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BEHAVIOUR OF RC BEAMS STRENGTHENED WITH WOVEN JUTE FIBERS

Tanvir Ahmed Khan[1] and Md. Mahfuzur Rahman[2]

[1] Undergraduate Student, Department of Civil Engineering, Khulna University of Engineering & Technology, Bangladesh, e-mail: tanvir.khan@live.com
[2] Assistant Professor, Department of Civil Engineering, Khulna University of Engineering & Technology, Bangladesh, e-mail: m_mahfuz11@yahoo.com
[3] Undergraduate Student, Khulna University of Engineering & Technology, Khulna-9203, Bangladesh, e-mail: solaimankuet117@gmail.com

ABSTRACT

Bangladesh is one of the largest Jute producing country in the world. Considering efficiency, cost and availability, potential application of jute in various engineering purposes should be searched. For experiments associated with this paper, three beams were cast and strengthened by heat treated woven jute fiber and tested under three-point bending load. Main objective of this study was to observe the effectiveness of natural bio-based woven jute fibers for strengthening of RC beams. Load carrying capacity, first cracking load and load-deflection behaviors were also observed experimentally. Sample beams were cast and retrofitted with bio-based woven jute in different wrapping configurations. It was found that the woven jute fiber can be a very effective retrofitting material for strengthening of RC beams.

Keywords: *RC beams, Flexural Strength, Strengthening, Woven Jute Fiber.*

1. INTRODUCTION

In developing countries like Bangladesh, buildings are mostly low-rise structures. Due to lack of awareness, regulation and law enforcement, in most of the cases buildings are not built according to national or international codes. Moreover, rapid and unplanned development of construction creates scare of land which forces people to extend building vertically, most of the cases, which are not designed to carry this increased loading. This increased loading, inadequate design and lack of detailing for seismic and other severe natural events may result in considerable structural damage and loss of life, particularly in reinforced concrete buildings. Since, construction of new buildings or rebuilding is not a very good option because of their costing, strengthening is the best solution to preventing collapse of the damaged RCC structures and ensuring safety.

If design and construction of these elements are not proper and adequate, some problems such as excessive deflection, flexural and shear failure as well as materials degradation i.e. spalling of concrete and corrosion of steel may occur. To prevent fatal collapse, the elements require flexural strengthening (Reddy, 2013). Flexural strengthening may also be required if there is a change in the use of a structure, and this change results in an increase in the applied loadings. Generally, strengthening is a means of enhancing the structural performance of an existing structure beyond its current level. When the strength of a damaged concrete structure is enhanced and its design life extended, several economic and environmental problems can be avoided since concrete is bulky and rarely recycled. On the other hand, Bangladesh is the second largest Jute producing country in this planet. So, jute is readily available and price is very low cost per unit volume basis comparing to artificial fibers. Jute is also very eco-friendly as it is completely bio-degradable.

Many experiments have been carried out to assess the flexural response of RC members externally strengthened with FRP fabrics both natural and artificial. Dundu (2011), Olga

