Strength Analysis of Physically Treated Rattan as Reinforcement of Concrete Beam

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Abstract: In the Philippines, reinforced concrete is the most common construction material used when building structures. However, the use of steel as reinforced concrete's primary reinforcement has proven difficult to maintain once it has been damaged and is costly to repair, thus poor communities may not have access to such materials when in dire need. As a viable alternative to steel, this study analyzed and investigated the properties of rattan as a reinforcement in concrete due to its tensile strength capability as well as its availability and accessibility for poor communities. Physical corrugations were placed on rattan canes to determine if this can improve the bond strength between rattan and concrete while an analytical flexural analysis was conducted, factoring in the effects of slippage from concrete. The results from the study determined that physical corrugations were able to marginally improve the bond strength of rattan with concrete. Despite this finding, this improvement cannot replace steel as reinforced concrete's main reinforcement because rattan is a much weaker material than steel. The yield strength and the modulus of elasticity of rattan were established to be only about a tenth of steel's and there was a 77.61% percent difference between the calculated moment-capacities of a rattan-reinforced beam and a steel-reinforced beam. In recommendation, instead of being used for slip-critical members like beams, rattan-reinforced concrete can be investigated for members that are not subjected to large bending.

Key Words: Rattan Reinforcement; Reinforced Concrete; Physical Corrugation; Analytical Flexural Analysis.

1. INTRODUCTION

Corrosion is a common type of failure of steel as a reaction to the presence of chloride ions and carbonation (Ahmad, as cited in Aguirre-Guerrero & Gutiérrez, 2018). Yet this involves high maintenance and costly repairs once it occurs. However poor communities may not have access to such funds for maintaining their structures. With this, different studies involving possible steel alternatives, like natural fibers such as bamboo and rattan, are continuously developed to find sustainable and locally made reinforcements that are resistant to corrosion.

One of the natural stem fibers used in different steel alternative studies is rattan. Rattan species are found in tropical countries like Indonesia and the Philippines. It is a fast-growing flexible plant which is cheap and can be easily accessible by communities. In 2015, a comparative study on steel, bamboo, and rattan as reinforcement was conducted by Adewuyi et al. According to this, rattan marginally satisfied the ductility requirement of 12% while bamboo did not.

Tan (1993) studied the mechanical properties of two species of Philippine rattan, namely Tumalim and Palanok. This resulted to tensile strengths that ranged from 37.71 MPa to 46.33 MPa with modulus of elasticities ranging from 265.97 MPa to 360.25 MPa. Lastly, the bond strength between rattan and concrete ranged from 0.0295 to 0.0443 MPa. The research recommended to find ways on how to improve the bond strength of rattan with concrete due to its smooth surface that caused slippage.

Rattan was chosen as the material to be investigated since this has similar material properties to bamboo, especially its flexibility, is less expensive than that of steel, and is easily accessible by poor communities.

This paper aims to experimentally investigate the bond strength of physically treated rattan with concrete and to analytically investigate the flexural strength of a rattan-reinforced concrete beam. The specific objectives of this study are the following:

1. To obtain the tensile strength of untreated rattan;
2. To search for the best physical corrugation on rattan that will improve its bond strength with concrete; and
3. To obtain the moment-strain diagram of a rattan-reinforced concrete beam through an analytical flexural analysis.

2. METHODOLOGY

Fig. 1 presents the experimental procedure undertaken by the researchers which includes the procurement of materials up to the analytical flexural analysis of the rattan-reinforced beam.

2.1 Sample Preparation

The materials prepared for the research are the following: rattan with half-inch diameters and lengths of 900 mm and a concrete-mix with a strength of at least 21 MPa.

Three types of physical corrugations were applied to the rattan canes: helical/spiral, hatches, and notches. All corrugations are of 3 mm in depth. The corrugation patterns are presented in Fig. 2 and there would be a total of 16 samples to be tested for pullout: four for each physical corrugation as well as an additional four plain canes.

