

Behavior of Concrete Slabs Strengthened with Multi layers of Fabricated Fiber Meshes

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Abstract: Fiber meshes are used in concrete slabs to strengthen the concrete and slow the spread of cracks, which raises the concrete modulus of elasticity and plasticity. This paper presents the experimental study conducted on six concrete slabs resting on the Winkler support with square dimensions of (800×800) mm and a thickness of (100) mm, with a fabricated steel mesh (Ø4mm@150mm) located near the center section of the slab, and strengthened with different types which of fiber meshes are fiberglass, polypropylene, carbon, geogrid and waste rubber fibers, located in the tension and compression zones. The Winkler foundation is used to represent the ground soil in the study of concrete slabs on the ground in terms of toughness, stiffness, and ductility index. Twelve rubber supports with a stiffness of (7500) kN/m are used, and they are supported by a steel plate that is (800×800) mm in size and has a thickness of (10) mm. According to the testing results, all of the specimens strengthened with fiber meshes have shown a considerable improvement in toughness and ductility index, especially the specimen that strengthened two-layer carbon fiber meshes, where the increases were 331.8% and 4.76 respectively, and a large improvement in the stiffness was in the specimen that strengthens two-layer glass fibers by 44.2%. The slab-strengthened polypropylene has the lowest percentage increase in toughness (22.1%), while the slab-strengthened geogrid and waste rubber has the lowest percentage increases in stiffness (37.2%) and lowest improvement in the plasticity index was in slab-strengthened two-layer from polypropylene fiber by (1.90). Early cracking appeared in the slab-strengthened polypropylene, which had less load capacity than the other specimens, and the maximum ultimate load was (45.5) kN/mm, which is near the maximum ultimate load of the control slab.

Keywords: Ductility; Toughness; Stiffness; Slab on ground; Modulus of subgrade reaction; Fiber meshes

1. Introduction

One of the building's most important structural components is the slab concrete. Despite being utilized extensively in many structural components, concrete still has a number of drawbacks that limit its usage, including low toughness, low tensile and flexural strength, and high brittleness [1]. In order to improve the mechanical performance and load capacity of concrete, several additives such as steel fibers, glass, horsehair, plastic raw materials, and other types of fiber (polypropylene, carbon, etc.) have been employed recently. Because of its exceptional flexural rigidity, supportability, and sustainability, fiber-strength concrete has been used successfully in structural projects [2], [3]. According to the ACI Code, concrete slabs are crucial structural elements of constructed structures and are utilized for a number of applications, such as industrial slabs, sidewalks, and roads [4]. A slab on the ground be defined as one that supports applied loads in accordance with the amount stipulated in its design [5]. Fibers were introduced to enhance the mechanical properties of concrete, as it lacks resilience to various loads [6]. Fibers are small, thin, thread-like materials that are flexible under pressure. They can be made from glass, steel, polypropylene, and other materials [7].

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When added this fiber to concrete, the majority of these fibers have comparable qualities, significantly reducing the propagation of cracks and increasing the concrete tensile strength, durability, and flexibility. [8],[9], [10]. Additionally, several fibers have unique qualities. Such as glass fibers have the ability to withstand salts and acids, making them appropriate for usage in both industrial and marine environments. [11],[12]. Because polypropylene fibers don't react with water and don't absorb concrete water, it's more resistant to corrosion and shocks [13]. Because of its extremely high tensile strength, carbon fiber usage in high-performance applications, such as components for automobiles and airplanes [14]. Concrete mechanical qualities, such as foundation reinforcing and soil slope leveling, are improved and deformation is significantly decreased by geogrid fiber [15], [16]. Waste rubber fiber is very resistant to vibration and stress [17], [18], [19].

