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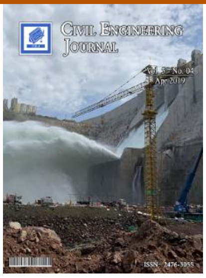

Concrete Beams Strengthened with Jute Fibers

Yaseen A. Salih [a], Nadia N. Sabeeh [a], Muhammed F. Yass [a], Ahmed S. Ahmed [a], Ektiffa S. Khudhur [a*]

[a] *Civil Engineering Department, College of Engineering, University of Tikrit, Iraq.*

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Abstract

Nowadays, the reinforcement of concrete with natural fibers can consider being an effectual scheme to achieve the global demand for sustainable development. Due to sustainability, bio degradability, and environmental friendly, natural fibers are preferred as compared to synthetic fibers. The present study investigated the effect of width and thickness of jute fiber strips on the mechanical properties of reinforced concrete beams (RC beams). The experimental program consisted testing of twenty-four RC beams (150*150*1000 mm) comprised of four groups. The first group consisted of three reference RC beams, the second group consisted of three RC beams strengthened longitudinally with carbon fiber strip (CFRP) of 15 cm width, the third group included nine RC beams strengthened longitudinally with one layer of jute fiber strips (JFRP) having variable width, 5, 10, and 15 cm, and lastly the fourth group which was same as the third group except using double layer of jute fiber strips. Generally, the results showed that toughness, ultimate flexural strength, and load carrying capacity of RC beams strengthened with JFRP were increased with the increase of the strip width and thickness. On the other hand, ductility and stiffness were decreased with the increase of the strip width. Test results showed that load carrying capacity was improved by 5.56 and 11.1% for one layer of jute fiber strips of 5 and 15 cm width respectively as compared with the reference specimens. On the other hand, the load carrying capacity was improved by 3.95 and 8.75 % for two layers of jute fiber strips of 10 and 15 cm width respectively as compared with the one layer strengthened specimens. Concerning the CFRP strengthening, the load carrying capacity was improved by 77.76% as compared with the reference specimens.

Keywords: Carbon Fibers; Jute Fibers; Load Carrying Capacity; Reinforced Concrete Beams.

1. Introduction

The design life of a structure varies depending on the purpose of the structure, its nature, and its usability. Day by day, the deterioration of concrete structure, as a result of exposure to different effects, can be considered a major challenge which makes the engineers responsible to find effective and sustainable methods to modify and improve the performance of the deteriorated structures during their service life [1].

Worldwide, repair and strengthening of damaged and deteriorated concrete structures by using fiber reinforced polymer composites (FRPs) are noticeably increased [2]. Artificial FRPs, carbon, aramid, and glass, have many advantages such as corrosion resistance, ease of installation and repair, high specific stiffness and specific strength, light weight, and can be designed to satisfy different engineering requirements [3]. On the other hand, FRPs possess many disadvantages like, high cost and adverse impact on the environment. Therefore, researchers tried to find natural strengthening alternatives like bamboo fiber, coir fiber, jute fibers, sisal fiber...etc. Due to sustainability, bio degradability, and environmental friendly, natural fibers are preferred as compared to artificial fibers [4]. Researches concerning jute fiber strengthening for structural elements, beams and columns, are considered very little. Beams are

* Corresponding author: engmuna1991@gmail.com

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classified as the critical structural members subjected to shear, torsion, and bending and they are one of the most important load carrying elements in a structural system [2]. Keeping in mind the sustainability and the importance of beams in the structural system, the present study is conducted to investigate the effect of jute fiber width and thickness on the mechanical properties of reinforced concrete beams.

Haleem, (2008) [5] studied the effect of jute fibers on the mechanical properties of epoxy at varying temperature (0, 25, 40, and 60 ºC). Polymeric composite was prepared from epoxy resin reinforced by glass and jute fibers individually and in combination to form a hybrid. The results revealed that the jute- reinforced composite had better properties than the epoxy alone, but at the same time it had fewer properties than the glass- reinforced composite. The jute reinforcement enhanced the material toughness, fracture toughness, and elasticity modulus by 565, 593, and 623% as compared to the unreinforced epoxy samples.

