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Production Economical Reinforced Concrete Slabs using Eco-Friendly Material

Mustafa S. Shubber [1], Thaer J. Mohammed [2], Khalid M. Breesem [3*]

[1] Department of Civil Engineering, Faculty of Engineering, University of Kufa, Kufa, Najaf, Iraq.

[2] Department of Civil Techniques, Institute of Technology/Baghdad, Middle Technical University, Baghdad, Iraq.

[3] Al-Mussaib Technical Institute, Al-Furat Al-Awsat Technical University, 51009 Babylon, Iraq.

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Abstract

Concrete is a material that is strong in compression but weak in tension. To overcome this issue, reinforcement must be used to improve the tensile strength of the concrete. However, it is acknowledged that steel has its drawbacks, such as the fact that it has a high cost and corrosion potential, and the rebar is heavy, non-renewable, and non-environmentally friendly. Thus, this experimental study investigates the potential product of economical reinforced concrete slabs using eco-friendly materials. Firstly, to enhance the concrete properties, a compressive, tensile, and flexural test, also a concrete with the addition of polypropylene fiber outlasted the control mix design in terms of strength and durability. The results included the control mix (CM), F1 0.25%, F2 0.50%, F3 0.75%, and F4 1%. The specimen with the highest compression and tensile strength was 24.28 MPa and 3.15 MPa, respectively, for the F1 specimen with 0.25% short fibers. Secondly, the bending test was carried out on ten slabs to check the structural behavior of these slabs reinforced with reed rods as the eco-friendly material. The good results of the bearing capacity of a partially reinforced concrete slab with a reed have been obtained at 23.8 kN. Meanwhile, to obtain better results, this research has enhanced the behavior of the concrete slab by improving the concrete's properties by adding polypropylene synthetic microfiber to the mixed concrete. In addition, giant reeds treated with epoxy increase the bonding strength with concrete, improve tensile strength properties, and reduce the absorption of reeds. Therefore, the bearing capacity results of the reed-reinforced concrete slab became the best, which were 35.83 kN. Thus, reinforcement of one-way slabs by reed partially with appropriate diameters could be substituted to obtain good performance in the reconstruction of low-cost buildings. As a result, economical reinforced concrete slabs have been produced using eco-friendly materials.

Keywords: Treated Reed; Epoxy: Polypropylene Fiber; Concrete; Slab; Central Line Loading.

1. Introduction

Reeds were used thousands of years ago as reinforcement for bonding materials such as plaster, mud, and asphalt, for example, in the Temple of Ur before 4000 BC in Iraq. Later, there has been an increasing scientific trend towards exploiting plant fibers for structural purposes [1, 2]. Therefore, the sustainability of materials is a global target [3]. There is much research on using bamboo, hemp fibers, and others to reinforce concrete, but studies on reeds are scarce. Concrete is one of the most significant building materials in many engineering constructions. Concrete cracks in the tension zone because, characteristically, it is a material that is strong in compression but weak in tension. Concrete and steel are combined to create reinforced concrete, where the steel reinforcement increases the tensile strength that the concrete lacks [4]. The reinforcement of the concrete slab by steel bars was more beneficial in

* Corresponding author: inm.khld@atu.edu.iq

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improving the slab capacity, and steel stiffeners decreased the crack width of the slab [5]. The reinforcement ratio affected the responses of slabs and failure modes by impeding crack extension [6]. However, steel has drawbacks, such as its high cost and corrosion potential [7]. Also, rebar is heavy, non-renewable, and non-environmentally friendly. Much work is being done to find a sustainable alternative material for steel [8]. Therefore, it is necessary to use a sustainable, renewable, and environmentally friendly material as an alternative to rebar [9]. Much interest in concrete reinforced with renewable materials such as bamboo led to its use in re-construction. Thus, bamboo is a viable alternative to steel-reinforced concrete elements [10, 11].

The flexural strength of the one-way slabs using bamboo bars as the reinforcing materials decreased slightly, but with the advantage of weight reduction compared with concrete slabs reinforced with steel bars [12]. Bamboo is becoming a promising alternative material for concrete reinforcement [13]. However, the maximum bearing capacity value remains constant with the increase in bamboo reinforcement percentage in the slabs because the bonding between the bamboo and the concrete has failed [14]. Also, the rebar-bamboo reinforcement was found to have reduced the ductility of the panels [15]. Because it was available in immense quantities, the reed was used to produce reinforced concrete in buildings at a low cost [16]. The findings by Ismail and Jaeel supported the idea that employing reed ash offers a long-term solution to the pollution issues brought on by the buildup of this product, where changed characteristics were added to the concrete [17]. The research by Madurwar et al. investigated the possible use of agricultural waste [18].