The six concrete slab specimens used in this study by measuring (800×800×100) mm and reinforced with BRC mesh (Ø4 mm @ 150 mm). One slab serves as a control, while the other five specimens are resting on the ground and reinforced with various fiber meshes, including waste rubber, glass, polypropylene, carbon, and geogrid. A Winkler model, which consists of twelve rubber supports sitting on an (800×800) mm steel plate foundation with a thickness of 10 mm, is used to simulate the soil during testing in order to determine the subgrade reaction value (k_s). Comparing the fiber mesh-strengthened slabs with the control slab strengthened with BRC mesh just and examining their toughness, stiffness, ductility, and load-bearing capacity are the objectives of the current study. Following the crack pattern and yielding with loads of each type are the primary variables in this study. It also looks into each specimen's toughness, stiffness, ductility, and load-carrying capacity.

2. Literature Overview

Alani & Beckett, (2013) An experimental investigation was conducted on the Mechanical properties of a large-scale synthetic fiber reinforced concrete ground slab, using a sample of a (6000×6000) mm concrete slab with a thickness of (150) mm. The results indicated that there were small cracks on the edges of the concrete slab, which became more severe with increasing load. According to the tests, the synthetic fiber-reinforced slab performed better than the steel fiber-reinforced slab [20]. El-Hanafy et al., (2022) The Behavior of Concrete Slabs Reinforced by Different Geosynthetic Materials was studied by conducting six experimental samples of concrete slabs with dimensions of (1000×1000) mm and thickness of (100) mm. It was proven that concrete slabs reinforced with (Tenax and Secugrid) meshes provide the concrete with excellent resistance and displacement and significantly postpone the stage of concrete failure. Concrete reinforced with polypropylene fibers showed little resistance to bending and load bearing and lowest the development of concrete cracks [21]. Sorelli et al., (2006) used steel fibers of different sizes and shapes to experimentally examine the behavior of reinforced concrete slabs. The results demonstrate that steel fibers significantly increase the slabs' ductility and flexibility, increase the concrete's load-bearing capacity, and significantly reduce the chance of concrete cracking [22]. Sucharda et al., (2017) the benefits of steel fibers in concrete slabs were examined, with a focus on the properties of the material and the impact of the fibers on the strength of the concrete. The results showed that the fibers had a major influence on the tensile and flexural strengths [23]. Tahwia et al., (2024) further examined the experimental study of rubberized concrete slab-on-grade utilizing five reinforced concrete slab models that were 60mm thick and 1000 x 1000 mm in size. The results showed that crumbly rubber concrete slabs were more durable than control slabs. It shown strong resistance to slowing the spread of fractures [24].

3. Experimental program

3.1 Materials

3.1.1 Cement

Portland cement of the Sinjar cement type Ordinary Portland Cement (OPC) was used to cast all experimental materials for this study, and they were tested chemically and physically. In light of this, the results of the chemical and physical tests are shown in Tables (1) and (2), respectively. The results met the standards and criteria of Iraqi Specification No. 5/2019.

3.1.2 Fine aggregate

Natural Fine Aggregate (NFA) has a maximum size of 4.75 mm. The Concrete Technology Laboratory at the University of Mosul was the site of the physical examinations and sieving analysis. According to Iraqi Regulation No. 45 of 1984 [25], Tables (3) and (4), respectively, list the physical characteristics and categorization of natural fine aggregate.

3.1.3 Coarse aggregate

The Concrete Technology Laboratory, College of Engineering, University of Mosul, performed the screening analytical and physical testing on the experimental samples, which were cast using gravels no bigger than 12.5 mm. Tables (5) and (6), respectively, present the Iraqi standard No. 45/1984 for the classification of natural coarse aggregate and its physical attributes.

3.1.4 Water

Mix all the elements that go into the concrete mixture with ordinary drinking water.

3.1.5 Reinforcing steel

Positional wear of the concrete slab with overall dimensions of (800×800) mm is achieved by using BRC reinforcement (4mm@150mm) at a distance of 55 mm from the base of the wooden form in all specimens. As seen in Fig. (1a). In accordance with ASTM A615-16 (ASTM A615/A615M 16, 2016), steel mesh is tested for performance. Table (7) provides a summary of the Properties of reinforcing steel mesh. As shown in Fig. (2a), show results the tensile test was carried out on the steel bar in the Testing Materials Laboratory at the University of Mosul / College of Engineering.