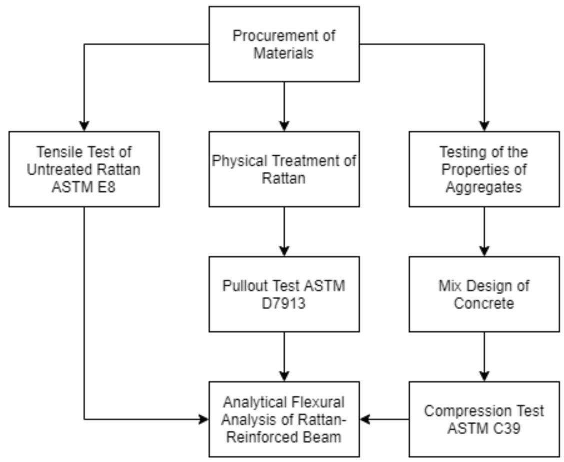

Fig. 1. Experimental procedure.

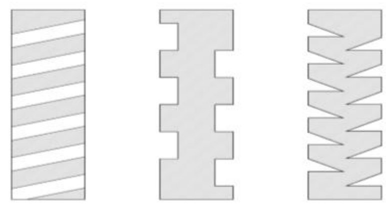

Fig. 2. Physical corrugations (from left to right): helical/spiral, hatches, and notches.

Concrete specimens were prepared in four batches which were subjected to compression tests following ASTM C39 under loads from a Universal Testing Machine (UTM).

2.2 Tension Test

To determine the tensile strength of rattan, the researchers adopted a modified version of ASTM E8 wherein a plain rattan specimen was subjected to tensile forces under a UTM until failure. The length of rattan was be modified to fit the UTM.

2.3 Pullout Test

The 16 rattan canes were embedded 19 cm into concrete cylinders while adapting a modified version of ASTM D7913. The researchers used a metal box shown in the set-up in Fig. 3 to be able to simulate the pullout test with a UTM.

Fig. 3. Actual pullout test specimen.

2.4 Analytical Flexural Analysis

An analytical flexural analysis was performed to simulate the behavior of a steel-reinforced concrete beam using the conventional formulas to establish the critical moments at the different loading stages. An example of the computations converted into a moment–strain diagram is shown in Fig. 4.

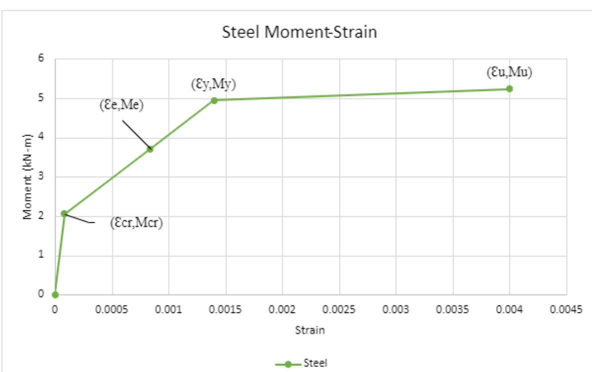

Fig. 4. Moment-strain diagram of steel reinforced concrete beam.

The analytical flexural analysis was performed to simulate the behavior of a rattan-reinforced concrete beam. The moments were obtained by using a trial cross-section for both rattan and steel. This study uses similar dimensions to that of Obilade & Olutoge (2014) which is presented in Fig. 5. The number of rattan reinforcements is four with diameters of 12.7 mm while the number of steel reinforcements is two with diameters of 10 mm. Parameters such as the yield strength, ultimate strength, and the modulus of elasticity of rattan were obtained from the performed tension test. These parameters are used in calculating bending moment at different stages of loading. By following same computations as done with a steel reinforced concrete beam, the moments at cracking, elastic, yielding, and ultimate were obtained. However, there would be a difference to later parts in the computation when involving slippage. A plain concrete beam with the same dimensions was also computed for.

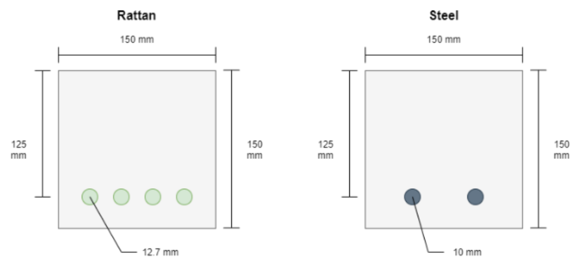

Fig. 5. Cross-section of rattan and steel used in the analytical flexural analysis.