As a component of alternative sustainable building materials, agro-waste, as an environmentally friendly building material, offers a solution that saves energy and natural resources [19]. The production of alternative materials for bricks, cement, aggregates, steel, aluminum, wood, cladding, and partitioning materials is exponentially needed to fulfill the world's rising housing demand [20]. Scientific proof of the efficiency of giant reed fibers in the production of green building materials, such as bricks or laying mortars, was provided through the findings of Badagliacco et al. to understand the flexural behavior of new eco-compatible natural fiber-reinforced mortars for masonry application [21]. A study has been carried out through the experimental work of Shon et al. The test findings showed that adding CRF to the mortar mixture lowered its unit weight and increased its absorption capacity. Compressive and flexural strengths were increased when common reed fiber and steel fiber were used together, even though utilizing CRF in the mortar mixture did not improve these properties compared to the reference mixture [22]. According to Caponetto et al.'s findings, blocks formed of the lime-reed combination perform well mechanically in terms of thermo-physical behavior when compared to blocks made of more common construction materials, such as hollow clay or hemp, that are of the same thickness [23], while Amran et al. stated that the use of polypropylene fibers for various constructions, including load-bearing, enclosing, road, and hydraulic, demonstrated significant results [24].

Moreover, the enhancement of mechanical properties is greatly aided by the use of natural fibers [25]. Reeds were used in this paper to reinforce the slabs after their properties and bonding strength were improved with concrete as they were coated with epoxy. Polypropylene was also used to improve the behavior and properties of concrete mixtures and reduce cracks. It presents new findings about the behavior of reed-reinforced concrete in bending and an attempt to use reeds in the construction sector, especially in low-cost housing, as it is a cheap construction material and is available in considerable quantities in Iraq.

1.1. Significance of Study

Concrete is a material that is strong in compression but weak in tension. With this in mind, reinforcement must be used to improve the tensile strength of the concrete. This experimental study investigated the potential effect of unconventional bars for reinforcing concrete one-way slabs as an alternative to traditional reinforcing steel bars. Reinforcing steel is an unavailable, unsustainable material that is exposed to rust and is also very expensive. There is a tendency to use natural materials such as reeds in reinforced concrete instead of steel to reduce costs and limit environmental impacts. On the other hand, natural reeds are light and have a fast growth cycle. As a result, giant reed rods treated with epoxy as well as polypropylene as eco-friendly materials are considered structural materials subject to minimal loadings, such as the kitchen ceiling and isolation or partition walls that can be used in constructing low-cost buildings.

2. Experimental Program

The experimental program of concrete properties was carried out in two parts, that is, in a fresh and a hardened state. According to BS 1881:102, the slump test was performed using a slump cone after the concrete mix had been prepared. To ascertain the properties of the hardened concrete, a conventional cube, a cylinder, and beam molds were used to cast concrete after the slump test. After 24 hours of casting, the concrete was removed from the molds and submerged in water to cure until the testing date. The compressive strength test based on BS EN 12390-3:2009, the flexural strength test based on BS EN 12390-5:2009, and the splitting tensile strength test were performed in the second stage of the investigations, as shown in Figure 1.