Table 1 Chemical Properties of Cement

Chemical Compounds	Content (%)	Limits of Iraqi Specifications No.5 (2019)
SO ₃	1.92	≤ 2.5% if C ₃ A ≤ 5% ≤ 2.8% if C ₃ A ≤ 5%
Loss on ignition (L.I.O.)	1.71	≤ 4%
Insoluble residue (I.R.)	1.12	≤ 1.5%
C ₂ S	26.67	—
C ₃ S	45.60	≤ 3.5
C ₃ A	6.04	—

Table 2 Physical Properties of Cement

Properties	Results	Limits of Iraqi Specifications No.5 (2019)
Consistency	0.28	—
Initial Setting Time (minutes)	120	≥ 45 min

Final Setting Time (hrs.)	195	≤600 min
2 days Compressive Strength (MPa)	23.2	≥10
28 days Compressive Strength (MPa)	43.2	≥42.5
Fineness for Sieve No. 170 (%)	2.6	≤10
Soundness by Le Châtelet method (mm)	2.3	≤10

Table 3 Physical Properties of fine aggregates

Physical Properties	Test Result	Iraqi Specifications No.5 (1984)
Sulfate Content (%)	0.11	≤0.5
Absorption (%)	1.80	—
Specific Gravity	2.58	—
Bulk density (kg/m ³)	1550	—

Table 4 Fine aggregate properties

Sieve Size (mm)	Passing (%)	Iraqi Specifications No.45 (1984)
4.75	96.5	90-100
2.36	80.0	75-100
1.18	65.5	55-90
0.6	54.3	35-59
0.3	28.9	8-30
0.15	4.7	0-10

Table 5 Coarse aggregate properties

Sieve Size (mm)	Passing (%)	Iraqi Specifications No.45 (1984)
19	100	100
12.5	94	100-90
9.5	59	70-40
4.75	1	15-0
2.36	0	5-0

Table 6 Physical Properties of coarse aggregates

Physical Properties	Test Result	Iraqi Specifications No.5 (1984)
Sulfate Content, %	0.031	≤ 0.1
Porosity %	2.20	—
Specific Gravity	2.61	—
Bulk density (kg/m ³)	1620	—

Table 7 Properties of reinforcing steel mesh

Item	Test result
Actual Diameter (mm)	4
Yield Stress (MPa)	562
Ultimate Strength (MPa)	670
Total Elongation (%)	9

3.1.6 Glass fiber mesh (GL)

Area of fiber section is calculated by (0.16 x 1.1) mm glass fiber section which used to determine the equivalent area between the various types of fiber meshes, and two layers of this mesh are to be merged and the equivalent amount as shown in table (8). As shown in Fig. (2b), show results the tensile test was carried out on the glass fiber in the Testing Materials Laboratory at the University of Mosul / College of Engineering. As shown in Fig. (1b), the reinforcement specimen was used in the tension zone in the distance (25) mm from the bottom base of the wooden formwork and in the compression zone in the

distance (25) mm from the surface top of the specimen.

3.1.7 Polypropylene fiber mesh (PP)

A diameter of (0.92) mm polypropylene fiber section is used, to determine the equivalent area between the various types of fiber meshes, and two layers of this mesh are to be merged and the equivalent amount as shown in table (8). As shown in Fig. (2c), show results of the tensile test carried out on the polypropylene fiber. The polypropylene strengthen specimen was used in the tension zone at a distance (25) mm from the bottom base of the wooden formwork, and in the compression zone for a distance (25) mm from the surface top of the specimen, as shown in Fig. (1c).

