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The Properties of Short Circular Reinforced-Concrete Columns Strengthened by Treated Natural Jute and Non-Treated Jute Fibres

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Abstract: The technique of fibre-reinforced polymers (FRP)-strengthening of concrete columns has emerged in recent years as an excellent alternative to the iron plate reinforcement and strengthening using reinforced concrete cover. That is because the mechanical properties of fibre-reinforced polymers (FRP) being (lightweight, has excellent tensile resistance, has high corrosion resistance) and finally speed of work execution. In this research, the behaviour of short reinforced concrete columns with circular sections and strengthened with treated natural jute and non-treated jute fibres was studied. The practical program includes casting and testing 24 specimens of short circular tubed reinforced concrete columns where laboratory testing was carried out under axial compression load. All columns were 700 mm in height and 150 mm in diameter. Regarding fibre treatment, there are four methods used in this research; chemical treatment, thermal treatment, red iron oxide treatment and epoxy treatment. The results showed that the columns strengthened by jute fibres, in general, have higher durability than the unstrengthened columns. Moreover, it was shown that the treatment of jute fibres in the four different ways has a significant effect on improving the performance of jute fibres in the process of strengthening in different proportions depending on the nature of the treatment, where the strengthening of the regular untreated fibres led to an increase in ultimate load capacity by 24.8%. Besides, the process of jute fibre treatment (chemical, thermal, red iron oxide and liquid epoxy) resulted in an increase of ultimate load by 35.6%, 39.28% 48.56% and 59.07% respectively compared with reference columns. The results also showed that the strengthening of jute fibres reduced the agitation and longitudinal deformations of the columns at the same load values as well as increased both ductility and toughness with the increase of ultimate load.

Keyword: Circular, column, jute fibres, treatment, ultimate load, ductility.

1. Introduction

In recent years, there has been an increasing demand for rehabilitation and strengthening of concrete structures. That demand can be attributed to various causes, including natural disasters such as earthquakes, floods and hurricanes, or as a result of a poor structural design, poor quality work implementation, lack of maintenance works, loss of steel reinforcement areas due to corrosion and rusting over time, or the need to add new floors, or damage caused by wars, etc. All these causes are potential reasons to make the structural elements carry additional loads, higher than the loads taken into consideration during the initial design process. Consequently, these reasons mentioned above make the structure unable to perform the role which was created for [1,2]. Since demolishing a building or removing parts of the damaged structural elements and rebuilding costs too much with a waste of time, the process of structural rehabilitation is often the best decision in terms of cost and time. It is necessary to increase the capacity of the structural members to withstand the applied forces [3]. The strengthening of reinforced concrete

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columns is one of the most important roles in civil engineering. The reasons for strengthening may be the removal of some adjacent loaded structural elements, a change in structural use, or when the column is used differently for the pre-planned purposes, or column damage, in order to increase the capacity against axial loads and moments [4]. Previously, several methods were used to strengthen reinforced concrete columns, such as enlarging the column section with reinforced concrete or by adding additional steel sections to the column, which were not economically suitable [4], that what led researchers to look for alternative materials. One alternative method used is external strengthening with the use of fibre-reinforced polymer (FRP). The strengthening of concrete columns by compounds of (FRP) is one of the essential applications of fibre-reinforced polymers (FRP) where these compounds improve the column strength to resist the imposed loads in all forms [7,6,5]. On the other hand, the most important disadvantages of these polymers are being relatively expensive besides being composed of carbon compounds which are harmful to the environment.

In this study, natural jute fibre will be investigated and used to strengthen concrete columns externally after being treated with several methods to improve some of its properties. The reasons for using jute fibres are the availability, low cost and are environmentally friendly.

In terms of column testing, Mirmiran and Shahawy (1997) [8] examined thirty cylindrical concrete specimens (152.5 x 305) mm. The work included the casting of six plain unstrengthened reference columns and twenty-four columns that were strengthened and fully wrapped in FRP, where these concrete specimens divided into three different groups with different mixing ratios and target strengths. The results showed that the strengthened columns behaved differently from the reference columns. This study provided a framework for a better understanding of the behaviour of confined fibre-reinforced concrete columns.