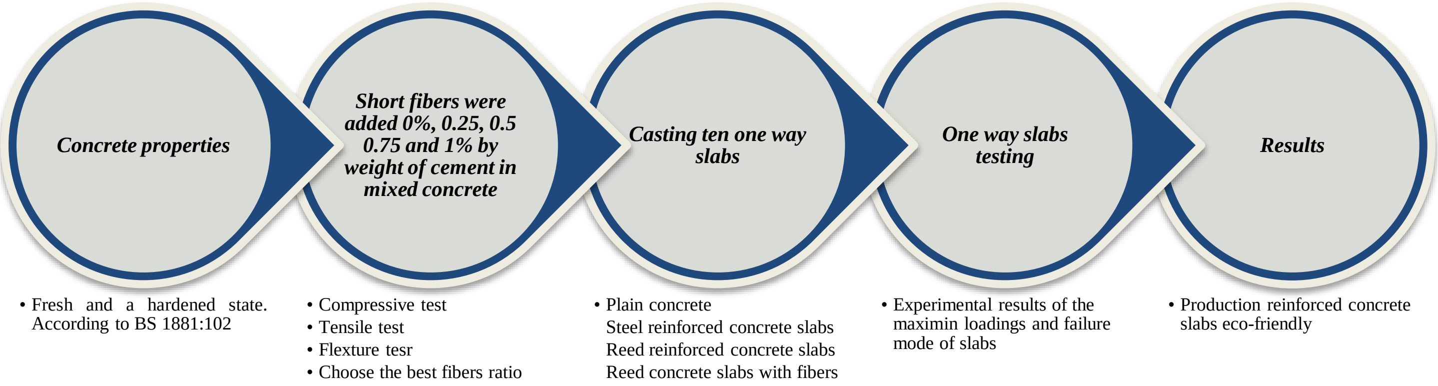

Figure 1. Flowchart of the research methodology

The Portland cement produced in the Kubaisah plant, which conforms to Iraqi specifications Q.P./5, was used. Sand and Gravel of 10 mm were used with a gradation and a percentage of salts that also conformed to the Iraqi specification. The mixing ratio used was (1 cement:2 sand:4 gravel) with water to cement ratio of 0.48. The additional Polypropylene fiber of 0%, 0.25%, 0.5%, 0.75%, and 1% by weight of cement has physical characteristics as presented in Table 1.

Table 1. Polypropylene fiber's physical characteristics

Details	Description
Length	5-12 mm
Tensile strength	500–600 MPa
Elastic modulus	3000–3500 MPa
density	0.90 g/cm

The concrete slabs subjected to testing were classified into several groups, as follows. The first group consists of a concrete slab without reinforcing steel (S-P), a slab reinforced with steel bars with a diameter of 8 mm (S8-150), and a slab reinforced with 10 mm reinforcing bars every 150 mm (S10-150), which is the control group. In contrast, the second group consisted of concrete slabs containing a type of reed reinforcement in different proportions. In particular, they were slabs (R8-250 and R10-250) consisting of a reed-reinforced concrete slab with a diameter of 8 mm and 10 mm at every 250 mm c/c. The slabs (R8-150 and R10-150) consist of a reed-reinforced concrete slab with a diameter of 8 mm and 10 mm at 150 mm c/c. In the last group, the slabs (SR8-150 and SR10-150) consist of partially reed-reinforced concrete of approximately 33% reed and 66% steel with a diameter of 8 mm and 10 mm at 150 mm c/c (see Figure 2).

Figure 2. (a) Treatment of reed (b) Reed-reinforced concrete (c) Photo of Polypropylene

Beside the two parts, the slabs were cast with dimensions of 800 mm by 350 mm and a thickness of 80 mm. The reinforced concrete slabs were made of steel or reeds with a 20 mm concrete cover after pouring the concrete slabs inside a laboratory at a temperature of about 25 degrees Celsius. Molds were opened, and concrete slabs were covered with a wet cloth for treatment (see Figure 3). The slabs were tested after 28 days.

The experimental slabs were tested under the influence of central-line bending. A 200 kN capacity of a hydraulic machine was used to test the slab until there was an obvious failure under the static load. The long slab is 800 mm, and the distance between the two supports is 700 mm, with the central point's load at a distance of 350 mm at the support. The slabs were placed on two steel supports, and the loads were applied by the central loading line, as shown in Figure 4. The loading rate was 20 newtons per second. The results of the initial cracks and final failure were documented visually on slabs and recorded.

Figure 3. Treatment reed- reinforced concrete slabs by wet cloth

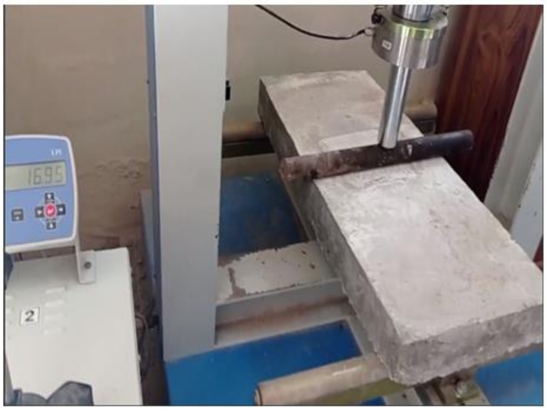

Figure 4. The experimental slabs under the influence of central-line bending

3. The Experimental Results

The present paper sheds light on the production of the slabs reinforced with giant reed rods treated with epoxy as well as polypropylene as eco-friendly materials under the central line load. The tests have been run on the concrete properties, a compressive, tensile, and flexural test before and after adding the polypropylene and compared with the control mix design to examine the strength and durability. Then, economical production of reinforced concrete slabs is done using eco-friendly materials.