3.1.8 Carbon fiber mesh (CR)

A carbon fiber mesh measuring (5.0×0.2) mm was prepared and used as a single layer to obtain the equivalent area between the different fiber meshes as shown in Table (8). The tensile test for carbon fiber was conducted as shown in Fig. (2d). Reinforcement with a carbon fiber mesh in the tension zone in the distance (25) mm from the bottom base of the wooden formwork, and in compression zone for the distance (25) mm from the surface top of the specimen as shown in Fig. (1d).

3.1.9 Geogrid fiber mesh (GG)

A geogrid fiber mesh measuring (0.5×4.0) mm was prepared and used as a single layer to obtain the equivalent area between the different fiber meshes as shown in Table (8). The tensile test for geogrid fiber was conducted as shown in Fig. (2e). The reinforcement with the geogrid fiber mesh in the tension zone in the distance (25) mm from the bottom base of the wooden formwork, and in the compression zone for the distance (25) mm from the surface top of the specimen, as shown in Fig. (1e).

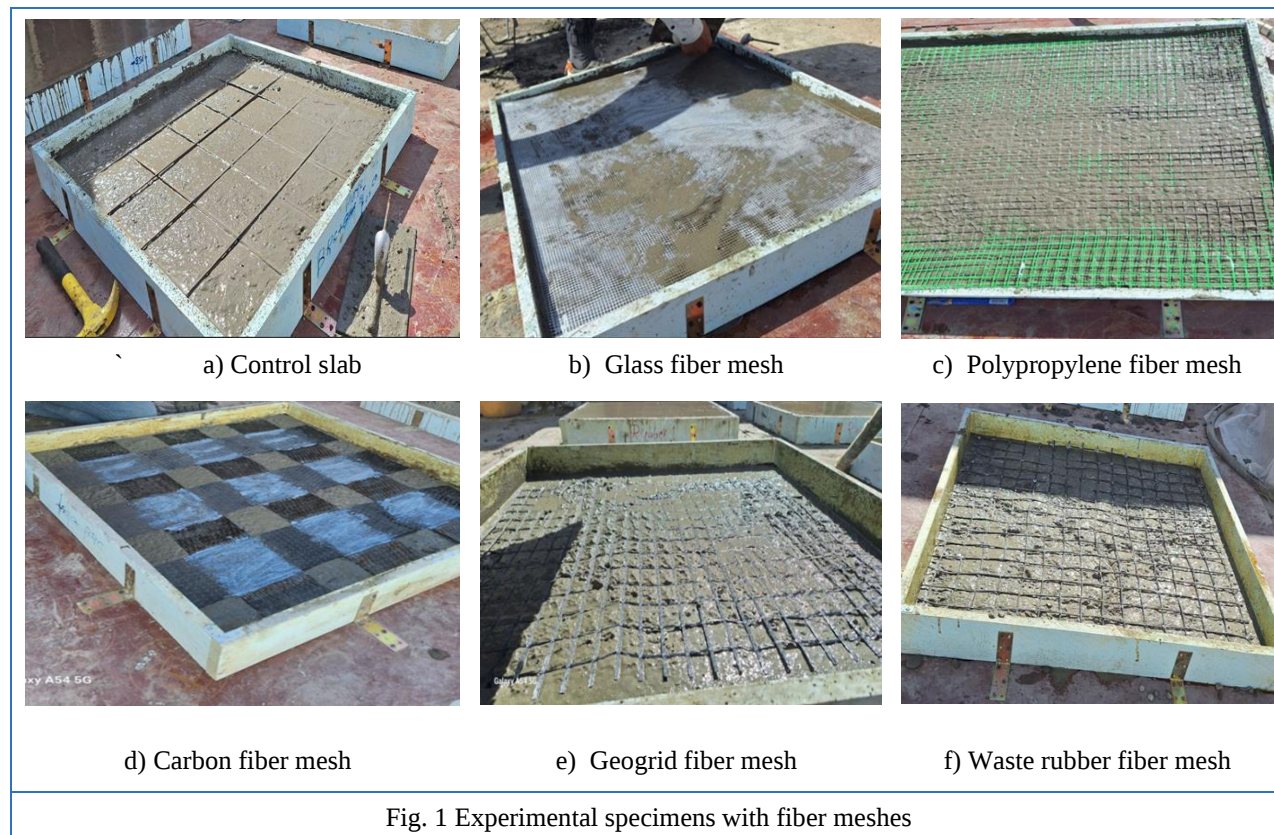
3.1.10 Waste rubber fiber mesh (WR)