Furthermore, Rochette and Labossiere (2000) [9] tested thirty-two specimens of concrete columns with different cross-sections. The columns in these specimens were confined with carbon fibre reinforced polymer (CFRP) and aramid fibre reinforced polymer (AFRP) and examined under the axial load. Then, exploring the effect of fibre strengthening used and the shape of the column cross-section on the strength of concrete columns. The results showed that the effect of the strengthening was linked to the shape of the section, where it was obtained that the most effective strengthening is of circular cross-section, also concluding that excessive strengthening leads to sudden destructive failure that should be avoided.

Moreover, Hadi (2007) [10] presented the results of testing nine cylindrical concrete columns (925 mm height and 205 mm diameter,) three of which were strengthened by three layers of fibreglass polymers (GFRP) and another three columns were strengthened by three layers of carbon fibre reinforced polymer (CFRP). For each group, one column was tested under the concentric axial load, the second column was tested under 25 mm eccentric load, and the third column was tested under 50 mm eccentric load. The results showed that CFRP was more effective than other FRP’s strengthening in increasing the strength and ductility of columns.

Another experimental study was carried out by Wang and Wue (2010) [11] about the effect of strengthening using aramid fibre reinforced polymer (AFRP) on the performance of high-strength concrete short columns. Strength and strain modes were developed based on experimental results where two types of axial (stress-strain) curves were identified based on the confinement with AFRP. It was found that the strength of the columns and the ductility increased when these columns fully wrapped with AFRP while only the strength increased when there is partial confinement with AFRP.

Wang and Wue (2011) [12] presented more results by testing 135 short concrete columns under axial compressive loading. Among these specimens, thirty-six were unconfined with square and circular cross-sections and ninety-nine columns with AFRP’s confinement. Hence, to assess the interaction and size impacts between AFRP’s confinement and the size of the specimen, statistical analyses were used. From the results, it was concluded that the size of the column has a different impact on the target strengths. Moreover, for the strength of columns with AFRP’s confinement, there was a significant effect due to the size of the specimen. There was a lesser impact on curves (stress-strain) and a slight influence on failure modes.

Apart from these results, Silva (2011) [13] presented more tests on reinforced concrete columns axially loaded. Some specimens were unstrengthened while others were strengthened with FRP. Concrete columns strengthened were either by AFRP or CFRP, and the columns were circular and square in cross-sections. The specimens were examined under the axial load to obtain the maximum strength and ductility. From the results, it was clear that the performance of the confinement was better for circular cross-section specimens than square cross-sections.

Another experimental study was accomplished by Kabashi et al. (2014) [14] to determine the effect of carbon fibre strengthening on columns with different cross-sections. The research included tests on three circular columns and six rectangular in cross-sections. In addition, there were three rectangular columns and three circular columns as reference specimens. Specimens of rectangular columns were strengthened in two different methods, where they were fully wrapped once and partially again. On the other hand, specimens of circular cross-sections were fully strengthened. For each group, three samples were used, and tests indicated that the strengthening of circular columns was more effective in increasing the ultimate axial load. Moreover, the strengthening of the columns either fully or partially wrapped, does not differ significantly in rectangular columns.

Murugadoss et al. (2015) [15] explored the use of CFRP in reinforced concrete columns by testing seven circular columns (125 mm diameter and 800 mm height), three of which were strengthened externally by carbon fibre reinforced polymers (CFRP) with 50mm wide and a spacing of 20 mm between one layer and the next one. In contrast, the other three columns were strengthened by carbon fibre reinforced polymers (CFRP) with 50mm wide as well, but with a larger spacing of 40mm between one layer and the next one. It was obtained that there is an increase in axial deformation and concrete strength by a maximum of 99.2% compared with the reference specimen. On the other hand, the column confined with CFRP and spacing of 40mm between the layers failed by crushing the concrete alone, which occurred before CFRP reached the ultimate strain.

Ananthi.p and N.sakthieswaran (2015) [16] conducted tests on twenty-one reinforced concrete column with jute fibre (FRP wrap) in several layers wrap which was wrapped partially and fully. The specimens were divided into three groups; each group includes seven reinforced concrete circular columns at different heights of the column. The first group at the height of 450mm, The second set is 750mm height, and the third one is 1050mm height. The results of the compressive strength test showed that the strengthening using jute fibre has contributed to the increased compressive strength of the columns confined with jute fibre compared with the plain columns. Also, the results showed an increase in the compressive strength of the fully wrapped columns by 8% for three layers, four layers by 17% and five layers by 35% and for partially wrapped columns for three layers by 3%, four layers by 9% and five layers by 15%.