Tariq et al. (2011) [6] prepared a polymer composite material from unsaturated polyester resin reinforced by jute fiber at different fractions of volume (3, 4, 5 and 6%). The buckling and the tensile of the composite beam were analyzed by the finite element method and the experimental work. Concerning the modulus of elasticity, the results of experimental work were closed to the results of finite element methods. The increasing of the volume fractions led to increase the critical load. The experimental work results for critical load were 610N and 830N at volume fraction 3% and 6% respectively. While, the corresponding values for finite element methods were 619N and 877N at volume fraction 3 and 6% respectively.

Sen and Reddy (2013) [2] conducted a study to evaluate the efficacy of JFRP as compared to glass fiber reinforced polymer(GFRP) and carbon fiber reinforced polymer (CFRP) on flexural strength of reinforced beams and compare the results with reference specimens. The experimental work was divided into three groups using full and strip U- wrap technique. The results showed that CFRP, GFRP, and JFRP strengthening increased the ultimate flexural strength of RC beams by 150, 125 and 62.5% for full wrapping and by 50, 37.5 and 25% for strip wrapping technique respectively as compared with the control specimens.

Anggaraini et al. (2016) [7] investigated the effect of different chemical treatment on the mechanical properties of jute fibers used for soil strengthening. The results showed that fibers treatment by sodium hydroxide (NaOH) for 24 hr improved the soil properties as the treatment increased the surface roughness of fibers leading to enhance the bonding between fibers and soil.

Sakthieswaran and Ananthi (2015) [8] tested twenty one circular reinforced column, having different slenderness ratio of 3, 5, and 7, wrapped partially and fully with JFRP. The results showed that JFRP enhanced the compressive strength of fully and partially wrapped columns by 35 and 15% as compared with the unconfined specimens.

Fidelis et al. (2016) [9] discussed the degradation mechanisms of concrete specimens reinforced with two types of jute fibers, coated and uncoated. Before testing, the specimens were exposed to a relative humidity of 99% and a temperature of 40ºC over 28, 56, 90, 180, and 365 days. To evaluate the jute yarn degradation, micro structural analyses were performed. The results demonstrated that polymer coatings reduced fiber degradation and improved the matrix and fiber bonding.

Shaia et al. (2016) [10] used the natural jute fiber to reinforce the subgrade soil. Jute fiber sheet coated and uncoated with bitumen material, equal to the diameter of CBR mould were placed at the second, fourth, and fifth of soil layer to check its behavior on CBR reading. The results showed that reinforcing the second layer of soil with jute fiber sheet increased the CBR by 80% as compared with the unreinforced specimens. The results depicted that using coated jute fiber has no significant improvement in CBR.

Al-Hameidawei et al. (2016) [11] suggested a new technique using one layer of jute fiber as an interface layer between the subbase layer and subgrade soil to improve the performance of pavement. The experimental work included comparison different suggested locations with the traditional method of soil stabilization. California Bearing Ratio (CBR) test was conducted on jute fiber only, samples with jute fiber sheet coated and uncoated with bitumen. To investigate the effect of new technique on the vertical strain, Finite Element Model utilizing ABAQUS program was used. The results showed that the samples with bitumen coated jute fiber sheet subjected at the interface between soil and subbase exhibited a superior performance as compared with unreinforced samples (190% penetration resistance). On the other hand, the CBR value increased by 125% as compared with the traditional reinforcement.

Razmi and Mirsayar (2017) [12] studied the effect of adding different percentages of jute fibers, 0.1, 0.3 and 0.5% and of 20 mm length to the plain concrete. Test results showed that jute fiber reinforced specimens exhibited higher crack growth resistance than the plain concrete specimens. It is found that Jute fiber enhanced the flexural strength, splitting tensile and compressive strength of concrete.

Patwary (2017) [13] studied the effect of adding different sizes 1, 2 and 4 mm and different percentages 5, 10 and 15% of jute fiber to polypropylene matrix composites. The results showed that the optimum percentage is 10% with a fiber size of 2 mm as it gives the highest tensile strength.