To get the same area as the other fiber meshes, a fiber mesh constructed of old tires was created and made with a size of (2×2) mm per 50 mm, as shown in Table (8). A tensile tester was utilized to test a strand of the used fiber mesh the results as shown in fig. (2f). The strength of the waste rubber fiber mesh in the tension zone in the distance (25) mm from the bottom base of the wooden formwork, and in compression zone for the distance (25) mm from the surface top of the specimen as shown in Fig. (1f).

3.1.11 Comparison of fiber meshes after tensile test

To compare the behavior between all fiber meshes after tensile testing in terms of response, Fig. (3) shows the differences between the response of these fiber meshes, where the highest stress is in the carbon fiber and the lowest response is in the polypropylene fiber, noting that the highest strain is in the geogrid fiber, while the lowest strain was in the carbon fiber.

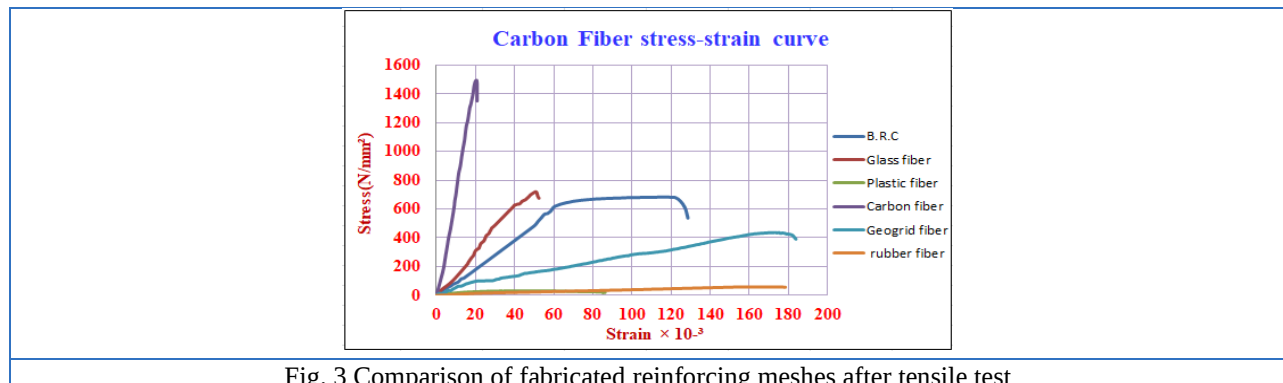
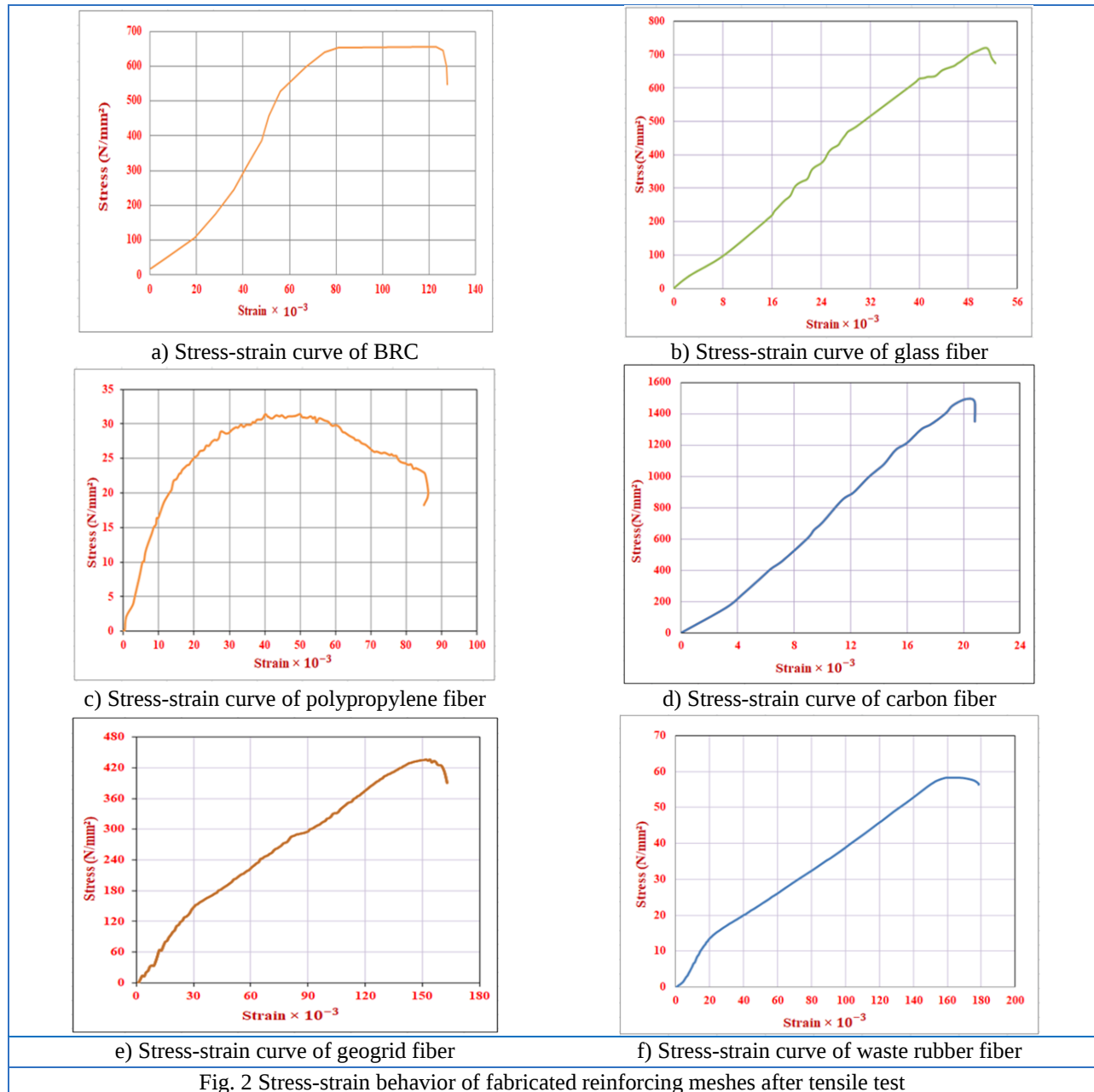
Table 8 Area of fiber section and equivalent area of each mesh per (50 mm length)				
Fiber mesh	Area of fiber section (mm ²)	Area of 1-mesh per (50 mm length)	No. of meshes	Equivalent area (mm ²)
Glass	0.175	1.94	2	3.88
Plastic	0.66	1.99	2	3.96
Carbon	1.0	8.0	0.5	4.00
Geogrid	2.0	4.0	1	4.00
Waste rubber	2.0	4.0	1	4.00



3.2 Concrete Mixture

The mixture used in the research of design compressive strength $f_{cu}=30$ MPa, the gradients of this mixture are displayed in Table (9)

Table 9 Concrete design mix characteristics.		
Description	Unit	Results
Design compressive strength	(MPa)	30
Cement content		380
Fine aggregate content	(kg/m ³)	800
Coarse aggregate content		950
Tap water content		175



3.3 Preparation of Winkler support and testing setup

Fig. (4) Shows the slab that is on the ground (Winkler support) and has form dimensions of 800 x 800 mm and a thickness of 100 mm, the specimen is cast and strengthened with various fiber meshes, and slab is examined on a plate steel with twelve rubber supports for installed in it, as detailed in Fig. (6b), to simulate soil. The device shown in Fig. (8b) is used to examine the specimens. As shown in Fig. (8a), shows, the side view of the specimen the size of the rubber supports, the placement of the load in the middle of the specimen, and the locations of the strengthened. Figure (6a) displays the placements of the LVDT in the specimen to track deformations in the center and sides. These LVDT are connected to the data logger reader in Fig. (5).