Thanakit V. et al. (2017) [17] investigated the effect of preheating on the tensile properties of jute fibres. That was done by exposing jute fibres to three heating temperatures at 40 ºC, 80 °C and 100 °C for 1, 8 and 42 hours respectively before being used in the treatment and curing of concrete cylinders. The experimental program included the casting of thirty-six concrete cylinders of 20cm height and 10cm in diameter, three of which were non-treated concrete cylinders. For untreated jute reference specimens, the elastic modulus coefficient improved by 20.3%, the ultimate strain value improved by 9% and compressive strength improved by 38%.

2- Experimental program

The experimental program includes:

2.1 Materials used

The most important materials used in this study are:

2.1.1 Jute fibres

Jute fibres are natural plant fibres and are free of carbon compounds and are therefore environmentally friendly where these fibres do not cause any environmental damage in addition to the ease of disposal of their residues without significant damage. Jute fibres are made up of compounds of rapidly degrading plant materials Cellulose and Lignin [18]. These fibres have great features and encouraging for engineering uses where it has a density of 1300 kg/ m³, and its tensile strength is about 300-700 MPa. It is soft in its natural condition, and figure 1 shows the type of fibre used.

Figure 1: Jute fibres

2.2 Adhesive material

Two types of adhesive materials which were used as follows:

2.2.1 Epoxy (Sikadur-31)

The first adhesive material used in this research is known in the market as (Sikadur-31), a high strength adhesive material containing medium viscosity substances with a density of 1.65 kg/L. It is divided into two parts, Resin A, as a glue and it is white, and the second one is the hardening material, Hardener B, which is dark grey that is similar to the black. When these two materials mixed together, resulting in grey colour, and the mixing ratio is (2:1) used for jute fibre installation with the column.

2.2.2 Epoxy (Sikadur-52)

The second adhesive material used in this research is known commercially as Sikadur-52, used to treat jute fibre before being used in strengthening. It is a highly binding material containing medium-viscosity substances with a density of up to 1.1 kg/L. It is divided into two parts: part (A) which is a yellow liquid and part (B) a brown liquid, then the mixing ratio is (2:1).

3. Concrete columns

Short circular reinforced-concrete columns were cast according to the following requirements:

3.1 Mixing of concrete

A concrete mixture was designed with 30 MPa compressive strength, water-to-cement ratio (w/c) of 0.44 and slump of (75 - 100) mm. This mixture was used in the casting of reinforced columns where all the necessary tests were carried out to verify that this mixture is conformed to the standard specifications.

3.2 Columns reinforcement

Circular columns (150 mm diameter x 700 mm height) were reinforced longitudinally by 7 Ø6mm, but to resist the shear forces, they were reinforced with Ø6mm@90mm. Moreover, figure 2 shows the cross-section of the columns.

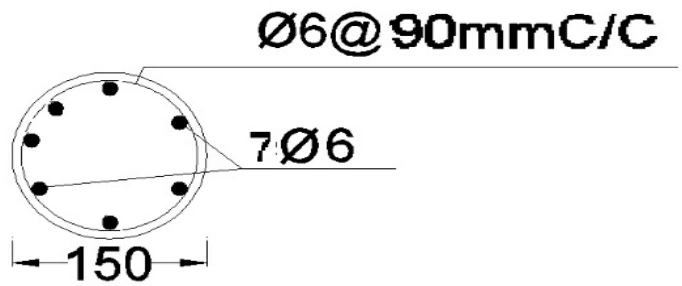


Figure 2: The circular cross-section of the column

3.3 Groups of reinforced concrete columns

The columns were divided into eight groups; three columns were cast for each group. Details of these groups are presented in table 1 and figure 3.

Table 1: Strengthening and treatment details for each group

Groups	Form of external Strengthening (mm)	*Type of treatment for jute fibre*
CCR	-----------------	*Control column*
CCJ	*150 mm strip width with distance 125 mm between strips*	*Jute without treatment*
CCJ1	150 mm strip width with distance 125 mm between strips	*Jute with chemical treatment*
CCJ2	150 mm strip width with distance 125 mm between strips	*Jute with heat treatment*
CCJ3	150 mm strip width with distance 125 mm between strips	*Jute with an oil paint treatment*
CCJ4	150 mm strip width with distance 125 mm between strip s	*Jute with epoxy treatment*

CCJ4-1	*300 mm strip from top*	*Jute with epoxy treatment*
CCJ4-2	*230 mm strip from top and bottom*	*Jute with epoxy treatment*