Kumar and Srivastava (2017) [4] investigated the mechanical properties of jute fiber reinforced epoxy composite. The results revealed that the tensile and compressive strength for jute epoxy was improved. It is found that bending strength, compressive strength, and tensile strength increased with the increase of jute fiber percentage, while there is no noticeable change for impact strength after jute fiber addition.

Thanakit, et al. (2017) [14] studied the effect of preheating on the tensile properties of jute fibers. Jute fibers were exposed to three different range of heating temperature, 40, 80, and 100 ºC for a period 1, 8, and 24 hr. The experimental program comprised of casting 36 concrete cylinders of 20 cm height and 10 cm diameter. Results showed that the optimum curing temperature was 80 ºC for a period lasting for 24 hr as it enhanced the tensile strength, elastic modulus, ultimate strain, and compressive strength by 20.2, 20.3, 9 and 38% as compared with the reference specimens.

Raval et al. (2017) [15] studied the effect of adding different percentages, 0.5, 1, 1.5 and 2% of jute fiber on the split tensile strength and compressive strength of concrete. The results showed that the optimum percentage was 0.5% as it increased the tensile strength.

Dayananda et al. (2018) [16] investigated the effect of adding different ratios, 0.1, 0.5, and 1% of jute fibers on the properties of concrete. The results showed that adding jute fibers led to increase the split tensile strength and compressive strength by 10 and 33% respectively as compared to the reference specimens. On the other hand, increasing the adding ratio beyond 0.5% led to decrease the tensile strength and compressive strength of concrete.

Kundu et al. (2018) [17] studied the effect of using pretreated jute fibers, as fiber reinforcement, on the physico–mechanical properties of the concrete paver blocks. The test results showed that using 1 wt % of the modified jute fiber enhanced the flexural strength, compressive strength, and flexural toughness by 49, 30 and 166% respectively as compared to the reference blocks.

Khan and Rahman (2018) [18] investigated the effect of preheated jute fibers on the strengthening of cracked reinforced concrete beams (RC beams). Two types of wrap configurations, partially and fully, were used. Test results showed that using full wrap, three sided technique improved the ultimate capacity of RC beams by 40%, while the corresponding result for strip wrap, three sided techniques is 25% as compared to the reference specimens.

Raval and Maulik (2018) [19] investigated the effect of using alkali treated jute fibers on the percentage of weight loss of concrete. The specimens were immersed in 5% sulphuric acid (H_2SO_4). The results demonstrated that adding alkali treated jute fibers led to keep the weight reduction of concrete due to sulphate attack within the permissible limits.

Islam and Syed (2018) [20] evaluated the jute fibers addition on the properties of fresh and hardened concrete. The concrete beams and cylinders were prepared by using different percentages of jute fibers, 0, 0.25, 0.5 and 1% and different length, 10 and 20 mm. The results demonstrated that the addition of (0.25%) jute fiber had a positive effect on the properties of hardened concrete. On the other hand, the addition of jute fiber by 0.5% exhibited an adverse effect on the properties of fresh concrete.

Balye et al. (2018) [21] studied the longitudinal tensile and compressive behavior of unidirectional natural fibers. The results revealed that the tensile strength of the fiber is higher greater than the compressive strength. It is found that the compressive strength of the fiber increases with the fiber volume fraction, but the maximum value maintains lower than 140 MPa.

1. Materials and Method

1.1. Materials

1.1.1. Fibers

In the present study, two types of fibers were used:

- **a-Jute fibers**

  Jute fiber is a plant cellulose fiber with density of 1300 kg/m^3 and tensile strength varies between 393 and 800 MPa. It is environment friendly fiber that its usage does not cause any environmental damage because it mainly composed of the plant materials cellulose and lignin [16]. Natural jute fibers have a soft touch, unlike woven fibers which are rough. Jute fibers used in this study are brown vegetable fibers (woven type) were taken from the Jute bags, collected from the local market. The average thickness of the fiber was 2.0 mm.