Oronthalyova & Olga Koron (2005), T. Munikenche Gowda (1999) and many others conducted experiments on carbon fiber reinforced polymer (CFRP), Glass fiber reinforced polymer and other artificial polymer wrapping strengthening, and found them very impressive. On the other hand, Andressa Cecília Milanese (2011) did their research on mechanical behavior of natural fiber composites. Experimental results showed a higher tensile strength for these natural fibers. Parthraj R. Puranik (2014) did research on use of Woven Fabrics for strengthening of RC beams. Finding of the experiment was that double wrapping does increase ultimate load bearing capacity as expected, because of increase in fabric stiffness around the beam limits deflection of beam. Jochen Gassan (1999) investigated on improving the mechanical properties of jute/epoxy composites by alkali treatment. A comparison with comparable glass-fiber/epoxy composites showed that the Young's moduli of composites with NaOH-treated and untreated jute fibers were respectively, approximately 30% and 50% lower. T. Munikenche Gowda (1999) conducted experiment for evaluation of the mechanical properties- modulus, Poisson's ratio and strength of woven jute fabric-reinforced composites. From this experiment, it was found that the mechanical properties of jute composites do not have strengths like those of artificial composites but they do have better strengths than wood and some plastics composites. Therefore, these composites could be considered for future materials use. Since the reinforcing material is eco-friendly, non-toxic, non-health hazardous, low in cost. Tara Sen (2013) researched on pretreatment of woven jute FRP Composites as well as their use in strengthening of reinforced concrete beams in flexure. The study concludes that woven jute FRP is a suitable material which can be used for flexural upgradation of reinforced concrete beams. John Summerscales (2010) reviewed on bast fibers and their composites. S.V. Joshi (2004) conducted their experiment on the environmental impact of natural fibers on environment and compared it with other artificial fibers like glass fiber composites. The future of natural fiber composites predicted to be better as they are more affordable, lightweight and eco-friendly to glass and carbon fiber composites. Alva Peled (2000) experimented on geometrical characteristics and efficiency of textile fabrics for reinforcing cement composites. The improved bonding in low modulus yarn was found to be mainly the result of the special shape of the yarn induced by the fabric. When the strength of a concrete structure is enhanced and its design life extended, several economic and environmental problems can be avoided since concrete is bulky and rarely recycled (Dundu, 2011).

Carbon Fiber Reinforced polymer (CFRP) and Glass fibre Reinforced Polymer(GFRP) are two popular artificial materials used for strengthening beams by wrapping. A comparison of cost and relative strengthening among GFRP and CFRP (Reddy, 2013) and woven jute fiber, is presented in Table 1.

Table 1: Comparison of Woven Jute Fiber with CFRP and GFRP (Reddy, 2013)

Materials	Woven Jute Fiber	GFRP	CFRP
Relative Cost (considering woven jute fiber as 1/ft^2	1	25	45
Increment of Strength (%)	40	125	150

So, Fiber Reinforced Polymer composite materials offers an attractive method to any other strengthening and retrofitting technique in the field of repair and strengthening of concrete elements. Most used fibers, which are used for the strengthening of concrete structures are artificial fibers which are carbon, glass, and aramid, etc. However, the cost of those synthetic fibers is very high. Natural fibers like jute has several mechanical properties, such as, it have high specific stiffness and strength, a good fiber aspect ratio and they are readily available from natural sources. By some treatment properties like flexural strength and tensile strength of jute fiber caul be enhanced. It is realistic to expect that there will be existing cracks in the reinforced concrete element prior to the application of any strengthening method. In this context, the influence of the presence as well as the orientation of woven jute on cracked RC beams is investigated in this paper.

2. METHODOLOGY

2.1 Geometry of specimens

Three identical reinforced concrete beams were cast from same batch of concrete at the same time. The first one was considered as reference beam (RB) and other two were strengthened by wrapping partially and fully with woven jute fiber and denoted as SW and FW, respectively. The cross-section of beams was 4″×6″ and the length was 5′ as summarized in Table 2.

Table 2 : Geometry of reinforced concrete beams

Beam	Specification	Cross-Section (in×in)	Length (ft)	Effective Length (ft)	Thickness of Wrap (mm)	Wrap Configuration
RB	Reference Beam	4×6	5	4.5	0	Unwrapped
SW	Strip Wrapped	4×6	5	4.5	7	Strips of 6 inch
FW	Fully Wrapped	4×6	5	4.5	7	Fully wrapped

2 nos. 10 mm diameter mild steel deformed bar was used as tensile and compression reinforcement and 8 mm diameter stirrup was used @12inch c/c with 0.5 inch clear cover, as shown in Figure 1.