CCJ2 CCJ1 CCJ CCR

CCJ4 CCJ4-1 CCJ4 CCJ3

Figure 3: Samples setups and failure modes

3.4 Specimen testing

All reinforced concrete columns were tested by the hydraulic testing machine which its maximum capacity is 1200 KN, under the axial load at a loading speed rate of 0.5 KN/Sec. In each column, strain gauges were installed, two vertically and another two horizontally on both sides of the column and perpendicularly, to calculate the rate of vertical strains generated because of applying axial loads where these strains are read by the data logger as shown in figure 4. Furthermore, one vertical LVDT was installed with an accuracy of 0.001mm and applied in the direction perpendicular to the specimen to calculate vertical deformations as it can be seen in figure 5. The value of applied loads is monitored by a load cell with high accuracy and a sensitivity of 1 KN. Hence, the values of applied loads, vertical strains, and deformations were recorded.

Figure 4: Data logger device and strain gauge installation

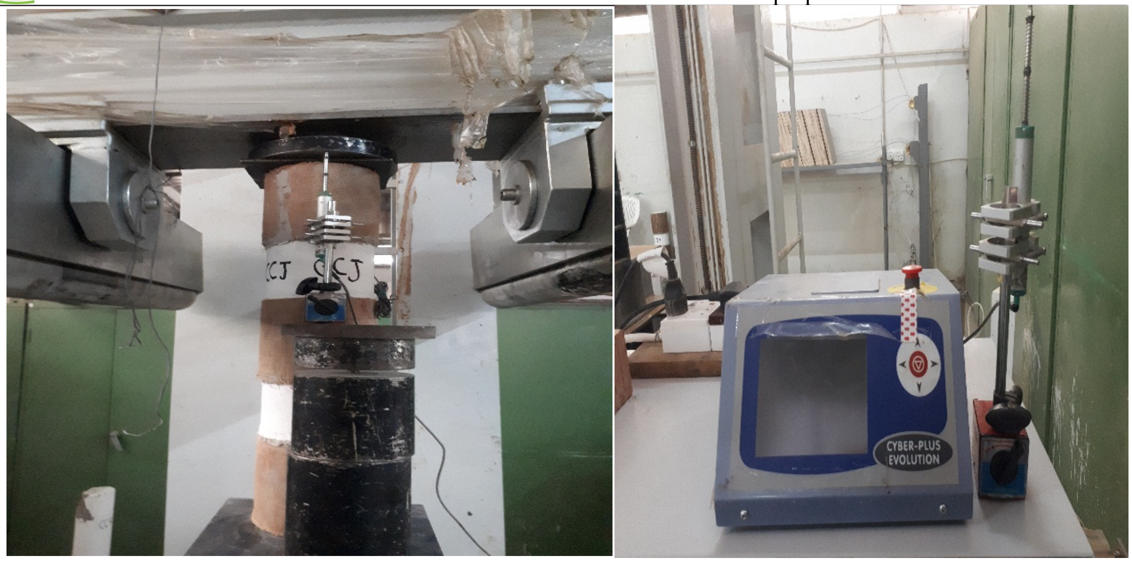


Figure 5: LVDT device installed on the specimen

4. Methods of fibre treatment

Several treatment methods were used, including:

4.1 Chemical treatment

Chemical treatment involves treating jute fibre by immersing 1kg of it in calcium chloride solution $CaCl_2$ for 24 hours and then it is immersed in a solution made up with 10 ml of sodium hydroxide NaOH dissolved in 10 litres of distilled water for 24 hours to form calcium hydroxide $Ca(OH)_2$. After that, it is lifted from the solution, then washed with distilled water again to get rid of sodium chloride NaCl3 resulting from the reaction, and finally left for 24 hours to dry at room temperature.

4.2 Heat treatment

This treatment includes cutting jute fibre according to the required measurements for strengthening and placing it in an electric oven at 50°C for 48 hours. Then, these fibres are extracted from the oven to be placed in a closed room so it cannot absorb moisture because moisture is the main reason for weakening the fibre structure. Following that, these fibres are ready to be used for column strengthening.

4.3 Red iron oxide treatment

Jute fibre is coated with red iron oxide as it acts as a protective layer for fibres as this coating prevents moisture from being raised.

4.4 Epoxy treatment

Jute fibre is treated by immersion in a liquid epoxy material (Sikadur-52) for five minutes. Then, it is lifted and left for seven days at the laboratory temperature. Finally, the jute fibre treated with epoxy is ready to strengthen the columns.