The initial analysis assumes that the rattan has a perfect bond with concrete so that the conventional formulas for steel reinforced concrete beam for evaluating bending moments at different stages of loading may be used. Subsequent simulations include the losses of strength due to the slippage of rattan with concrete. To compute for such, the steps will be elaborated as shown below:

1. Compute for moment at cracking (M_{cr}), yielding (M_y) and ultimate (M_u) of rattan at perfect bond.
2. Obtain the first stress developed in the pullout data and label as $\sigma_{init-slip}$
3. Compute for strain ($\varepsilon_{init-slip}$) given the stress with use of Eq. 1.
$$\varepsilon_{init-slip} = \frac{\sigma_{init-slip}}{E_s} \qquad \text{(Eq. 1)}$$
4. Using the given strain, interpolate in between the cracking and yielding moment to get the moment at initial slippage ($M_{init-slip}$) using Eq. 2.
$$M_{init-slip} = \frac{M_y - M_{cr}}{\varepsilon_y - \varepsilon_{cr}}(\varepsilon_{init-slip}) + M_{cr} \qquad \text{(Eq. 2)}$$
5. Plot the moment and strain for the initial slippage alongside the existing moment-strain diagram. This is seen in Fig. 6 and is the point of slippage.
6. Solve for the difference in strain ($\varepsilon_{pullout}$) between the yield point and initial slip as shown in Eq 3.
$$\varepsilon_{pullout} = \varepsilon_{yielding} - \varepsilon_{init-slip} \qquad \text{(Eq. 3)}$$

7. With this value, find the corresponding stress from the pullout data given this strain and label as $\sigma_{pullout}$.
8. Solve now for the moment at pullout of reinforcement as found in Eq. 4

$$M_{pullout} = A_s \sigma_{pullout} \left(d - \frac{kd}{3}\right) \qquad \text{(Eq. 4)}$$

9. Plot the moment and strain for the pullout. This is labelled as point of pullout.

where:

$\varepsilon_{init-slip} =$ strain at initial slippage

$M_{init-slip} =$ moment at initial slippage

$\sigma_{init-slip} =$ stress at the start of slippage

$\varepsilon_{pullout} =$ strain at pullout

$M_{pullout} =$ moment at pullout

$\sigma_{pullout} =$ stress at pullout

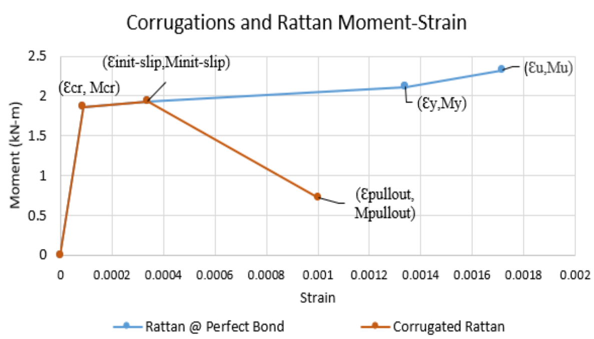

Fig. 6. Moment-strain diagram of rattan at perfect bond with concrete and rattan.

Once the computations are complete, this now simulates the rattan reinforcement when experiencing slippage of the member. Through this, it completes the analytical flexural analysis of the study.

3. RESULTS AND DISCUSSION

After obtaining data from the tests, this was used to analyze how a rattan-reinforced concrete beam would react when simulated analytically through computations. From the specimens tested, the average compressive strength of concrete was 28.87 MPa. This was the average from 23 samples, with five to six concrete cylinder specimens made from each batch of pullout samples.

With the tensile test, a total of 15 samples were tested and to obtain the yield and ultimate strength of the rattan members. The 0.5% offset method was adopted to determine the yield point. This was similarly to that done by Mahzuz et al. (2014). Through this, a yield strength of 29.08 MPa, an ultimate strength of 37.208 MPa, and a modulus of elasticity of 21,680.02 MPa was found for the rattan canes. In comparison to Grade 280 steel, with a yield strength of 280 MPa and a modulus of elasticity of 200,000 MPa, rattan only obtained 10.4% and 10.8% of the said mechanical properties, respectively.