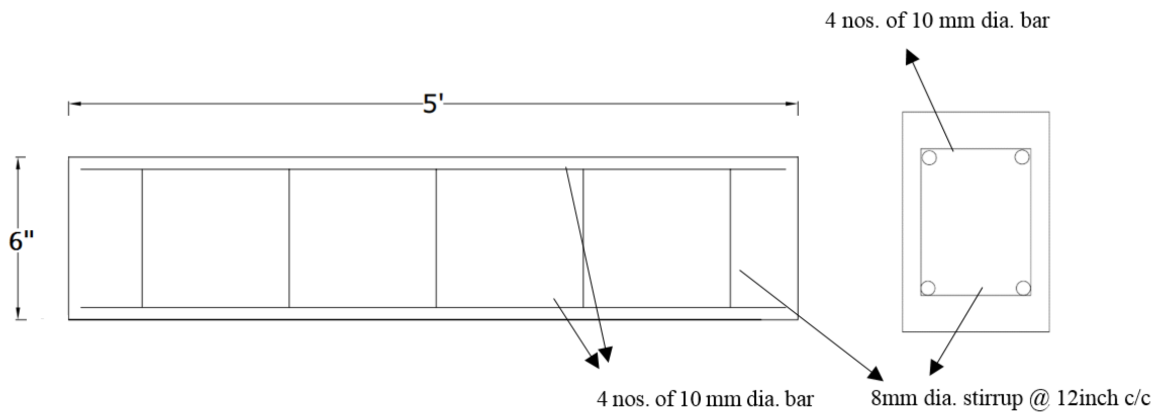


Figure 1 : Detailing of beams

2.2 Properties of Jute Fiber

The jute fabric was collected locally and all other chemicals used for the fabrication of the natural jute fiber textile composite such epoxy adhesive which consists of Part A epoxy resin, and Part B hardener were obtained from local market of Khulna, Bangladesh.

2.2.1 Pre-treatment of Jute Fiber

The mechanical treatment in the form of heat treatment was carried out. Jute fabric mats were cut into the size as required for tensile strength test as per ASTM D 638- 03, for the natural fiber woven mats. These woven fiber mats were then placed into the oven at 50˚C for 48 hours. After that the samples were kept in an air tight chamber so that atmospheric moisture could not be absorbed by these samples.

Basically, when the fibers are exposed to atmosphere, it results in the absorption of moisture. This moisture which gets accumulated in the fiber which is required to be eliminated. This elimination of the moisture from the fibers was attained by the process of heat treatment. Heat treated composites of natural fabrics or mats have shown a higher strength than untreated composites of natural fiber fabrics or mats. The effect of elevated temperature conditioning can be described as a threefold effect on the cellulosic fibers of jute. Firstly, the modification of cellulosic structure by enhanced cross-linking. Secondly, increased amount of crystallinity in the fibers and thirdly, by de-moisturization, which improves adhesion between fibers and natural rubber backing. (Tara Sen, 2013)

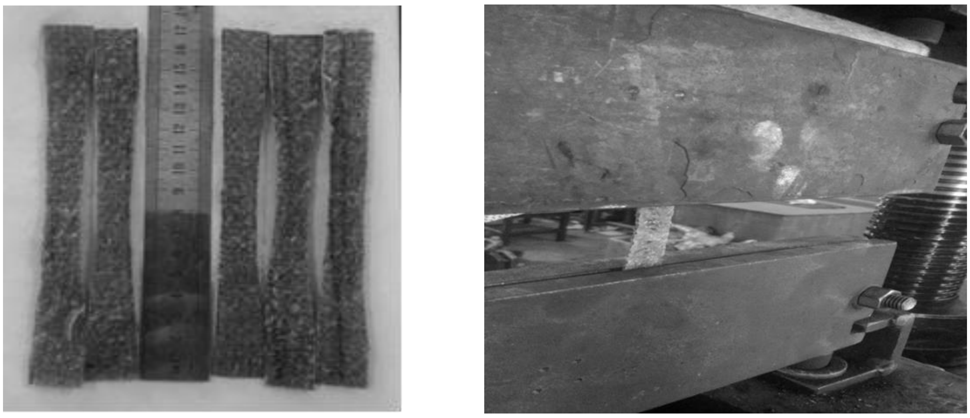
Thermal treatment also results in moisture loss of the fabric thereby enhancing the extent of bonding between fabric and the natural rubber backing. As we know that de-moisturization plays a vital role in enhancing mechanical properties, the overall properties of composites prepared with high temperature conditioned woven jute are better than the composites prepared with untreated ones of the same woven fibers of jute. (T. Munikenche Gowda, 1999)

