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Laminated Jute and Glass Fibre Reinforced Composite for Repairing Concrete Through Wrapping Technique

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Abstract: Natural fiber reinforced composite in concrete structure material has attracted many researchers and engineers in recent decades due to its good agreement in mechanical properties, economics, and sustainability. An experimental investigation was conducted to investigate the jute and glass fiber laminated composite for cylindrical concrete repair. Jute and glass fiber were used as reinforcement, and vinyl ester (VE) served as the matrix. The vacuum bagging technique was used to wrap the cylindrical concrete columns with a diameter of 50 mm and a height of 150 mm. Compression and Brazilian tests were performed on the specimen. It was discovered that the four (4) layers of jute fiber reinforced thermoset (JFRT) composite had the highest mechanical properties, with an improvement of 72.62% when compared to glass fibre reinforced thermoset (GFRT) composite. It can be concluded that both GFRT and JFRT had the potential to improve the mechanical properties performance of cylindrical concrete specimens with an increase of up to five (5) layers of woven fiber. The results presented here may facilitate improvements in the concrete specimen by using JFRT where it was suggested to have a higher improvement for the concrete specimen with the optimum layers applied. As a result, jute fiber has been shown to perform better and can be used as an alternative to glass fiber. As a result, jute fiber has been shown to perform better and can be used as an alternative to glass fiber.

Keywords: Natural fiber, synthetic fiber, laminated composite, concrete strengthening

1. Introduction

Today, concrete is commonly used as a building material due to its high compressive strength and durability. Plain concrete requires an ingenious atmosphere by supplying moisture for a minimum duration of 28 days for good hydration and to achieve the required strength. Any laxity in curing can have a significant effect on the strength and longevity of the concrete [1]. Additional steel reinforcement is added to improve the performance of concrete in carrying load and preventing it from failure [2]. In a comprehensive review by Singh and Rai [1], the term hybrid fiber reinforced concrete (HyFRC) is used for reinforced concrete containing the composition of one or more types of fibers of different sizes, shapes or origins. HyFRC has a unique feature in building the original performance of the structure to

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resist micro cracks and is also widely used as a secondary reinforcement. However, Brown et al. [3] raised a great deal of concern about the deterioration of concrete structures due to steel corrosion due to the expensive structural repair process. The concern of the integrity of concrete structures must be preserved or rapidly restored immediately after the earthquake, which underlines the value of rapid reinforcement and repair techniques [4] [5]. Furthermore, additional problems and uncertainties associated with strengthening and repair also need to be discussed, such as localized adjustments in the membership rigidity that can alter the structure's dynamic properties and thus alter the seismic demands on individual elements or the entire building as stated by Zhao and Wang [6].

Kovler and Chernov [7] explain that some cases of concrete destruction are unable to determine. The pattern of cracks of the structure can be analyzed through inspection which then tells the historical data that only experienced engineers can visualize the cause and effect on the structure. According to He et al. [8], repairing damaged RC columns on the existing structure is expensive and time-consuming. For example, Mohammed et al. [9] state the estimation of more than USD 5 billion is invested annually in the construction of RC bridges in countries like the United States, Canada, and Europe. Pickering and his co-workers [10] claimed that the idea of utilizing fiber-reinforced polymer is getting familiar to increase the strength of the concrete structure. In addition, Harajli and Dagher [11] stated that fiber-reinforced polymer will be more practical in the field than the traditional steel jacketing method.