- **Carbon fibers**

  A type of artificial fibers widely used, consisted of 99% dark carbon with a density of 1790 kg/m^3 and tensile strength of 3900 MPa, available on the local markets in the form of roll with 45.7 m length and 305- 610 mm width. It is usually used in reinforcing concrete and steel structure to increase shear and flexural strength [22].

Carbon fibers used in strengthening concrete beams in this study is Sika Wrap – 300C. Figure 1 shows both of jute fibers and carbon fibers.

Figure 1. Jute fiber and carbon fiber

1.1.2. Epoxy

Epoxy used in this research is commercially known as Sikadur®-31, with medium viscosity and density of 1.31 kg/L, combined of the resin substance (Resin A) and the hardening material (Hardener B). The mixing ratio is 1:3 (i.e., the mixture obtained by mixing (1 Kg) of the hardener (B) with (3 Kg) of the glue substance (A) [22].

1.2. Concrete Beams

1.2.1. Mix Design of Concrete

Concrete mix design of 30 MPa compressive strength and water cement ratio w/c (0.54) had been adopted with slump test value of (75-100) mm. This mix design was used in casting concrete beams after verified its properties by the necessary tests. The quantities of concrete mix components are shown in Table 1.

Table 1. The quantities of mix design contents per (1) m^3

Mix	Cement (Kg)	Sand (Kg)	Gravel (Kg)	Water (Kg)
Design Mix	400	720	795	216

1.2.2. Reinforced Beams

The reinforced concrete beams specimens had a cross-section (150 × 150 mm) and a length of (1000 mm). These beams were reinforced with (2Ø6) mm bars at the top, (3Ø6) mm bars at the bottom and for shear resisting (Ø6mm@60mm). The beam cross-section is shown in Figure 2.

2.2.3. Groups of Beams

Four groups of twenty- four reinforced concrete beams had been designed as following:

- First group: Three beams were designed as controlled beams without any type of fibers strengthening, designated as (A).
- Second group: Three specimens were strengthened longitudinally with one layer of carbon fibers of 15 cm width, entirely covered the width of the beam as shown in Figure 3. These beams also used as reference group and designated as (E).
- Third group: This group was designed to investigate the effect of jute fiber width). Nine beams were strengthened longitudinally with one layer of variable width jute fibers, (5, 10, and 15 cm), designated as (J5-1, J10-1 and J15-1) respectively. Three specimens were casted for each width. Figure 4 shows the jute fiber strengthening.

- Fourth group: This group was designed to investigate the effect of jute fiber thickness. Nine beams were strengthened longitudinally with two layers of variable width jute fibers, (5, 10, and 15 cm), designated as (J5-2, J10-2 and J15-2) respectively. Three specimens were casted for each width.

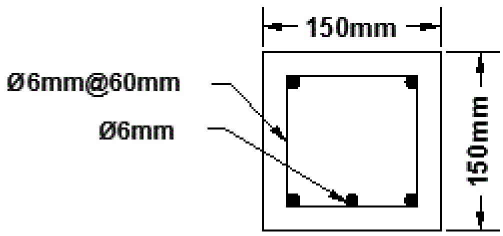

Figure 2. Cross-section of concrete beam

Figure 3. Strengthening beam with carbon fibers

Figure 4. Strengthening beam with jute fibers

All specimens were casted and tested under one-point load test with support span 900 mm using a hydraulic testing machine with a load capacity of 300 KN. Deflection of the beams was measured using dial gauge within the accuracy of 0.001 mm fixed at bottom of the beam at the mid-span. Figure 5 shows concrete beam under the test. By using the load-deflection relation, the properties of the beams such as, ultimate load, yield load, ductility, stiffness, and toughness were calculated.

Figure 5. Concrete beam under bending test

3. Results and Discussion

3.1. Strengthening Concrete Beams with One Layer of Jute Fiber

Figure 6 displays the load-deflection curve showing loading capacity of the beams strengthened with 5 cm of jute fibers compared with the reference beams, without any strengthening, and another beams strengthened with carbon fibers. The results show that load carrying capacity of the beams strengthened with jute fibers and carbon fibers were enhanced by 5.56 and 77.78% respectively as compared to the reference beams.

