elasticity modulus	$E_c = 4700\sqrt{f'_c}$
Poisson's ratio	$\nu = 0,2$
Softening compression	$W_d = 0,0005 \text{ mm}$
Tension softening type	1-exponential, regarding G_f
Compressive strength of cracked concrete	$c = 0,8$
Tension stiffening stress	$\sigma_{st} = 0$
Retention shear factor	Variable
Tensile-compression failure function	linear
Fracture energy G_f regarding Vos (1983)	$G_f = 0,000025 f_t'^{ef} \text{ [MN/m]}$
Strain localization orientation factor	$\gamma_{max} = 1,5$

Note: - The unit used is MPa.

- Parameters that are not written have a default of zero.

Table 3. Concrete Material Data

No.	Specimen	Modulus of Elasticity (MPa)	Poisson's Ratio	Tension Strength (MPa)	Compressive Strength (MPa)
1	BN	31212	0.2	4.41	-44.10
2	BSTV1	29505		3.87	-39.41
3	BSTV2	30745		4.28	-42.79
4	BSTD1	30230		4.14	-41.37

Table 4. Reinforcement Steel Material Data

No.	Reinforcement	Yield (MPa)	Modulus of Elasticity (MPa)
1	Ø5,9	466.28	224539
2	D12,8	457.23	226403
3	D15,8	487.23	243460
4	D18,8	494.56	247280

Table 5. Constitutive Model Parameters of NFRP

Mechanical Properties	Value
Ultimate tensile strength (σ)	Experiment result
Ultimate strain (ϵ)	Experiment result
Modulus of elasticity (E_f)	Experiment result
Poisson's Ratio (ν)	$\nu = 0,21$ (Renjith dan Nair, 2019)
Bonding strength	Experiment result
The unit used is MPa.	

Table 6. Data of NFRP

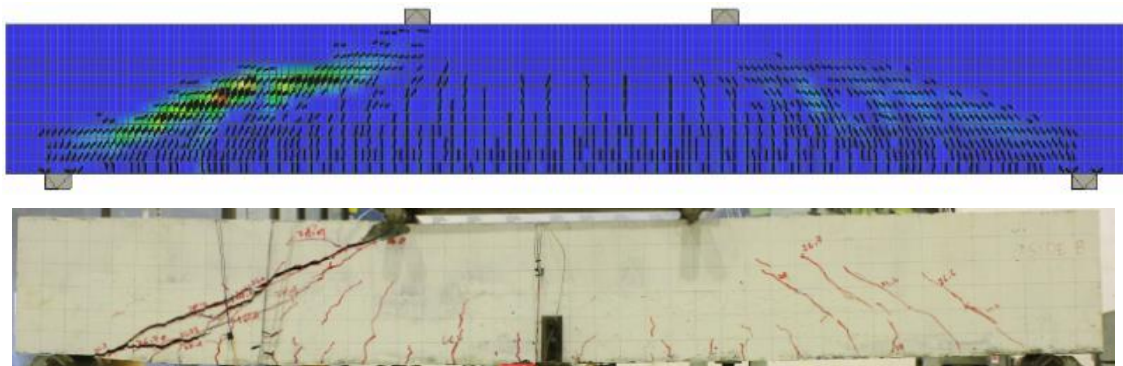
Young's Modulus (MPa)	Poisson's Ratio	Tensile Strength (MPa)
2628.5	0.21 (Renjith and Nair, 2019)	54.58

The reinforced concrete beam specimen was modeled by providing two equal concentrated loads on the reinforced concrete beam. While the boundary conditions for reinforced concrete beams are modeled as simple beams which have boundary conditions in the form of joint supports that resist translational movement in the x and y directions, while the z-direction is free; and bearing rollers that support the y-direction of translation, while the x-direction and z-direction are independent. Point monitors are used to seeing structural responses such as loads and deflections on reinforced concrete beams along with stress and strain behavior on reinforcing steel.