Recently, researchers had developed new findings that motivated them to use laminated composite or commonly known as a fiber-reinforced polymer to aid unhealthy structures and improve the current mechanical properties to withstand greater load as quoted by Li [12]. Hence, FRPs are widely used in the industries of aerospace, automotive, marine, and construction [13]. Moreover, Parvin and Wang [14] explore the trend of using fiber-reinforced polymer (FRP) on the concrete structure by focusing on the thickness of the laminates by multiplying the layers of the wraps on the concrete column. In addition, Attari et al. [15] claimed that the research and design guidelines indicate that externally bonded fiber-reinforced polymers (FRPs) effectively improve the strength of reinforced concrete. Wayadande and Pol [16] showed that the application of CFRP increases the flexural strength of undamaged beam by 40.45% and 40.50% for deteriorate beam. The finding is in line with Yu et al. [17] which performed an investigation to evaluate the effect of corrosive resistance of the concrete structure using FRP. Sen and Paul, [18] study on confining concrete with sisal and jute FRP as alternatives for CFRP and GFRP. They found that the natural FRP confinement demonstrated superior confinement modulus and confinement strength; additionally, the ultimate axial load of concrete cylinders confined with natural FRPs was increased by 66 percent by sisal FRP and 48 percent by jute FRP, when compared to controlled or unconfined cylinders.

However, to the best of the authors' knowledge, no report has been found so far using laminated jute and glass fiber reinforced composites for concrete repair. As a result, this study will look into the jute and glass fiber laminated composite for cylindrical concrete repair. The long-term implications of this study will impact our environment, potentially reducing the use of synthetic fiber.

2. Materials and Methodology

The bag of cement and fine sand was bought from Khem Mines Sdn. Bhd. The properties of the cement are shown in Table 1. Glass fiber and jute fiber fabrics have been purchased from My Tech Solution Enterprise and Himanshu Jute Fab. Vinyl ester (VE) resin solution from ML Fiberglass Sdn. Bhd. The properties of the VE resin are shown in Table 2. In this study, there are 66 cylindrical concrete columns was fabricated with a diameter of 50 mm and 150 mm height as shown in Fig. 1. The grade of concrete used was grade M10 which has a mixing ratio of 1:3 for cement and sand, with a water-cement ratio of 0.50. The fresh concrete is assessed by following ASTM C143 using slump test which it needs to pass the slump test between 50 to 75 mm before being poured into the mould to assure its viscosity so that the concrete can deliver great performance to the structure. A true slump of fresh concrete is compulsory to proceed for specimen casting.

Table 1 - Properties of OPC cement

Material	Portland cement
Density (ρ)	2240 - 2400 kg/m3
Compressive strength	20 - 40 MPa
Flexural strength	3 - 5 MPa
Tensile strength (σ)	2 - 5 MPa
Modulus of elasticity (E)	14 - 41 GPa
Permeability	1 x 10-10 cm/sec
Coefficient of thermal expansion (β)	10^{-5} °C^{-1}
Drying shrinkage	4 - 8 x 10^{-4}
Drying shrinkage of reinforced concrete	2 - 3 x 10^{-4}
Poisson's ratio	0.20 - 0.21
Shear strength (τ)	6 - 17 MPa
Specific heat (c)	0.75 kJ/kg K

Table 2 - Properties of the VE *(These properties were provided by the supplier)*

Specification	Vinyl ester (VE)	Hardener (MEKP)
Chemical type	Resin	Catalyst
Colour	Transparent	Transparent
Mixing ratio	100	1
Viscosity (25°C)	8500 mPa.s	350 mPa.s
Mixing viscosity (25°C)	1500 mPa.s	
Cure time (25°C)	5-6 hours	
Final hardness	24 hours	
Tensile strength	75 MPa	
Hardness	>70D	
Water absorption	<0.5 wt %	