5. Results and discussions

5.1 Behaviour of RC columns under (axial load–strain) curve

5.1.1 Concrete columns strengthened with untreated jute fibres

Figure (6) shows the effect of confinement by using untreated jute fibres for circular columns on the relationship of ultimate load with the axial strain to which it is exposed compared with that of the unconfined reference column. The results of the strengthened columns showed that the column confinement enhanced the strength capacity of columns by 24.8% compared with the reference column.

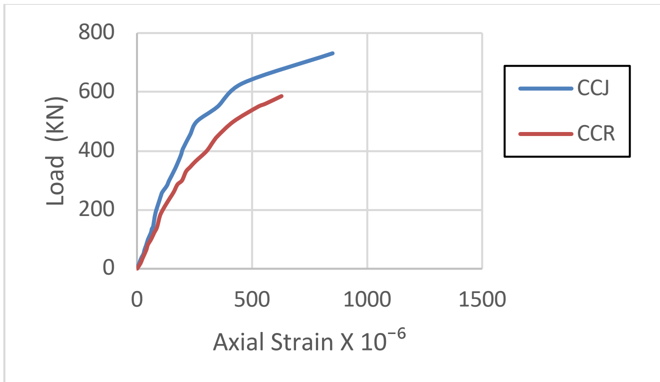


Figure 6: Load–axial strain curves for columns CCJ and CCR

5.1.2 Concrete columns strengthened with treated jute fibres

In this experimental program, four methods were used to treat jute fibres to be ready for concrete columns confinement. That included chemically, thermally, with red iron oxide and liquid epoxy treatments. Figure 7 shows the effect of these four fibre treatment methods on the relationship of ultimate load with the axial strain to which it is exposed versus the reference column. From the figure, it can be seen that using treated fibres led to an increase of strength capacity of columns by 35.6%, 39.28%, 48.56% and 59.07% respectively for the four methods of fibre treatment compared with the reference columns. These results illustrate the significant impact of fibre treatment in enhancing the strength capacity and durability of concrete columns. That resulting from the reduction of fibre moisture content and increased roughness. Also, figure 7 indicates that the best treatment used was liquid epoxy.

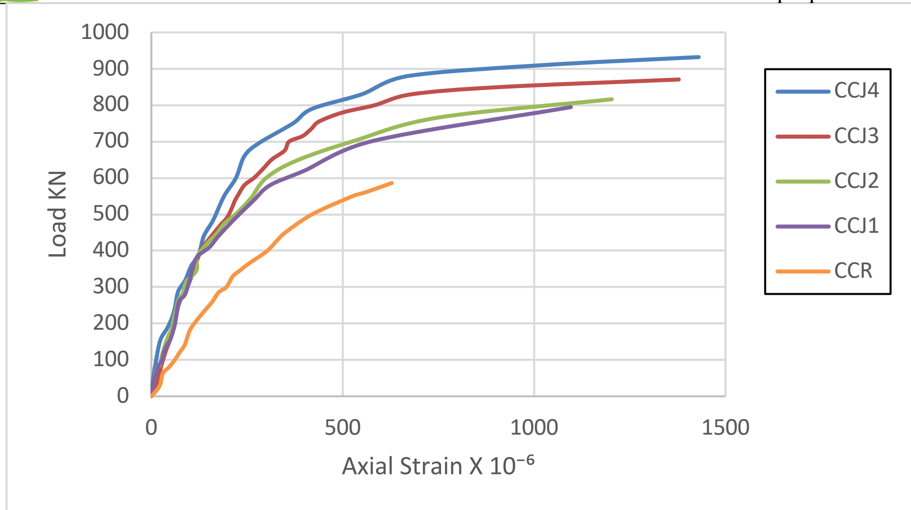


Figure 7: Load–axial strain curves for columns CCJ1, CCJ2, CCJ3, CCJ4 and CCR

5.1.3 Column strengthening area

As mentioned earlier, fibre treatment using liquid epoxy demonstrated the best improvement for the strength capacity of reinforced concrete columns. This method of treatment was effective in providing confined columns of 59.07% higher strength capacity than the reference columns. The process of column strengthening was done by wrapping the column partially in the form of strips every 150 mm with equal distances of 125 mm between them, and the symbol used for this specimen is CCJ4

The width of the strips which was used for confinement was changed in two different conditions, to find the effect of this change on the strength capacity of the column. At first, the columns were wrapped partially in a circumferential direction 300mm height from the top and the remaining height which is 400mm to be left without wrapping, CCRJ4-1 as a symbol was used for this specimen. Then, the column was wrapped from the top and bottom in 230mm height per each jute strip separately, leaving a spacing of 240mm in-between the layers, the symbol used for this specimen is CCRJ4-2.