Another important aspect for thermal conditioning is that the fibers are exposed to atmosphere during manufacturing, processing, transporting, etc. which results in the absorption of moisture by the fibers from the environment. This moisture which gets accumulated in the fibers also requires to be eliminated, and can be attained by the process of thermal conditioning. (Jochen Gassan, 1999)

2.2.2 Tensile Test of Jute Fiber

In order to conduct the tensile tests, it was necessary to prepare the coupon samples. The samples were cut to proper size according to ASTM D 638-03. All the specimens were cut to standard length 165 mm and gauge length 50 mm as shown in figure 2(a). The thickness of the jute fiber composite was 7mm.

For tensile strength test a Universal Testing Machine (UTM) was used. This machine is able to apply tensile loads as shown in Figure 2(b). Specimens were placed in Universal Testing Machine and pulled out until its failure.



(a) (b)

Figure 2 : (a) Samples of Jute fiber composites & (b) Test setup of Jute fiber coupons

2.2.3 Tensile Test Result of Jute Fiber

Table 3 shows the tensile test results of jute fiber composite and Figure 3 illustrates their stress-strain curves. Table 3 show the values of strength, elongation percentage and maximum deformation of jute fiber composites and their average values respectively.

Table 3 : Tensile Test results of Jute Fiber Composite

Tensile Parameters	Sample 1	Sample 2	Sample 3	Average
Maximum Deformation (mm)	1	0.96	0.97	0.98
Ultimate Strength (MPa)	88.25	83.5	86.8	88.18
Modulus of Elasticity (Mpa)	4062.5	4348.96	4474.23	4295

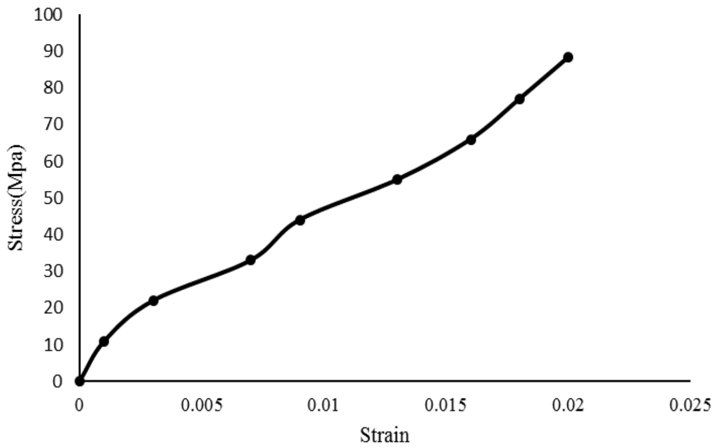


Figure 3 : Average Stress-strain curve of jute fiber composite

2.3 Other materials

Mechanical properties of materials used for the experiment was evaluated before casting of beams and are given in the Table 4 below.