3.1. Slump

The slump test findings are displayed in Figure 5. The mixture stiffened as more short fibers were added to it. The workability of concrete diminished as short fibers were added. Low workability results were obtained for short fibers with the amount of 1%.

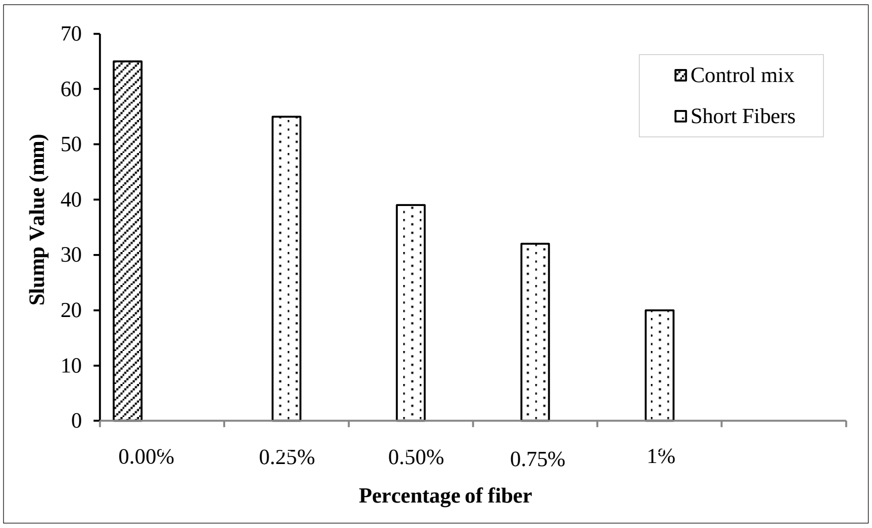

Figure 5. Slump test findings

3.2. Compressive Strength

The average compressive strength of fiber concrete (FC) at 7 days is shown in Table 2. The results included the control mix (CM), F1 0.25%, F2 0.50%, F3 0.75%, and F4 1%. Three specimens of each concrete mix were tested, but only the average findings are presented here. The compressive strength obtained from the concrete control mix was 21.46 MPa. Yet, the FC with 0.25% fibers has an average strength of 22% higher than the CM specimens. The fibers' ability to bridge cracks may cause this improved strength. The compressive strength steadily declines with the increased fiber content of the remaining specimens.

Table 2. Compressive strength of specimens

Mix Design	Compressive strength (MPa)
0.00% F Control mix (CM)	21.47
0.25% F (F1)	24.28
0.50% F (F2)	22.88
0.75% F (F3)	22.32
1.0% F (F4)	20.16

3.3. Splitting Tensile Strength

The results of the splitting tensile strength are displayed in Figure 6. The figure shows that concrete specimens with fibers added produced better outcomes than the control concrete. The specimen with the highest tensile strength, 3.15 MPa, is an F1 specimen with 0.25% short fibers. Because of the low workability of concrete, the tensile strength of models decreased as the amount of fiber increased.