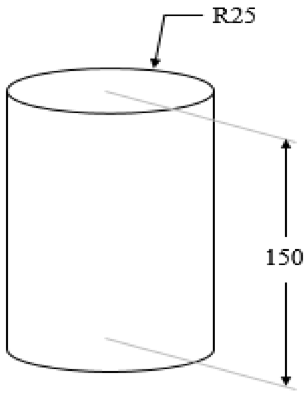


Fig. 1 - Cylindrical concrete specimen dimension

In addition, the layers of GFRT and JFRT on the cylindrical concrete column are up to five layers in each category. All GFRT and JFRT would be 0/90 oriented towards the long concrete column. The sample codes are shown in Table 3 for reference of the sample in each category. Note that N is the material used and n is the number of layer(s) used. Moreover, prior to the wrapping process on the concrete, the concrete was then healed in water for 28 days on the basis of the ASTM standard in order to obtain the highest maturity of the concrete. Vacuum pump RA 0100 F 503 with the BUSCH brand was used for the vacuum process with capacity Vmax 100 m3/h and Pab 0.1 hPa (mbar). Fig. 2 shows a specimen of the wrapping of concrete. Wrapping concrete is then tested under compression and Brazilian test conditions at Universiti Teknikal Malaysia Melaka, Malaysia, in accordance with ASTM C39/C39M and ASTM C496/C496M – 17 standards.

Table 3 - Specimen classification

Category	Material (N)	No. of layer (n)	Specimen code
Control specimen (CS)	n/a	n/a	CS-C-n
Control specimen (CS)	n/a	n/a	CS-B-n
Compression testing (C)	GFRP (1)/JFRP (2)	n	CN-n
Brazilian testing (B)	GFRP (1)/JFRP (2)	n	BN-n

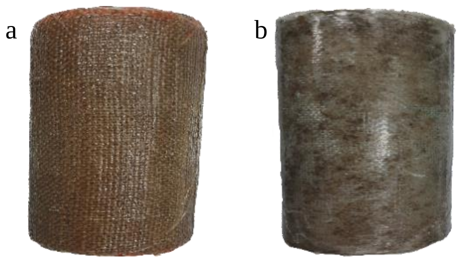


Fig. 2 - Specimen of wrapping concrete (a) JFRT and; (b) GFRT

3. Result and Discussion

3.1 Tensile Performance of Laminated GFRT and JFRT

Fig. 3 shows the GFRT and JFRT performance. From the figure, it is interesting to note that there is a similar trend between GFRT and JFRT, which increased its tensile performance by adding the number of layers. On the other hand, glass fiber has performed very well in tensile strength compared to jute fiber, which can be seen from the data presented as a major difference in tensile performance. This could be due to the greater extensibility of glass fibers (2.5–3.0) than jute fibers (1.5–1.8) [19]. Interestingly, in line with the findings of Raghavendra et al. [20], the present study found that the tensile performance correlation between glass fiber and jute fiber tensile performance clearly shows that glass fiber is the strongest. However, this is contrary to a study by Lotfi et al. [21] which emphasizes that jute fiber is an alternative material for laminated glass and carbon fiber composites for a wide range of applications. The statement is supported by Begum and Islam [22] which concluded that the use of natural fibers such as jute is highly likely to replace a large segment of synthetic applications.