Changing the location of jute fibre used in confinement of the reinforced column might affect the column strength. Figure (8) demonstrates the effect of this change as it was used in (CCRJ4-1) and (CCRJ4-2) modes. The figure shows this effect on the relationship of ultimate load with the axial strain to which it is exposed compared with both the mode of an unconfined reference column and with CCJ4. It is clear from the figure how the strengthening in the two new places led to the increased strength capacity of the reinforced concrete column by 35% and 50.2% respectively, for both modes when compared with the reference columns at the same strain values. On the other hand, these values decreased by 24.07% and 8.87% respectively, compared with CCJ4. It confirms that the method of strengthening the column through wrapping in the form of equal distances is the best. That is because jute fibre, in this case, plays a role similar to that of the reinforcement stripes in the shear area, which increases the strength of the columns and reduces the resulting strains.

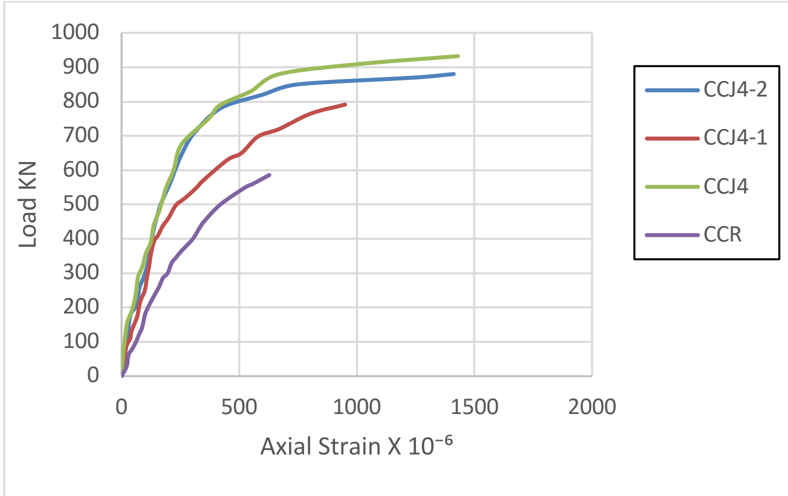


Figure 8: Load–axial strain curves for columns CCJ4, CCJ4-1, CCJ4-2 and CCR

5.2 The effect of jute fibre on the RC columns under the curve (load - axial deformation)

This paragraph discusses the results of testing of the reinforced concrete column specimens under the curve (load - axial deformation). Table (2) displays both the ratio of increase in the amount of ultimate axial deformations and the values of in-service deformations (Δs) at the service stage (service stage is considered at 70% of the ultimate load of the reference column) [19, 20, 21]. As can be noticed from the table, the strengthening by using untreated jute fibres led to an increase in the ultimate axial deformation of columns by 29% compared with reference columns. Moreover, there was an increase in the ultimate load applied to the column, while the in-service deformation value decreased to reach 1.54mm. Similarly, the confinement using treated jute fibres with various treatment methods (thermally, chemically, red iron oxide and liquid epoxy) has also increased the value of axial deformation of the columns with the increased ultimate load on the column and continued to decrease service deformation values at the service stage.

Table 2: Summary of specimen testing results

Column specimens	*Ultimate load* Pu (kN)	*Ultimate Axial deformation (mm)*	% Increasing	*Service Axial deformation* Δs (mm)
CCR	*586*	*2.9*	------	*1.78*
CCJ	*731.33*	*3.742*	*29%*	*1.54*
CCJ1	*794.62*	*4.493*	*55%*	*1.46*

CCJ2	*816.2*	*5.036*	*74%*	*1.4*
CCJ3	*870.56*	*5.36*	*85%*	*1.12*
CCJ4	*932.15*	*5.87*	*102%*	*1.035*
CCJ4-1	*791.1*	*4.21*	*45%*	*1.48*
CCJ4-2	*880.17*	*5.3*	*83%*	*1.125*

5.2.1 The behaviour of RC columns strengthened with untreated jute fibre

Figure (9) clearly shows the effect of strengthening using untreated jute fibres on the behaviour of reinforced concrete columns with an increase in ultimate load and ultimate axial deformation. Table (2) shows that strengthening has led to an increase in the ultimate axial deformation of circular columns by 29% compared with reference columns.