Table 4 : Material properties

Material	Test Name	Results	Test Method
coarse aggregate	Specific gravity	1.86	ASTM C127
	Absorption	11.26%	ASTM C127
	unit weight	1148 kg/m^3	ASTM C29
Fine Aggregate	Specific gravity	1.81	ASTM C128
	Absorption	10.85%	ASTM C128
	Fineness modulus (FM)	1.92	ASTM C136
	Unit weight	1021 kg/m^3	ASTM C29
Binder	normal consistency	28.5%	ASTM C187
	initial setting time	145 minutes	ASTM C191
	final setting time	270 minutes	ASTM C191
Concrete	Compressive Strength of Concrete	17.48 MPa	ASTM C39
Main Steel 10(mm)	Tensile Strength	68273 psi	ASTM A370
Stirrup Steel 8(mm)	Tensile Strength	66455 psi	ASTM A370

3. EXPERIMENTAL PROGRAM

All sample beams were cast on same day from same batch of concrete. The concrete mixing ratio was 1 (cement): 2 (fine aggregate): 4 (coarse aggregate) by weight with a water to cement ratio of 0.46 by weight. After casting, all beams were immersed into water and allowed for curing for 7 days.

All three beams, the reference beam (RB), fully wrapped beam (FW) and strip wrapped beam (SW) were tested in a loading frame under single point loading. Beam was simply supported and a dial gauge was placed exactly under the midpoint of the beam as shown in Figure 4. Load was applied by a hydraulic jack which has a self-weight of 25kg.

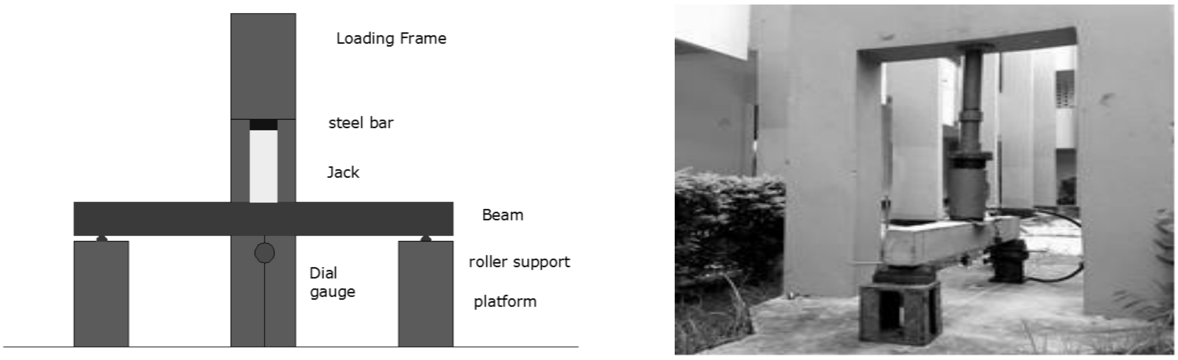
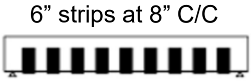


Figure 4 : Schematic Diagram and image of Experimental Setup.

The value of load noted in KN and corresponding readings from dial gauge were recorded at 2KN load increment. Load was applied until the crack initiated in tension zone and the corresponding cracking load was recorded. Beams were cracked to replicate a damaged beam.

Similarly, load equal to the cracking load of the beam RB was also applied to the other two beams, namely FW and SW. Summary of woven jute fiber wrapping configuration of beams are presented in Table 5.

Table 5 : Summary of woven jute fiber wrapping configuration on beams

Beam Name	Wrapping configuration	Strengthening material	Model beam designation	Type of strengthening	Strengthening scheme
Reference Beam	Nil 	Nil	RB	No strengthening	Nil
Beam 1	Full length wrapping, single layer Jute FRP 	JFRP	FW	Flexural strengthening using jute FRP	U – Wrap, three sided wrap
Beam 2	Strip wrapping, single layer 6” strips at 8” C/C 	JFRP	SW	Flexural strengthening using jute FRP	U – Wrap, three sided wrap

Finally, the beams were removed from loading frame and were kept in a simply supported condition. Beam FW and SW were then ready for strengthening with woven jute fibers. Surface of Beam FW & Beam SW was being roughen by scraping weir brush and dust was removed. Heat treated Woven Jute Fiber fabric was cut in necessary dimension. Standard adhesive resin and hardener were mixed thoroughly to prepare the epoxy resin. A layer of Epoxy Resin was applied on the surface of Beams by paint brush. One ply of woven jute fiber fabric was applied as U wrapping in two different orientations, as shown in Figure 5.