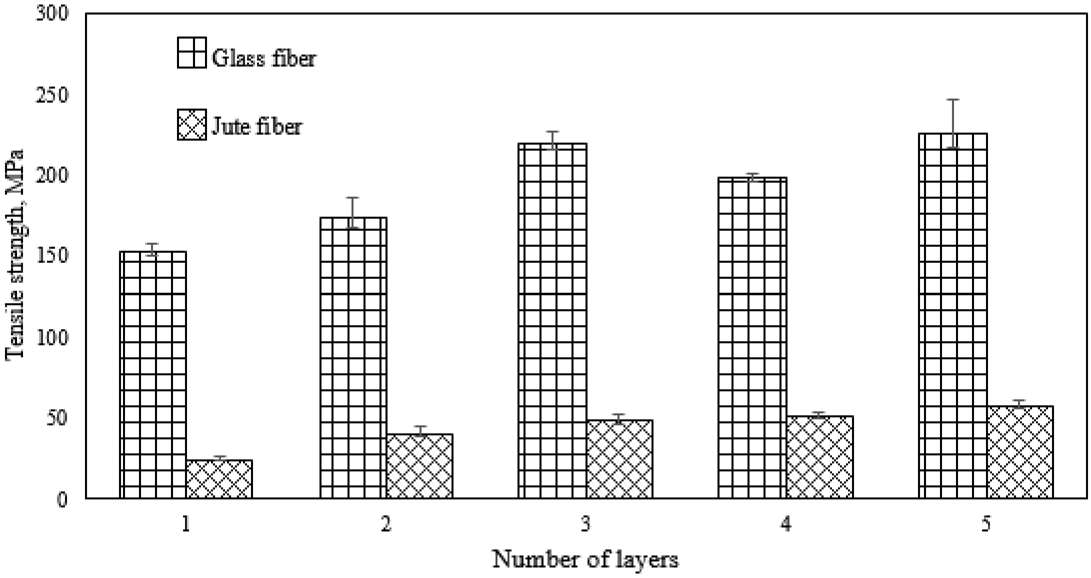


Fig. 3 - Tensile performance of laminated GFRT and JFRT

3.2 Compression Performance of Laminated GFRT and JFRT Wrapping Concrete

Fig. 4 demonstrated the compression performance for GFRT and JFRT wrapping concrete. For GFRT wrapping concrete, the lowest performance of 38.04 KN by C1-G and the highest performance of 63.69 KN by C4-G. This finding highlights that four layers of glass fiber showed an amazing improvement of 67.40% as compared to one layer. Interestingly, there is a slight drop of 2.32% compressive performance for C5-G at 62.23 KN comparing with C4-G. The ultimate force for C2-G and C3-G are 47.78 KN and 52.18 KN, respectively. Furthermore, the upward trend continues with the addition of glass fiber layers, gradually increasing the compressive performance of concrete specimens. The decrease in performance at C5-G was caused by the loss of confinement action caused by FRT rupture [23]. As a result, the C4-G specimen has the optimal number of layers. From the data in Table 4, it is clear that the GFRT failure mode or crack form has spread from top to bottom. The cracking of the increment number of folds started from the top and breaks at a certain point in the latitude direction showing the folding of the concrete column. This cracking behavior can be seen in the marked area where the higher GFRT latitude breakage shows the higher performance of the specimen. From the data, it was found that the C4-G had the highest latitude breakage and also had the highest performance.

In addition, the lowest compression performance for JFRT was C1-J of 25.83 KN and the highest compression performance was C4-J of 83.27 KN. This finding highlights that four layers of jute fiber showed an impressive 222.38% improvement in concrete compared to one layer. Interestingly, there is a slight drop in C5-G compressive performance of 14.72 per cent at 71.85 KN compared to C4-J. The final force for C2-G and C3-G is 64.10 KN and 70.12 KN respectively. Table 5 shows the propagation of the failure mode or cracking of the JFRT specimen. It is therefore clear that the crack formed by the JFRT propagated from bottom to top only for the C1-J specimen and breaks the laminated JFRT at the latitude of the specimen showing the buckling of the concrete column. Nevertheless, the formation of cracks for other layers spread from top to bottom. This cracking behavior can be seen in the marked area where the higher latitude breakage of the JFRT indicates the higher performance of the specimen. Thereby, C4-J has the cleanest form of cracks that break evenly, indicating its highest performance.

In conclusion, JFRT has the highest compression performance compared to GFRT. Both laminated composites demonstrate the same high-performance behavior with respect to the number of layers applied but with a slight drop in performance at five layers. In addition, it can be clearly seen that the buckling effect of the concrete specimens illustrates the compression performance by which, the higher the breakage point, the higher the resistance at the enduring compression load.