After which, when analyzing the pullout test, the notching, hatching, spiral, and plain corrugation bond strengths were as follows: 0.292 MPa, 0.265 MPa, 0.221 MPa, and 0.201 MPa respectively. Majority of the final failure of these pullout samples were found to be the snapping of the rattan leaving the corrugated part inside the concrete.

After obtaining the results from the pullout tests, the stress-strain data were obtained. In computing the cross-sectional area, 18 mm^2 was subtracted from the original area of 126.68 mm^2 to account for the depth of corrugation onto the reinforcements. This leaves an effective area of 108.68 mm^2. Shown in Fig. 7 is the average stress-strain diagram of each corrugation and its corresponding data now linearized by getting the curve's trendline through excel.

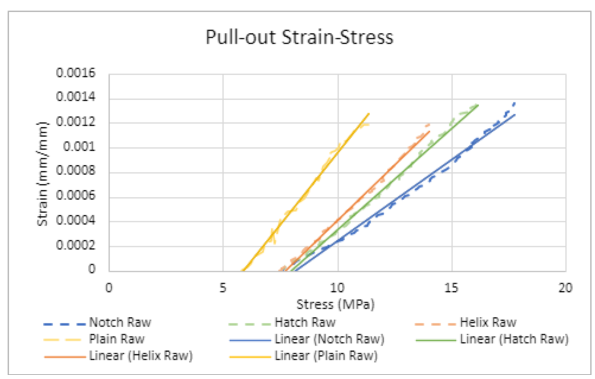

Fig. 7. Pull-out strain-stress data with linearized (solid) and raw (dashed) data.

By analyzing the figure, this shows at what value of stress the rattan will be pulled out from the concrete until it will totally slip. It was found that plain rattan's initial pullout is at 6.542 MPa while the corrugations had an average of around 8.127 MPa. In terms of maximum pullout, plain received the smallest at 11.361 MPa while the maximum value was found with notching corrugation at 18.0 MPa.

After performing the analytical flexural analysis on the sample section, this will now simulate the steel and rattan at perfect bond. This is presented in Fig. 8 wherein this shows a big difference with the strengths of rattan and steel. However, when comparing it to that of a plain concrete beam, rattan increased the beam's strength by 23.15%. Yet, the steel reinforcement increased its strength to almost 178.61%. This shows that rattan improves the strength of that of a plain concrete beam but when compared to that of steel, it is significantly weaker. To add, this is also the rattan at perfect bond with concrete. This value for moment will still decrease when including slippage in the computations.

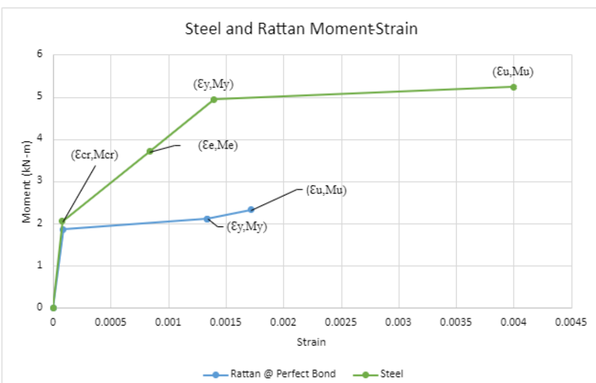

Fig. 8. Steel and rattan moment-strain plot.

While after applying slippage computations, the moment-strain among these values is shown below in Fig. 9. When analyzing this figure, the moment severely decreases due to the slippage of rattan. When comparing the notching value of 0.907 kN-m to the 2.3084 kN-m of rattan at perfect bond, it is merely only 39.29% of its strength. When comparing to the plain corrugation, the value is much less at 0.655 kN-m and is only 28.37% of the strength of rattan at perfect bond. While the corrugations improved the strength of rattan, it only increased marginally when the ideal situation is to increase it to almost perfect bond.

When comparing the rattan to steel, these showed even lesser promising results with the plain rattan canes only receiving 12.52% of that of steel's while the corrugated rattans received only around 14.40% to 17.33%. A summary of the moments computed throughout the study is shown in Table 1.