Also, the table shows the values of service deformations (Δs) at the service stage. The strengthening of untreated jute fibres led to a decrease in the value of the axial deformation of circular columns at the same load.

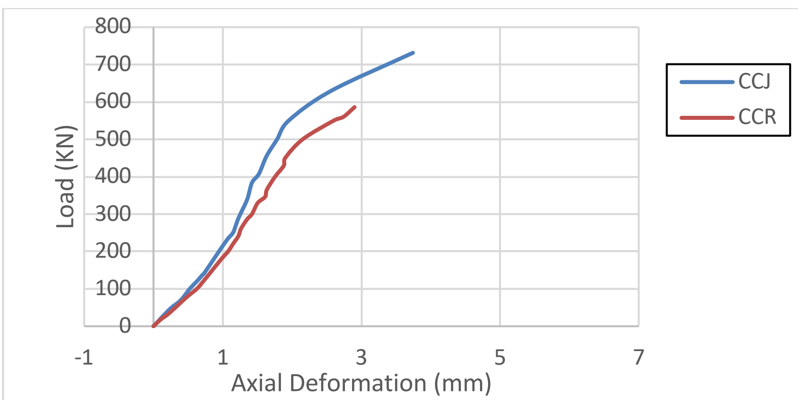


Figure 9: Load–axial deformation curves for columns CCJ and CCR

5.2.2 The behaviour of RC columns strengthened with treated jute fibre

Figure (10) demonstrates the effect of strengthening of the columns by using treated jute fibres in different treatment methods (chemically, thermally, red iron oxide and liquid epoxy) on the behaviour of reinforced concrete columns by increasing both ultimate load and ultimate axial deformation. Table (2) shows that the strengthening of treated jute fibres in various treatment methods (CCJ1, CCJ2, CCJ3, CCJ4, CCJ4-1 and CCJ4-2) has increased ultimate axial deformation by 55%, 74%, 85%, 102%, 45%, 83% respectively for circular columns compared with reference columns.

Besides, table (2) illustrates the values of service deformations in the service stage. Hence, the strengthening by using treated jute fibres with different treatment methods led to a decrease in the value of the axial deformation of circular columns at the same load.

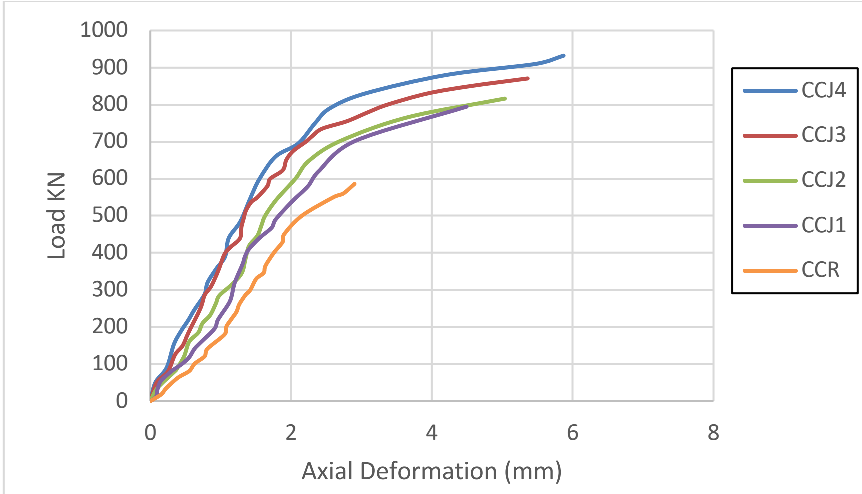
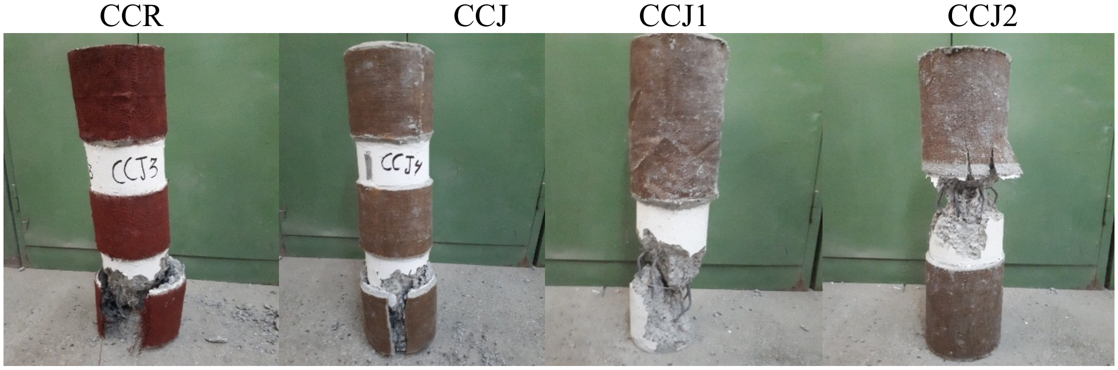