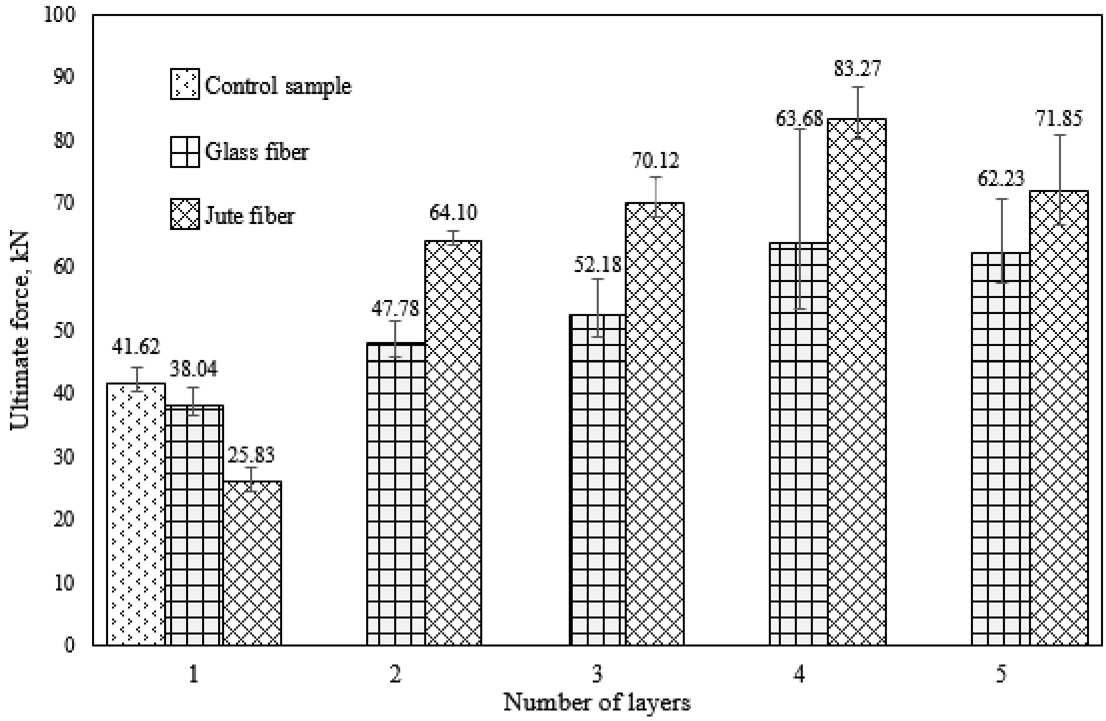


Fig. 4 - Compression performance of laminated GFRT and JFRT

Table 4 - Form of crack for GFRT laminated concrete cylinder

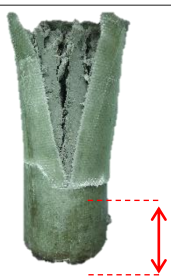
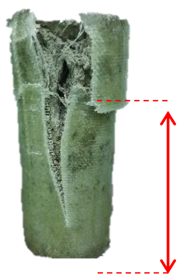
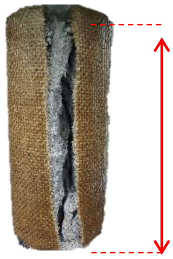
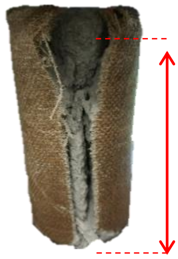
Control sample	C1-G	C2-G
		