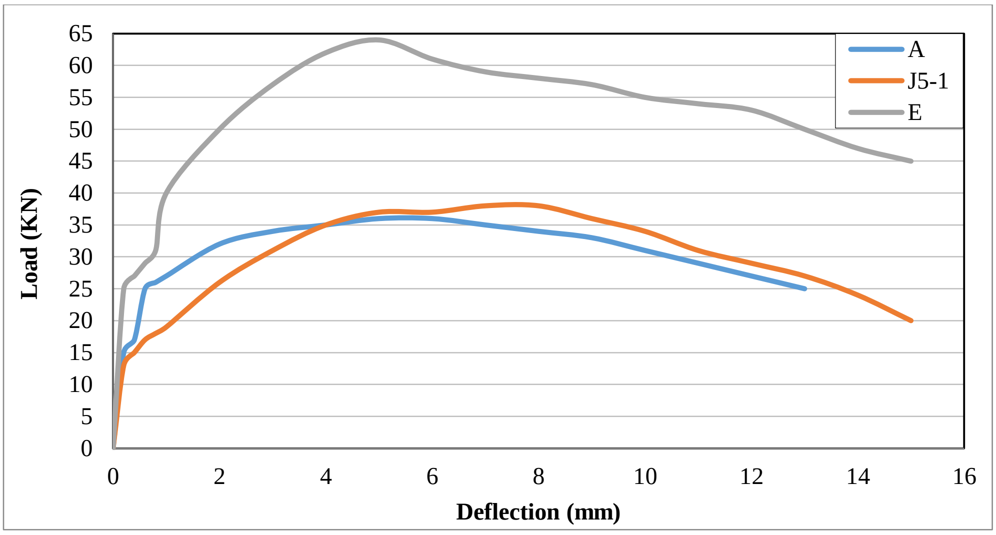

Figure 6. Load-deflection curve at mid-span for Concrete beams strengthened with 5 cm of Jute Fibers compared with reference beams and Carbon Fibers beams

Figure 7 shows load-deflection response of beams strengthened with jute fiber of 10 cm width. It can be noted that increasing jute fiber width from 5 to 10 cm does not affect the load carrying capacity of beams. The enhancement of load carrying capacity for the strengthened beams requires a relative high addition of jute fibers as the close addition percentages do not significantly affect the results. This is may be due to a relatively low tensile strength of jute fibers as compared to the carbon fibers. Most previous research and studies indicate that the tensile strength of the untreated jute fibers does not exceed 200 MPa, while for the carbon fibers it may reach 5 times its value in reinforcement steel [22].