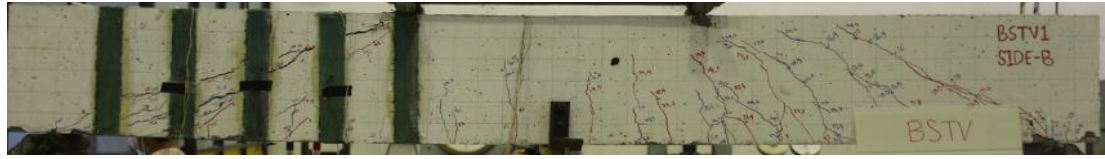
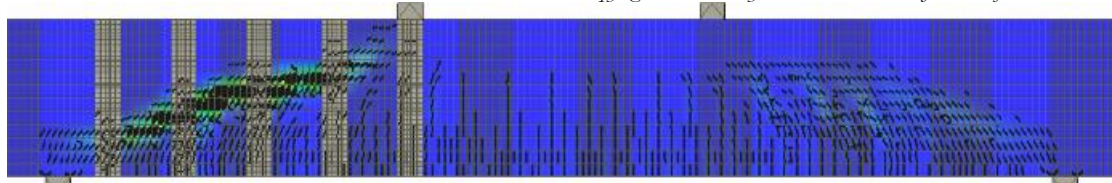
Results

Crack pattern and failure mode

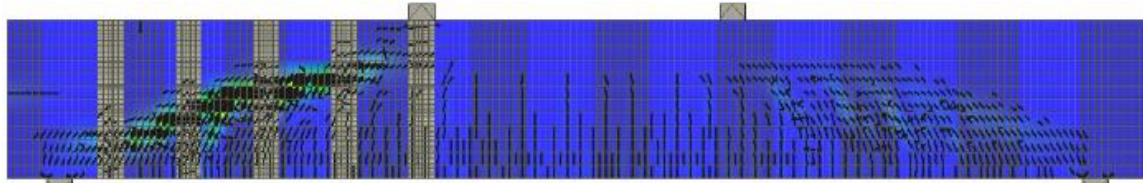
Comparison of the crack patterns between experimental results and numerical results in BN, BSTV1, BSTV2, and BSTD1 visually can be seen in Figure 5.



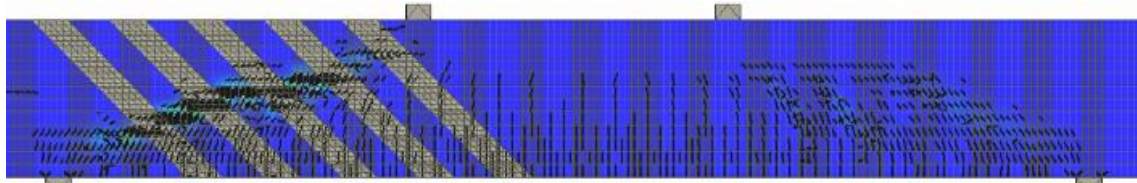
(a)



(b)



(c)



(d)

Figure 5. Crack Pattern of Failure Mode (a) Crack pattern of BN; (b) Crack pattern of BSTV1; (c) Crack pattern of BSTV2; dan (c) Crack pattern of BSTD1

Table 7 shows the angle of the destruction of each reinforced concrete beam at maximum load based on numerical analysis with ATENA V534 and experimental results. The destruction angle increases with the increase in the maximum load of the reinforced concrete beam. This show that the use of NFRP can minimize the shear destruction that occurs. The higher the angle of destruction, the higher the chance of the beam experiencing flexural failure. It suggests that NFRP is effective in resisting shear failure in reinforced concrete beams.

Table 7. The Angle of Crack Occurs at Maximum Load

No.	Benda Uji	Maximum Load		Angle of Crack	
		ATENA V534 (ton)	Experiment (ton)	ATENA V534	Experiment
1	BN	25,89	26,79	22°	24°
2	BSTV1	27,53	29,40	27°	29°
3	BSTV2	28,14	29,45	30°	31°
4	BSTD1	26,92	27,14	26°	28°