Figure 10: Load–axial deformation curves for columns CCJ1, CCJ2, CCJ3, CCJ4 and CCR

6- Failure patterns

Figure (11) shows the failure patterns of the tested specimens; reference columns and confined columns with jute fibres either treated or untreated ones.

CCR CCJ CCJ1 CCJ2



CCJ3 CCJ4 CCJ4-1 CCJ4-2

Figure (11): Failure patterns

Figure (11) shows that the reference column (CCR) was started cracking from the top. After increasing the load, the longitudinal cracks spread on the top third of the columns, and finally, the columns failed when the concrete cover was broken. The columns strengthened by untreated jute fibre (CCJ), treated jute fibres with anti-rust pigments (CCJ3) and jute fibres treated with liquid epoxy (CCJ4) for all these specimens cracking was detected within the lower third of the columns. Further loading, the crack developed between the layers of confinement gradually until observing longitudinal cracks on all sides of the column. Hence, the concrete core, which was confined with fibres, remained in good condition. After that, these specimens failed significantly in the unconfined area by the crushing of concrete along with the buckling of the longitudinal bars of reinforcement, thus rupture of fibres.

Columns confined with thermally and chemically treated jute fibres (CCJ1 and CCJ2) have begun to crack within the top third of the specimen. Cracks were detected between the layers of strengthening in the unstrengthened areas due to applying higher load. Then, the cracks continued increasing until reaching the strengthening layer, and finally, these specimens failed due to the crushing of concrete followed by rupture of fibres. On the other hand, columns strengthened by the jute fibre which was treated with liquid epoxy (CCJ4-1), cracks were found in the lower half of the column. By increasing the load, the concrete initiated to crack longitudinally with a good condition for concrete remaining under the layers of strengthening. Following that, the cracks continued developing in the column and spread clearly on the concrete with no cracks obtained in the fibres. Moreover, the buckling appeared in the longitudinal bars of reinforcement, and finally, these specimens failed significantly at an angle of approximately 45°. In contrast, the other columns strengthened by the jute fibre which was treated with liquid epoxy (CCJ4-2), cracks were initiated in the middle of the specimen and when the load increased, the concrete began to crack longitudinally in the middle of the specimen with the concrete remaining under the strengthening layers well. Additionally, the number of cracks increased and spread on the concrete followed by the buckling of longitudinal bars and rupture of fibres which were in contact with the unstrengthened area. Subsequently, these specimens failed significantly.

7- Conclusions

On completion of this study, the following conclusions can be drawn:

1- Tests were carried out on the specimens of the columns strengthened with jute fibres. The results showed that the use of jute fibres in the strengthening of the short reinforced circular concrete columns is effective in increasing the maximum strength applied to the columns.

2- The behaviour of jute fibre, when used in the strengthening process, is similar to that of stripes used in column reinforcement, so it reduces both longitudinal strain and axial deformations of the columns.

3- By increasing the surface area of the strengthening with a uniform distribution of this area, short reinforced concrete columns will express higher compressive strength.

4- It is possible to improve some mechanical properties of jute fibres such as fibres' tensile strength by treating these fibres before being used to strengthen the columns.

5- In this study, it was observed that the best type of treatments for jute fibre is epoxy (Sikadur-52).

6- Strengthening the columns using jute fibre increases the ductility and durability, which means an improvement of the seismic resistance and strength of the structure.

7- The successful use of treated jute fibre in the strengthening of short reinforced concrete columns will encourage to find and explore alternatives to carbon fibres and other industrial fibres which are most commonly used in this field.

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