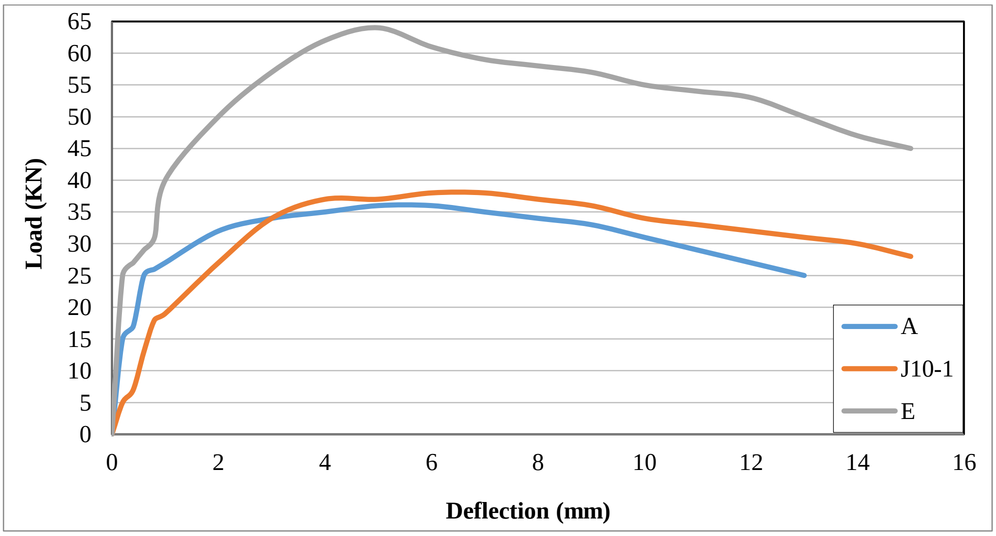

Figure 7. Load-deflection curve at mid-span for Concrete beams strengthened with 10 cm of Jute Fibers compared with reference beams and Carbon Fibers beams

Figure 8 indicated that increasing the width of jute fiber to 15 cm leads to increase the load carrying capacity of beams by 11.12% as compared with the reference beams. Increasing the width of jute fiber leading to increase the area of the used fiber which enhancing the capacity of the beams in certain limits, therefor three sides strengthening with jute fibers and along the beam (except area contacted with the supports) leading to increase the load carrying capacity. Increasing the area of jute fiber reinforcement to approximately 3 times (from 5 to 15 cm) led to doubling the load carrying capacity of the beams; this may be due to the characteristics of the jute fiber itself in terms of tensile strength and the nature of treated area of the beams. The area exposed to tensile tension is located at the bottom of the beam, which is reinforced entirely by the jute fiber that increases the load carrying capacity of the beam for deflection. The increment in the flexural strength of the fiber strengthened beams due to increase in fiber width simulates to some extent the increase of beam reinforcement for bending strength. This means that fiber strengthening performs the same role as steel reinforcing but at different ratios.

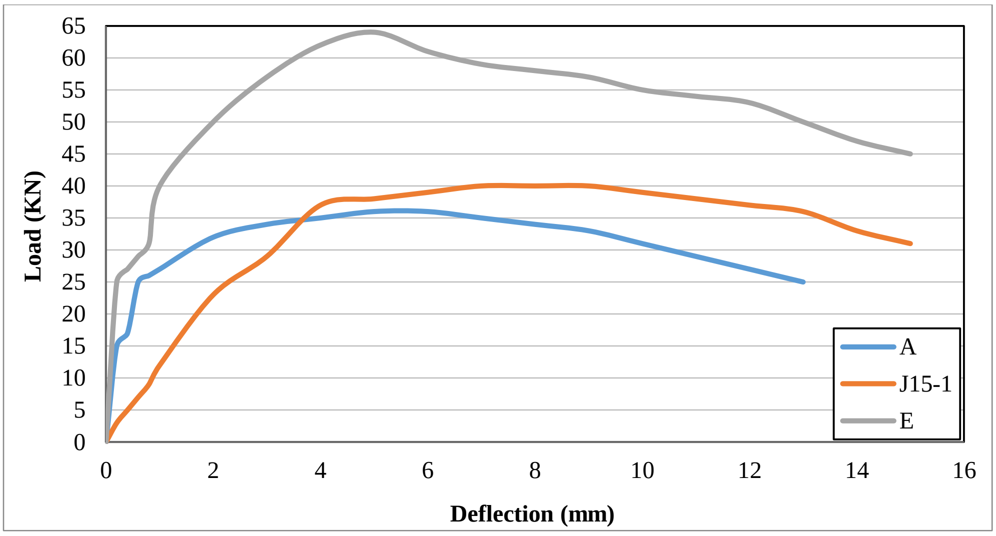

Figure 8. Load-deflection curve at mid-span for Concrete beams strengthened with 15 cm of Jute Fibers compared with reference beams and Carbon Fibers beams

3.2. Strengthening Concrete Beams with Two Layers of Jute Fibers

In order to investigate the effect of fiber thickness upon the beams strength, double layers of jute fibers with 3.5 mm thickness were used to strengthen the concrete beams at variable width 5, 10 and 15 cm. Figures 9 to 11 show the effect of using double layers' jute fibers of 5, 10, and 15 cm width respectively on the load carrying capacity of beams. It can be not from these figures that the great enhancement of load carrying capacity happens when jute fibers of 15 cm are used, this width increases the load carrying capacity by 8.75% as compared to the single layer jute fibers beams. On the other hand, using jute fibers of 10 cm width increases the load carrying capacity by 3.95% as compared to the single layer jute fibers beams, while using jute fibers of 5 cm width makes no noticeable impact on the load carrying capacity of beams as compared to the single layer jute fibers beams.