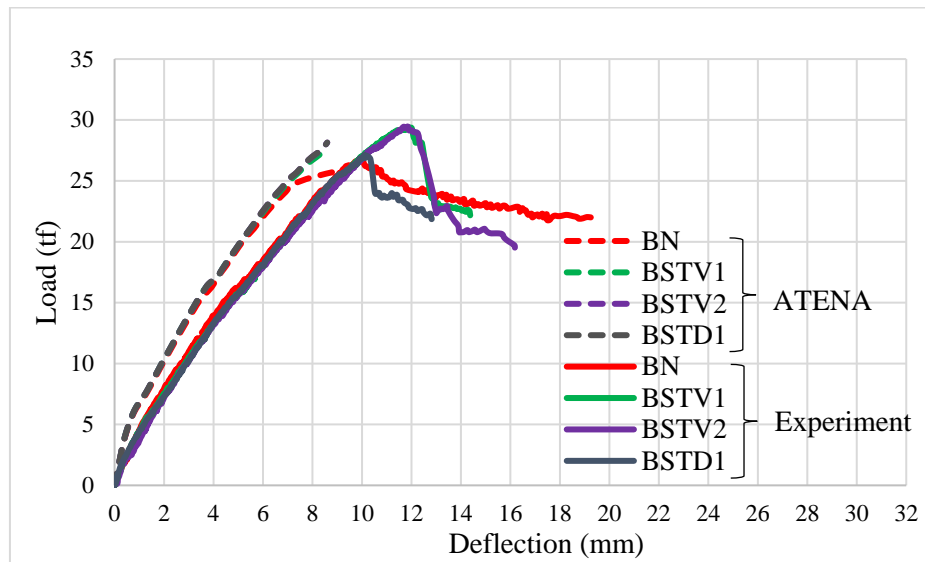


Figure 6. Load and deflection relationship curve

Table 8. Maximum of Load and Deflection

No.	Specimen	ATENA V534		Experiment	
		Load (ton)	Deflection (mm)	Load (ton)	Deflection (mm)
1	BN	25,89	9,20	26,79	9,91
2	BSTV1	27,53	8,54	29,40	11,89
3	BSTV2	28,14	8,60	29,45	11,86
4	BSTD1	26,92	8,16	27,14	10,10

Load and deflection

Comparison of the load and deflection of the four beams, namely BN, BSTV1, BSTV2, and BSTD1, based on the finite element method analysis results using ATENA V534 and experimental results in the laboratory can be seen in Figure 6 and Table 8. Based on Figure 6 and Table 8, it is found that each analysis based on ATENA V534 and the experimental results show almost similar results at maximum load. The results show that the beam with NFRP reinforcement has a higher maximum load than the beam without reinforcement. The results of numerical analysis based on ATENA V534 showed an increase in the maximum load of 6.33%, 8.69%, and 3.98% on BSTV1, BSTV2, and BSTD1, respectively. Meanwhile, based on the experimental results in the laboratory, the maximum load increases were 9.74%, 9.93%, and 1.31% on BSTV1, BSTV2, and BSTD1, respectively.

Discussion

The initial crack in the RC beam

Based on Table 9, the results of numerical analysis using ATENA V534 show an increase in the load on the initial crack of the beam with NFRP reinforcement in the shear area. The use of NFRP can slow down shear cracks that arise in reinforced concrete beams. The beam with NFRP reinforcement accelerates the initial flexural cracking in the initial shear crack. Numerical analysis using ATENA V534 gives good results for predicting early flexural and early shear cracks. However, the experimental results show differences in the initial cracks that arise. This is because the modeling using ATENA V534 simulates ideal structural conditions, where there is no influence on external factors, which generally occurs in experimental testing in the laboratory.

Table 9. Initial Crack of RC Beam

No.	Specimen	Initial Flexure Crack		Initial Shear Crack	
		ATENA V534 (tons)	Experiment (tons)	ATENA V534 (tons)	Experiment (tons)
1	BN	6,0	6,2	7,2	7,0
2	BSTV1	6,1	5,0	7,9	6,4
3	BSTV2	6,6	6,0	8,0	7,6
4	BSTD1	6,7	5,7	7,9	7,3

Table 10. Stiffness of RC Beam

No.		ATENA V534			Eksperimen		
		Initial Flexure Crack	Initial Shear Crack	Final Crack	Initial Flexure Crack	Initial Shear Crack	Final Crack
		(kN.m)	(kN.m)	(kN.m)	(kN.m)	(kN.m)	(kN.m)
1	BN	10893	8723	4043	6160	5940	3883
2	BSTV1	11130	8357	4631	6284	5590	3554
3	BSTV2	10212	8392	4702	6156	5932	3890
4	BSTD1	10460	8413	4737	5849	5255	3862

Maximum load and stiffness of RC beam

In the experimental results of the BSTV1 and BSTV2 beam specimens, there is an insignificant difference in the increase in the maximum load. This happens because BSTV2 has not worked perfectly. After all, NFRP has not worked optimally. Debonding occurs in NFRP due to the inertness of the glue used for NFRP double-layer reinforcement. However, the results of the analysis using the finite element method using ATENA V534 found that the maximum load increase was greater on BSTV2. This happens because ATENA V534 uses the Fix Contact model in modeling the interaction between concrete and NFRP. So that there will be no debonding failure in NFRP and the adhesiveness of the resin is neglected.