C3-G	**C4-G**	**C5-G**
		

Table 5 - Form of crack for JFRT laminated concrete cylinder

Control sample	C1-J	C2-J
		
C3-J	**C4-J**	**C5-J**
		

3.3 Brazilian Performance of Laminated GFRT and JFRT Wrapping Concrete

Fig. 5 shows that the Brazilian performance of laminated GFRT and JFRT wrapping concrete. The experimental data of Brazilian performance for GFRT in Fig. 5 clearly shows an increasing trend of ultimate force respecting the increasing number of plies. Referring to the results, the B1-G specimen is the lowest among other layers which have a value of 36.33 KN and B5-G has the highest value of force, which is 68.46 KN, respectively. Furthermore, GFRT laminated onto concrete cylinder performs a remarkable improvement of 120.36% increment for only one layer of glass fiber used. With additional layers of glass fiber applied for B2-G, B3-G, and B4-G, the ultimate force that the concrete specimen can withstand also gradually increase with the value of 48.54 KN, 52.51 KN, and 56.23 KN respectively. It is interesting to note that the Brazilian performance is steadily increased at two layers until four layers but suddenly increased by 19.62% at five layers. Hence, a hairline crack can be seen in the red marked area on the concrete as illustrated in Fig. 6. The illustration shows a vertical cracking formed along with the direction of forces that occurred inside of the concrete specimen. The specimen continues to withstand the load after the event of concrete cracking occurs until the specimen fails.

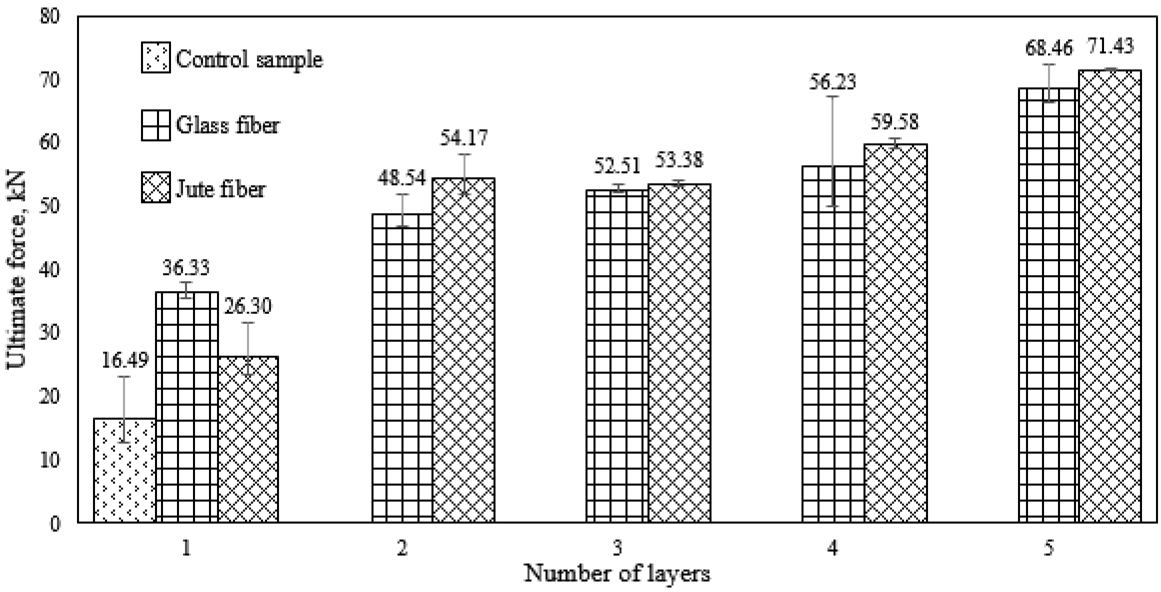


Fig. 5 - Brazilian performance for GFRT and JFRT wrapping concrete

In addition, for the Brazilian performance of JFRT, the B1-J specimen is the lowest among other layers which have a value of 26.30 KN and B5-J has the highest value of force, which is 71.43 KN, respectively. It is interesting to note that there is a rebound for B3-J of 53.38 KN between B2-J and B4-J with an ultimate force of 54.17 KN and 59.58 KN respectively. The Brazilian performance was increased by 18.09% at five layers of JFRT. Consequently, five layers of JFRT can be declared as the optimum layer which had similar behavior with compression performance whereas the performance would drop after a sudden increment. From the observation of testing, there is a slight drop at 20 kN to 30 kN of load during the testing that is due to the cracking of the concrete specimen. Hence, a hairline crack can be seen in the red marked area on the concrete specimen as illustrated in Fig. 7. The illustration shows an asymmetrical cracking formed along with the direction of forces that occurred inside of the concrete specimen. The specimen continues to withstand the load after the event of concrete cracking occurs until the specimen fails. Overall, the JFRT improves the mechanical properties of the concrete. This is due to fibers' ability to limit crack extension, reduce stress concentration at crack tips, and delay crack growth rate [24].