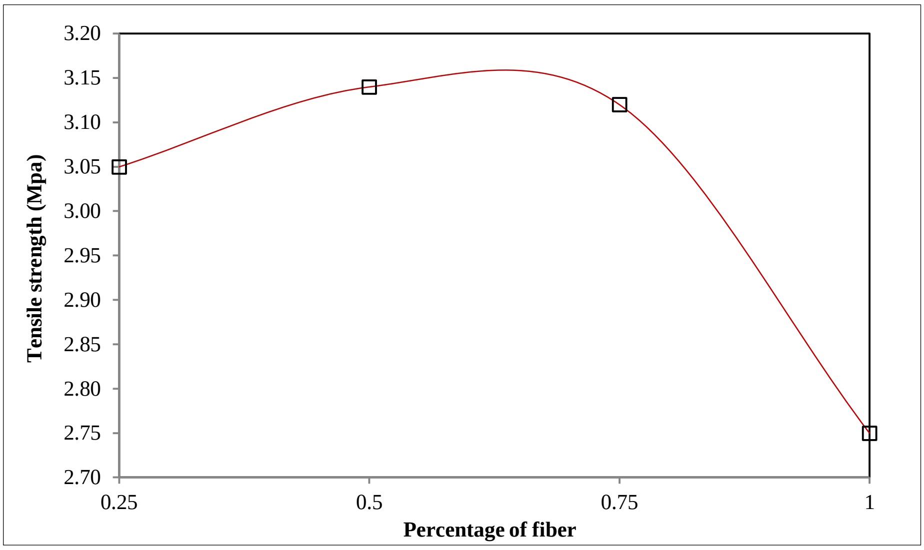

Figure 6. Splitting tensile strength test results

3.4. Flexural Strength

In a flexural test, the concrete with fiber outlasted the control mix design in terms of its durability. At every amount of replacement, every concrete specimen outperforms the CM specimens in flexural strength. The best outcome was attained in specimens with 1% fibers. Yet, as the fiber content rises, the flexural strength falls. For concrete with fiber, with more added fibers, this decrease is more pronounced, as shown in Table 3.

Table 3. Flexural strength test results

Mix Design	Flexural Strength (MPa)
0.00% F Control mix	2.95
0.25% F by weight of cement	3.00
0.50% F by weight of cement	3.1
0.75% F by weight of cement	3.02
1% F by weight of cement	3.01

3.5. One-Way Slabs Testing

One-way slabs were tested under central-point loading until failure. A universal machine with a capacity of 200 kN was used for the testing samples. The reed reinforcement has been used in these slabs' replacement as rebar. The test results show that the maximum load of the slabs increased with the decrease in the reed percentage. Table 4 summarizes the experimental results for the maximum loadings and all slab failure types. The initial cracks appeared at the range of loading between 5.6-22.1 kN and occurred at a range of 5.91–44.62 kN of maximum loading. The initial cracks of the slabs appeared in the lower face at the maximum tension stress, i.e., the middle slab, where there is the maximum moment. The first crack resulted from bending the S-0 slab at a load of 5.6 kN. Meanwhile, for slabs R8–250 and R10–250, the percentage of first cracking increased by 28.6% and 15.2%, respectively, with respect to the control slab. Meanwhile, the slabs R8–150 and R10–150 have first cracks of 6.2 and 5.4 kN, respectively, with differences that are unnoticeable compared to the control slab. For the slab with an 8 mm diameter rebar at a distance of 150 mm (slab S8-150), the cracking load (17.7) kN increased about 2.85 times as the slab (R10-150) with reeds rod served as the reinforcement. Furthermore, in the slab with a 10 mm diameter steel reinforcement at a distance of 150 mm (slab S10-150), the first cracking load (22.1) kN increased about 4.1 times for the slab (R10-150) with reeds rod that adopted the same method of reinforcement. Finally, for the slabs (SR8-150 and SR 10-150) consisting of partially reed-reinforced concrete, the first cracking load (17.4, 16.7) kN increased about 2.8 and 3.1 times compared with the same slabs that have reed rod as the reinforcement (slabs R8-150 and R10-150), respectively.

Table 4. Experimental results of the maximin loadings and failure mode of slabs

Slabs Code	Maximin loadings (KN)	Time %	Failure mode
S-P	6.3	-	Flexure
S8-150	40.04	6.4	Shear
S10-150	44.62	7.1	Shear
R8-150	6.97	1.11	Flexure
R10-150	5.91	0.94	Flexure
R8-250	9.11	1.45	Flexure
R10-250	7.45	1.18	Flexure
SR8-150	23.8	3.78	Flexure-shear
SR10-150	22.74	3.61	Flexure-shear
SR8-150 with fiber	35.83	5.69	Flexure-shear

In general, to understand the effect of the reed reinforcement at maximum load, the comparisons were divided as follows:

Firstly, the reinforced concrete slabs were compared to those with reed bars. The maximum load of the slab with steel bars of 8 mm diameter at a distance of 150 mm (S8-150 slab) was 40.04 kN, i.e., the amount of increase was about 5.74 times that for the same slab with the reed bar as the reinforcement (R10-150 slab). Moreover, for the slab with the steel reinforcement with a diameter of 10 mm at a distance of 150 mm (S10-150 slab), the load was 44.62 kN, i.e., 7.55 times more than the slab reinforced by the reed rod with the same reinforcement method (R10-150 slab).