The increase in maximum load between the results of numerical analysis with ATENA V534 and experimental results shows the graph of the same increase in each beam. The greatest increase in maximum load occurs in BSTV2 based on the results of numerical analysis with ATENA V534 and experimental results. The use of NFRP by increasing the number of layers of abaca fiber can increase the maximum load of reinforced concrete beams. Meanwhile, the BSTD1 beam shows the lowest maximum load increase, based on the results of numerical analysis with ATENA V534 and experimental results. This happens because the use of NFRP vertically can withstand wider shear cracks than the diagonal configuration of NFRP.

Based on the results of the study, there was a difference in the stiffness of the reinforced beams between the results of ATENA V534 and the experimental results, as shown in Table 10. The results of numerical analysis using ATENA V534 showed higher stiffness than the experimental results in both BN, BSTV1, BSTV2, and BSTD1 beams. . The experimental model shows a lower stiffness caused by the inhomogeneous nature of the concrete material. In comparison, the numerical results, the stiffness of the numerical model is higher because, theoretically, the concrete material is considered a homogeneous material. This shows that the numerical model is more rigid than the experimental model. This difference occurs because, in the numerical model, all materials are simulated under ideal conditions. It is different from the experimental model, which is not homogeneous because during the process of mixing and mixing the material and the casting process, it is very difficult to get the condition of the concrete material in ideal conditions. This will affect the stiffness of the reinforced concrete.

However, based on each analysis, the stiffness is almost similar in both the initial shear and flexural cracks as well as the final cracks in reinforced concrete. Reinforcement with NFRP does not increase the modulus of

elasticity of reinforced concrete beams. Therefore, it does not affect the stiffness of the reinforced concrete beam.

Conclusion

Based on the results of the study, it can be concluded that the test results of reinforced concrete beams with the addition of NFRP made from abaca fiber can minimize shear damage and increase the maximum shear load that occurs in reinforced concrete beams based on the results of laboratory tests and numerical analysis using ATENA V534. The results of numerical analysis using ATENA V534 show a lower maximum load value, higher stiffness, and lower deflection at maximum load compared to experimental results on all reinforced concrete beams analyzed in this study. Based on the results of numerical analysis using ATENA V534 and experimental results in the laboratory, NFRP reinforcement with a vertical configuration is recommended because it can increase the maximum load which is higher than the diagonal configuration.