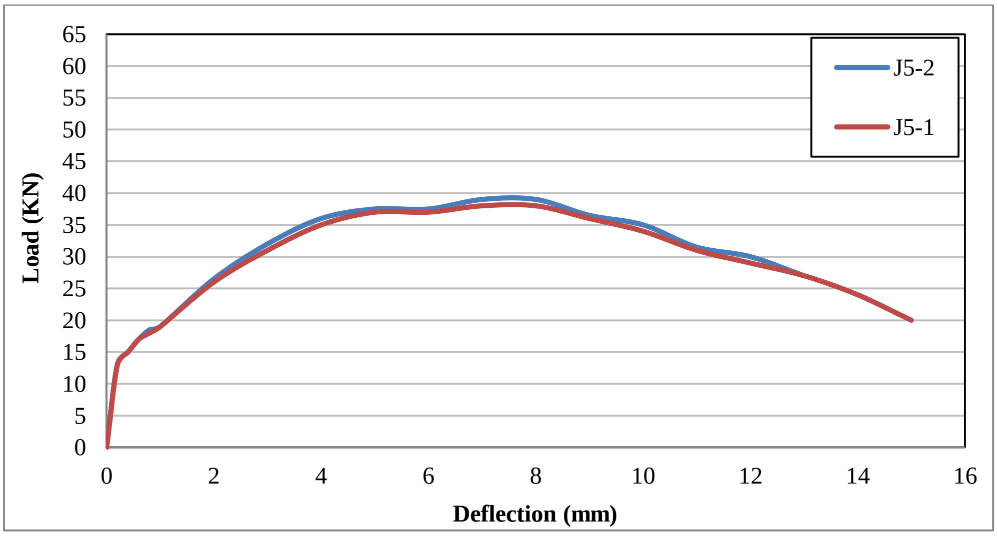

Figure 9. Effect of using two layers of 5 cm width jute fibers on the load capacity of beams

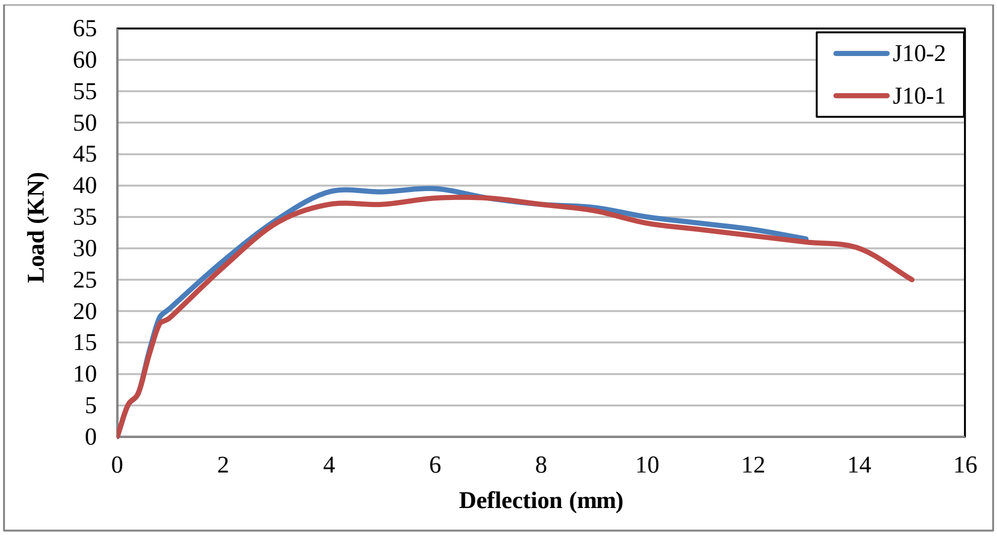

Figure 10. Effect of using two layers of 10 cm width jute fibers on the load capacity of beams