Secondly, the concrete slab reinforced with reed bars was compared with the unreinforced concrete slab, where it was found that the reinforcement with reeds with a diameter of 8 mm at a distance of 150 and 250 mm (slabs R8-150 and R8-250) had a maximum load of 6.97 and 9.11 kN, i.e., the amount of increase was about 1.11 and 1.45 times, respectively. As for the 10 mm diameter reinforced slab at a distance of 150 and 250 mm (slabs R10-150 and R10-250), it was 5.91 and 7.45 kN, which were 0.94 and 1.18 times, respectively, more than the unreinforced slab (plain concrete slab S-P).

Thirdly, slabs (SR8-150 and SR 10-150) consist of partially reed-reinforced concrete, which is approximately 33% reed and 66% steel, with a diameter of 8 mm and 10 mm at 150 mm c/c. The maximum loads of slabs (SR8-150 and SR 10-150) were (23.8 and 22.74 kN) increased by 3.4 and 3.85 times compared to the same panels with the reed bar only (Slabs R8-150 and R10-150), respectively. Meanwhile, these slabs (SR8-150 and SR 10-150) had lower percentages (59.4% and 50.9%) than the panels (Slabs S8-150 and S10-150) reinforced by steel bars only, respectively. That said, the reed demonstrated a slight improvement in the bearing strength of the slab and an unclear effect on the type of failure as the diameter of the reed increased (see Figure 7). It indicates that the smaller the diameter of the reed, the greater its effectiveness in the concrete due to a decrease in the gaps, which are considered weak areas. Therefore, the flexural response of a slab improved with increasing reinforcement.

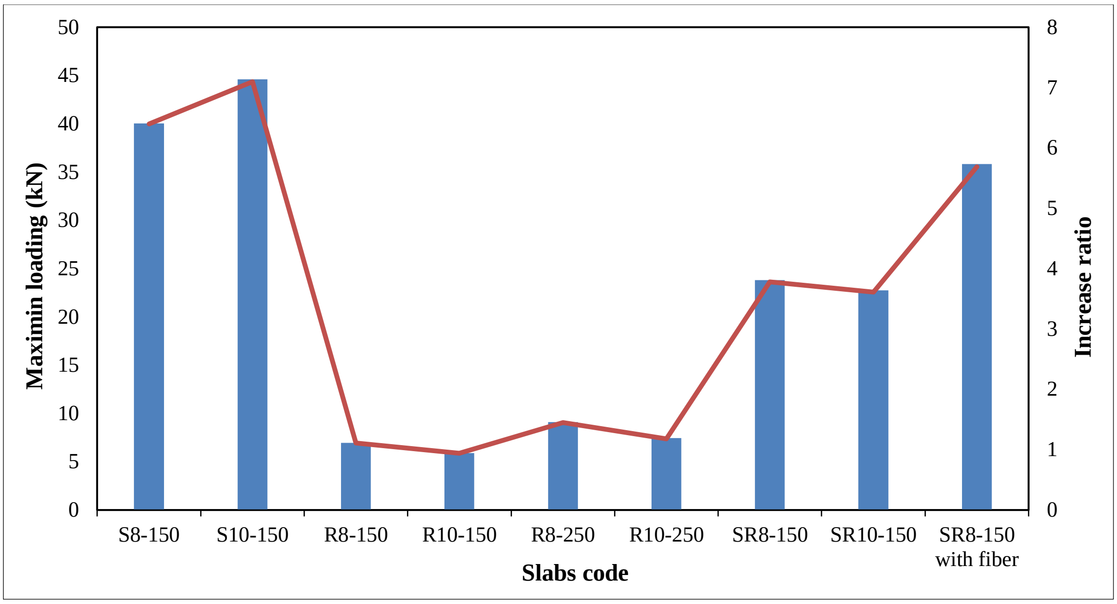

Figure 7. Flexure strength results of reed-reinforced concrete slabs

As a result of the above, it is possible to improve the behavior of the concrete slab by improving the properties of the concrete by adding polypropylene to the mixture; thus, the bearing capacity of the reed-reinforced concrete slab became 35.83 kN with less than 10.5% only compared to the traditional reinforced concrete slabs. It was found in this research that the best results for the concrete slab's behavior emerged from adding 25% polypropylene by weight of cement to the mix of concrete. Thus, one-way concrete slabs with giant reed treated by epoxy obtained good performance due to the improved bonding strength with concrete, increased tensile strength, and reduced absorption of reed. As a result, it produced economical reinforced concrete slabs with the use of the eco-friendly material.