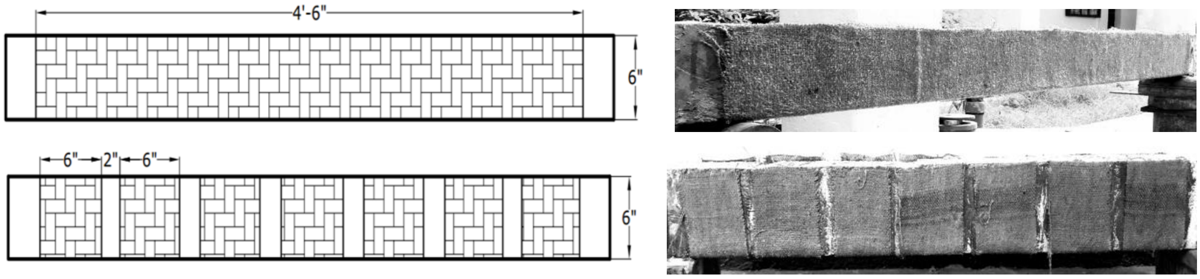


Figure 5 : Beams after wrapping with woven jute fiber

Single piece of Woven Jute Fiber was applied on three surfaces of beam FW. 6inch strips of woven jute fiber were applied on surface of Beam SW maintaining 2-inch gap between each strip to keep the 25% of total surface area of beam uncovered. Then another layer of resin was applied again on the woven jute fiber. Beams were kept 24 hours in simply supported condition to attain full bond strength between beams and woven jute fiber composites.

Next all beams were taken to loading frame and load was applied as previous experimental setup till ultimate failure. Beams after ultimate failure are shown in figure 6. The values of load were recorded in KN and corresponding readings from dial gauge were recorded at 2KN load increment.

(a) (b)

Figure 6 : (a) Beam FW and (b) SW after Failure

4. RESULTS AND DISCUSSIONS

All beams were tested in loading frame in the premises of Department of Civil Engineering, KUET. Loads were applied precisely in mid-span by hydraulic jack. Following Table 6 shows the ultimate capacity of all three beams in MPa and maximum deflection in mm.

Table 6 : Test Results of Reference Beam

Sample	Ultimate Capacity (MPa)	Maximum Deflection (mm)
Reference beam	17.51	9.94
Full Wrapped (FR)	22.65	13.8
Strip Wrapped (SR)	24.40	14.79

The load vs. deflection curves for the beams are shown in the Figure 7(a). The graph illustrates the variation of deflection with load at 2KN load interval. From the graph, the ultimate load carrying capacity of the reference beam is found to be 20KN and maximum deflection is 9.94mm. For the beams FR and SR strengthened with woven jute fiber composites, the graph illustrates the variation of deflection with load at 2kN load interval. From the graph, the ultimate load carrying capacity of two beams are found to be 28kN and 26kN and maximum deflections are 13.8mm and 14.79mm, respectively.