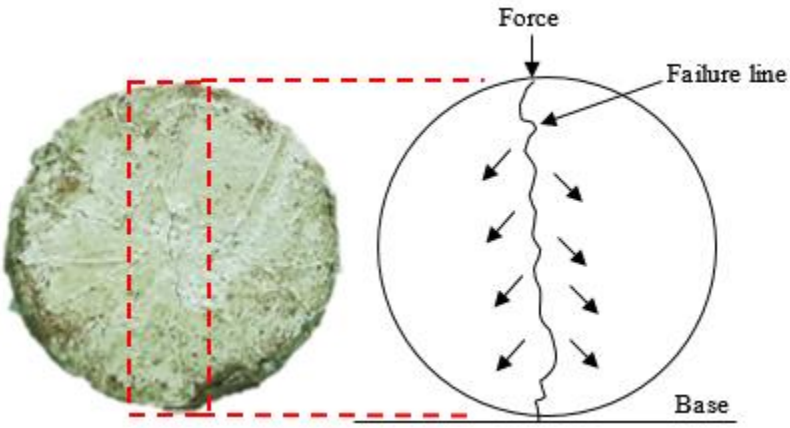


Fig. 6 - The hairline crack of GFRT specimen

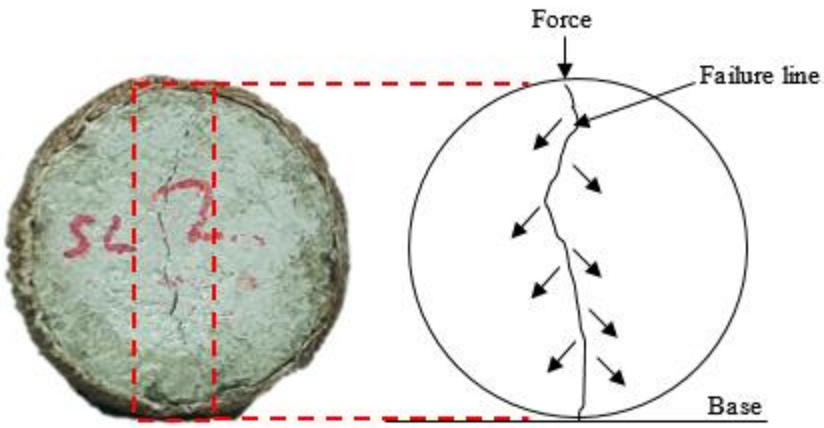


Fig. 7 - The hairline crack of JFRT specimen

4. Conclusion

The present study was designed to determine the effect of GFRT and JFRT wrapping onto the cylinder concrete. The results of this investigation show that the tensile strength of the laminated composite showed that GFRT and JFRT can be improved up to 47.93% and 138.25% with a maximum of 5 layers compare to one layer. Four layers of JFRT have the highest compression performance of 83.27 KN which improved the concrete specimen by 72.62% compare to GFRT. It was also shown that the concrete specimen had an excellent performance improvement of 333.20% in Brazilian test, which could withstand a final load of 71.43 KN from JFRT compared to GFR; T. Evidence from this study suggests that JFRT has an enormous potential to be used in the construction industry. More broadly, research is also needed to determine the technique of wrapping large poles while maintaining the strength of the pole due to the limited size of the jute fabric.

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