The crack patterns of the slab and damage types were determined. Regarding the crack patterns, it was noted that the one-way slab plain and reed concrete slabs had a clear crack line (flexural crack). Thus, the cracks on the bottom surface of the slabs were identified. By displaying the crack patterns of slabs in Figure 8, it was found that the crack pattern is the flexural crack at the center of the reed-concrete slabs under load. However, the crack pattern of the reed-steel concrete slabs becomes a flexural-shear crack. Meanwhile, the reed-steel concrete slabs with polypropylene also failed a flexural-shear crack (see Figure 9). Finally, as established in this paper, shear failure was found in the reinforced concrete slabs because the thickness of the concrete layer was thin with a suitable steel reinforcement ratio in the bending zone (see Figure 10). Also, the use of polypropylene improved the behavior and properties of the concrete mixtures by making bridges and preventing cracks. The meaning of the type of failure varies with the increase in flexural strength in the tensile zone of the slab, which obviously depends on the type and strength of the reinforcement.

Figure 8. The crack patterns of plain and reed concrete slabs (flexural crack)

Figure 9. The crack patterns of reed-steel concrete slabs without or with polypropylene (flexural-shear crack)

Figure 10. The crack patterns of reinforced concrete slabs (shear failure)

4. Conclusion

As a result of the above, the concrete properties that show an enhancement in the compressive, tensile, and flexural tests of concrete with the addition of polypropylene outlasted the control mix in terms of its strength and durability. Thus, the concrete specimen with 0.25% short fibers by weight of cement demonstrates the highest compressive and tensile strengths of 24.28 MPa and 3.15 MPa, respectively. Also, good performance of one-way concrete slabs has been obtained with giant reed treated due to the improved bonding strength with concrete, increased tensile strength, and reduced absorption of reed. Due to this, the giant reeds treated with epoxy demonstrated an improvement in the bearing strength of the reinforced concrete slab. The test results also show that the maximum load of the reed-concrete slabs increased with the small diameter of the reed rod. As for the type of failure, the crack patterns of plain and reed concrete slabs had flexural cracks. Meanwhile, the crack pattern of reed-steel concrete slabs becomes a flexural-shear crack. The shear failure was in traditional reinforced concrete slabs, evident through the display of the crack pattern. The bearing capacity of the reed-reinforced concrete slab with polypropylene was 35.83 kN. It could be substituted by reinforcing slabs with treated giant reeds with epoxy in reconstruction. Treated Reeds by having them coated with epoxy were used to reinforce the slabs to improve their properties and bonding strength with concrete. The use of polypropylene aims to improve the behavior and properties of the concrete mixtures by making bridges and preventing cracks. Finally, treated reed-concrete slabs were produced with good specifications by improving the concrete's properties using polypropylene. As a result, economical reinforced concrete slabs have been produced. Therefore, this paper contributes to new knowledge as the improved performance of concrete slabs has been achieved using eco-friendly materials. The prospects for future research lie in using reed fiber as a replacement for gravel in roofing slabs.

5. Declarations

5.1. Author Contributions

Conceptualization, M.S.S., T.J.M., and K.M.B.; methodology, M.S.S., T.J.M., and K.M.B.; validation, M.S.S.; formal analysis, M.S.S. and K.M.B..; resources, K.M.B.; data curation, T.J.M.; writing—original draft preparation, T.J.M., and K.M.B.; writing—review and editing, T.J.M. and K.M.B.; visualization, M.S.S., T.J.M., and K.M.B.; supervision, T.J.M., and K.M.B.; project administration, M.S.S., T.J.M., and K.M.B.; funding acquisition, M.S.S., T.J.M., and K.M.B. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available in the article.

5.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

5.4. Conflicts of Interest

The authors declare no conflict of interest.

6. References

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