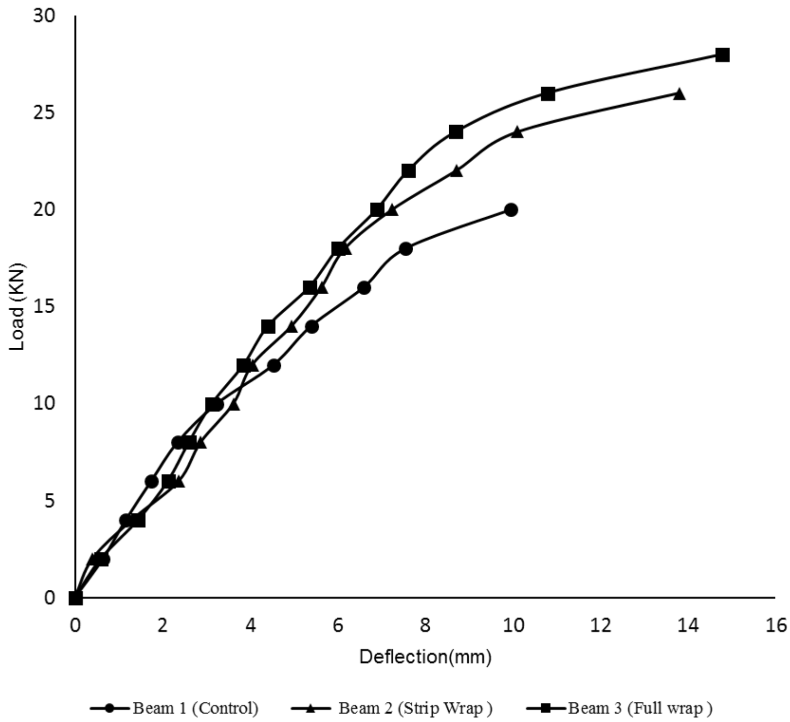


Figure 7 : Load deflection diagram for all beams

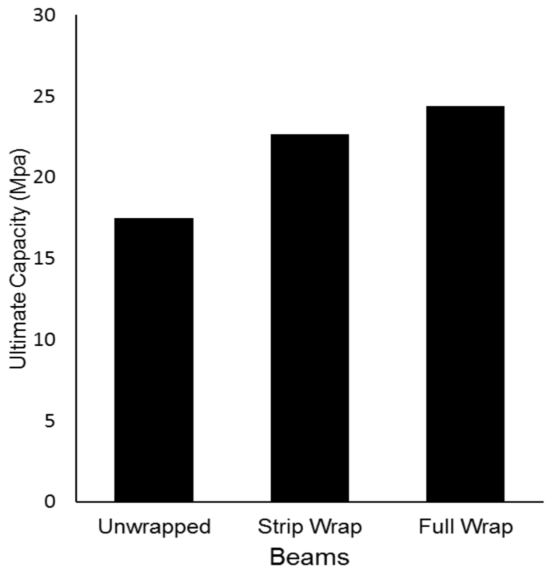


Figure 8 : Comparison of Ultimate Capacity(Mpa)

Figure 7 shows that deflection of beams decreases due to woven jute fiber wrap and bar diagram (Figure 8)) shows a comparison among the ultimate capacity of all three beams. The ultimate strength increases about 40% for full wrap configuration beam (FW) than that of the unwrapped control beam (RB) where the ultimate strength increases about 30% for strip wrap configuration beam (SW) than that of the unwrapped beam which was taken as control.

5. CONCLUSIONS

The experimental work was aimed to find out the efficiency of woven jute fiber composites for strengthening cracked reinforced concrete beam. The ultimate load carrying capacity of RCC beams is greatly influenced by the use of woven jute fiber composites. Full wrap configuration of woven jute fiber increased 40% of the unwrapped ultimate capacity of reference beam where only 25% ultimate capacity was increased due to Strip Wrap configuration. Considering the relative cost of woven jute fiber, CFRP and GFRP woven jute fiber is much more cost effective than the other available strengthen material. Considering the percentage increase in strength for other strengthening technique like CFRP or GFRP, woven jute fiber fabric is not as much effective. However, considering price and availability of Jute fiber, it could be used very efficiently instead of artificial polymer fiber composites like CFRP or GFRP for strengthening of damaged reinforced beams. A full wrapping technique is recommended as it increases strength considerably higher than strip wrapping technique and costing is not high at all.

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