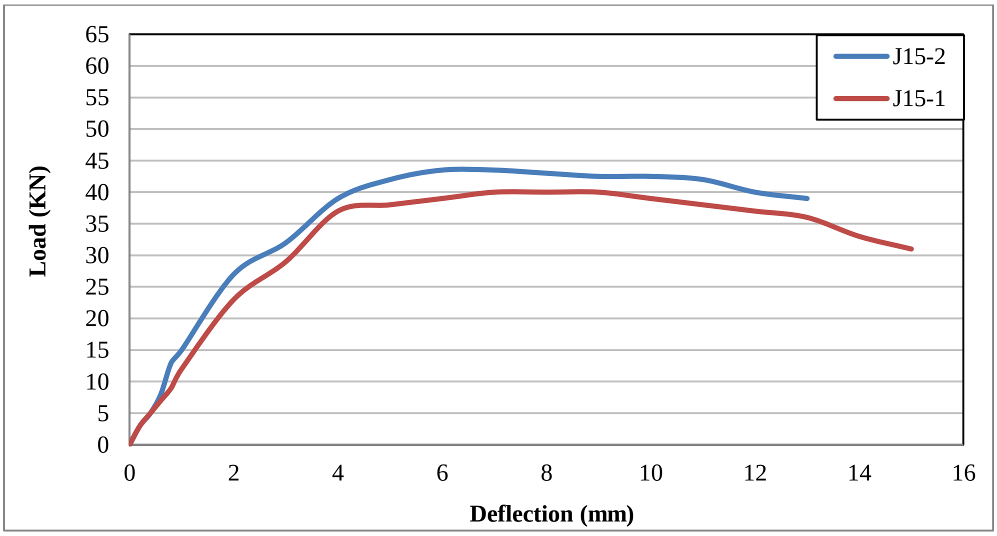

Figure 11. Effect of using two layers of 15 cm width jute fibers on the load capacity of beams

3.3. Characteristics of Concrete Beams Strengthened with Jute Fibers

It is necessary to know the effect of strengthening with jute fibers on the mechanical properties of concrete beams. Table 2 illustrates the effect of strengthening on ductility, stiffness, and toughness. It can be noticed that increasing the jute fibers width leads to decrease the ductility and stiffness, but at the same time, it increases the toughness of beams. Toughness is the ability of a member to absorb energy, and therefore; it is an indicator of the resistance to the seismic and dynamic loads [23]. Increasing the toughness due to strengthening by jute fibers indicates an enhancement of the impact energy absorption. The ductility of the beams decreases when the jute fiber is used, this is may be due to the fact that the ductility of jute fibers is much less than it is in the concrete beams; therefore, the concrete structural element acted as an integrated unit.

Table 2. Properties of the strengthened beams

Beam designation	Ductility	Stiffness (N/mm)	Toughness (N.mm)
A	10	41667	401500
E	6.25	38750	789500
J5-1	8.75	22500	452000
J10-1	4.5	13500	477000
J15-1	4	11500	496500

4. Conclusions

- In general, strengthening concrete beams with jute fibers gives good results and encourages further research in this field.
- Load carrying capacity was increased with the increase of the width and thickness of the jute fibers but the effect of increasing the width is greater than the effect of increasing the thickness.
- Strengthening beams with jute fibers generally decreases both of ductility and stiffness of the concrete beams and increases their flexural strength and toughness.
- Increasing the thickness of the jute fibers used in the beams strengthening does not necessarily mean increasing the flexural strength of the beams by the same ratio, and this is clearly indicated by the results.
- The jute fibers strengthening increased the toughness of beams, which means an increase in the structure resistance to the seismic and dynamic loads. This is very important property and should be studied extensively.

5. Acknowledgement

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6. Conflicts of Interest

The authors declare no conflict of interest.

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