References

- Alam, M. A. and Riyani, K. A. 2018. Shear strengthening of reinforced concrete beam using natural fibre reinforced polymer laminates. *Construction and Building Materials*, 162: 683-696.
- Arisno, D. 2009. Uji karakteristik serat abaca anyaman 3D pada fraksi volume (30%, 40%, 50%, 60%). Skripsi, Jurusan Teknik Mesin, Fakultas Teknik Universitas Muhammadiyah Surakarta.
- ASTM. D3039. Standard test method for tensile properties of polymer matrix composite materials. American Society for Testing and Materials.
- Cervenka, V. and Jan, C. 2016. ATENA Program documentation part 2-2-user's manual for program ATENA 3D Version 5.4.1, Prague: Cervenka Consulting s.r.o.
- Cheung, H., Ho, M., Lau, K., Cardona, F. and Hui, D. 2009. Natural fibre-reinforced composites for bioengineering and environmental engineering applications. *Composites: Part B*, 40: 655-663.
- Codispoti, R., Oliveira, D. V., Olivito, R. S., Lourenço, P. B. and Figueiro, R. 2015. Mechanical performance of natural fiber-reinforced composites for the strengthening of masonry. *Composites Part B*, 77:74-83.
- Jeyapragash, R., Srinivasan, V. and Sathiyamurthy, S. 2020. Mechanical properties of natural fiber/particulate reinforced epoxy composites – A review of the literature. *Materials Today: Proceeding*, 22: 1223-1227.
- Jirawattanasomkul, T., Likitlersuang, S., Wuttiwannasak, N., Ueda, T., Zhang, D. and Shono, M. 2020. Structural behaviour of pre-damaged reinforced concrete beams strengthened with natural fibre reinforced polymer composites. *Composite Structures*, 244.
- Ku, H., Wang, H., Pattarachaiyakoop, N. and Trada, M. 2011. A review on the tensile properties of natural fiber reinforced polymer composites. *Composites: Part B*, 42: 856-873.
- Nopriantina, N. and Astuti. 2013. Pengaruh ketebalan serat pelepah pisang kepok (*Musa paradisiaca*) terhadap sifat mekanik material komposit poliester-serat alam. *Jurnal Fisika Unand*, 2(3):195–203.
- Oller, E., Pujol, M. and Mari, A. 2019. Contribution of externally bonded FRP shear reinforcement to the shear strength of RC beams. *Composites Part B*, 164:235-248.
- Ozbakkaloglu, T., Lim, J.C. and Vincent, T. 2013. FRP-confined concrete in circular sections: Review and assessment of stress–strain models. *Engineering Structures*, 49:1068-1088.
- Renjith, R. and Nair, R. P. 2019. Structural analysis of NFRP composite boat hull using finite element method, journal of offshore structure and technology structural analysis of NFRP composite boat hull using finite element method. *Journal of Offshore Structure and Technology*, 6(1):10-17.
- Rodiawan, S. and Rosa, F., 2017. Analisa sifat-sifat serat alam sebagai penguat komposit ditinjau dari kekuatan mekanik. *Jurnal Teknik Mesin Univ. Muhammadiyah Metro*, 5(1):39–43.
- Saheb, D. N. and Jog, J. P., 1999, Natural fiber polymer composites: A Review. *Advanced in Polymer Technology*, 18(4):351-363.
- Saidi, T., Amalia, Z., Hasan, M., Hasanuddin, I. and Setiawan, K. 2020a. number of layer effect of abaca fiber as natural FRP material for shear-strengthened reinforced concrete beam. *Proceeding of The 10th Annual International Conference (AIC)*, October 15-16, 2020. Banda Aceh, Aceh Province, Indonesia.

- Saidi, T., Amalia, Z., Hasan, M., Hasanuddin, I., Salvana, W. and Akram. 2020b. An experimental study on bond strength of abaca fiber as natural FRP material. Proceeding of The 10th Annual International Conference (AIC), October 15-16, 2020. Banda Aceh, Aceh Province, Indonesia.
- Sathishkumar, T.P., Satheeshkumar, S., and Jesuarockiam, N. 2014. Glass fiber-reinforced polymer composites – A Review. *Journal of Reinforced Plastics and Composites*, 3(3): 1258–1275.
- Sen, T. and Paul, A. 2015. Confining concrete with sisal and jute FRP as alternatives for CFRP and GFRP. *International Journal of Sustainable Built Environment*, 4:248-264.
- Tang, B.M. 2004. FRP Composites technology brings advantage to the american bridge building industry. Proceeding of the 2nd International Workshop on Structural Composites for Infrastructure Applications, Cairo, Egypt; December 16-18.
- Teng, J.G., Chen, J.F., Smith, S.T. and Lam, L. 2003. Behaviour and strength of FRP-strengthened RC structures: a state-of-the-art review. *Structures and Building*, 156(1): 51-62.
- Tong, F.S., Chin, S.C., Shu I., Doh, and Gim bun. 2017. Natural fiber composites as potential external strengthening material – a review. *Indian Journal of Science and Technology*, 10(2):1-5.
- Tudjono, S., Lie, H. and Hidayat, B. 2015. An experimental study to the influence of fiber reinforced polymer (FRP) confinement on beams subjected to bending and shear. *Procedia Engineering*, 125.
- Widyarningsih, E., Herbudiman, B. and Hardono, S. 2016. Kajian eksperimental kapasitas sambungan material fiber reinforced polymer. *Jurnal Online Institut Teknologi Nasional*, 2(3):29-38.