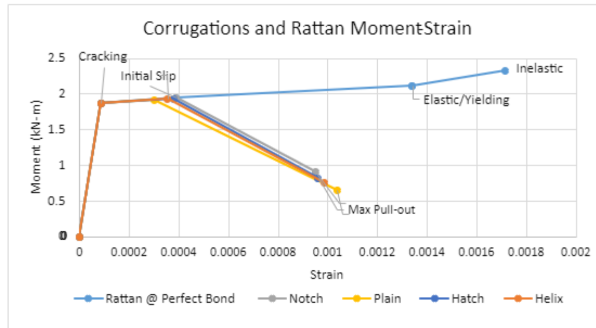

Fig. 9. Corrugations and rattan's moment-strain plot.

Table 1. Comparison of Moments Computed

	Maximum Moment (kN-M)	Moment at Failure (kN-m)
Steel Reinforcement Beam	5.235	5.235
Plain Concrete Beam	1.879	1.879
Rattan Reinforced Beam:		
Rattan at Perfect Bond	2.308	2.308
Notching Corrugation Rattan	1.940	0.907
Hatching Corrugation Rattan	1.938	0.823
Spiral Corrugation Rattan	1.933	0.754
Without Corrugation Rattan	1.922	0.655

After analyzing the values presented, it is evident that rattan may not be suitable as a possible replacement for steel as reinforcement in a concrete beam. When comparing rattan to steel, this only produced half of steel's strength. When considering an actual condition wherein slippage is included, this decreases the strength to only 12.52% of steel's and by adding corrugations, this only increased its strength to 17.33% of steel's by using notching corrugation. By these values alone, it shows that rattan may not be suitable as a reinforcement due to its weak mechanical properties (f_y, f_u, and E) in comparison with steel. Another reason is the slippage of rattan in concrete even with physical corrugations as shown through the analytical flexural analysis, resulting to lower strength and brittle behavior.

Lastly, to validate the simulation, the study of Adewuyi et al. (2015) was used as reference. Their study obtained the cracking and ultimate load of an actual rattan-reinforced concrete beam. To validate the procedure, the cracking and ultimate moments were computed and compared to the same loads that were experimentally found by testing Adewuyi et al.'s beam. It was found that the cracking moment and ultimate moment occurred at 1.125 kN-m and 1.5 kN-m respectively. When manually computed, the theoretical strengths were found to be 1.562 kN-m and 1.640 kN-m for cracking and ultimate, respectively. A summary of moments is shown in Table 2 with their corresponding percent differences. Through this, it was found that the data points for cracking moments are far from one another, where this may be due to the difficulty in pinpointing the actual cracking moment when done in an experiment setup. The ultimate moment has a percent difference of 8.96% difference which is acceptable considering the small strength of the loads applied.

Table 2. Validation of Moments

	Cracking Moment (kN-m)	Ultimate Moment (kN-m)
Computed Result	1.5623	1.6407
Experimental Result	1.125	1.500
Percent Difference	32.55%	8.96%

4. CONCLUSIONS

In conclusion, rattan was found to be a weaker and brittle material as compared to steel. Rattan was found to have only 10.39% and 10.84% of steel's yield strength and modulus of elasticity.

In terms of bond strength, notch corrugation achieved the highest bond strength of 0.292 MPa while the spiral pattern was the least effective physical corrugation. With this, applying corrugations was proven to improve the bond strength of rattan with concrete.

From the analytical flexural analysis, a rattan-reinforced concrete beam achieving perfect bond increased a plain concrete beam's strength by only 23.15%. However, the percent difference between the maximum moment of a rattan-reinforced and steel-reinforced beam was 77.61% having a higher maximum moment achieved for a steel-reinforced beam. After applying slippage loss, the moment of rattan-reinforced concrete greatly decreased.

Moment-strain of rattan was incomparable to steel's capacity. With this, it can be concluded that instead of rattan being used for slip-critical members like beams, it can be used as reinforcement for members that are not subjected to large bending.

As a recommendation, a larger diameter of rattan canes should be used to improve the bond with concrete. As was seen in this study, slippage became a significant factor to the brittle behavior of rattan-reinforced concrete beam. To fully utilize the rattan, better bond can be further explored through chemical treatments or other means of physical treatments.

5. ACKNOWLEDGMENTS

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