3.4 Mechanical properties of slab concrete

As shown in Fig. (7), Table (10) displays the values of the mechanical parameters at 28 days, including compressive strength[26], elastic modulus [27], splitting strength [28], and flexural strength [29].

Table 10 Mechanical properties of concrete		
Item	Sample	Test result
Compressive strength (MPa)	Cubic (150×150×150) mm	32.4
Elastic modulus (MPa)	Cylinder (Ø150×300) mm	28500
Splitting strength (MPa)	Cylinder ((Ø150×300) mm	2.3
Flexural strength (MPa)	Prism (400×100×100) mm	3.3



Fig. 5 Data logger used for control the loading and measuring the deflection in slab.

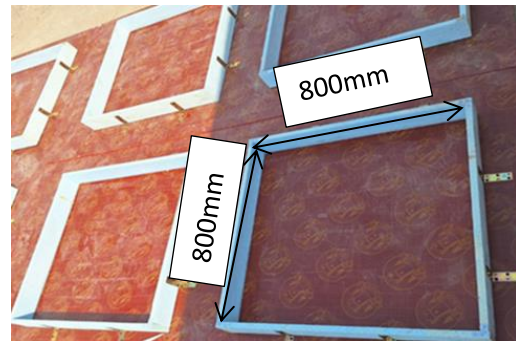
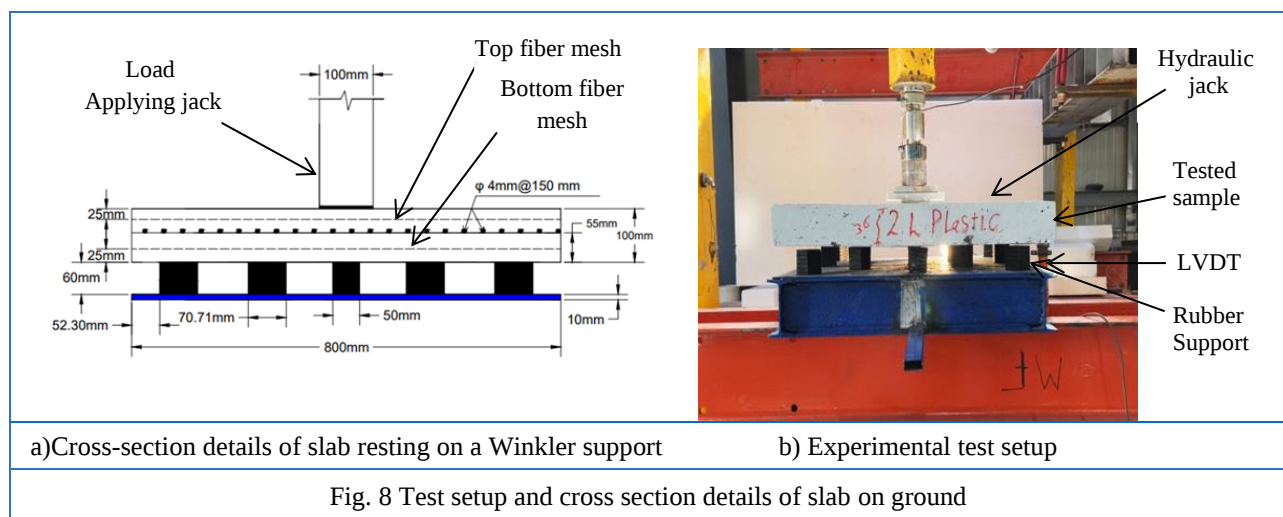
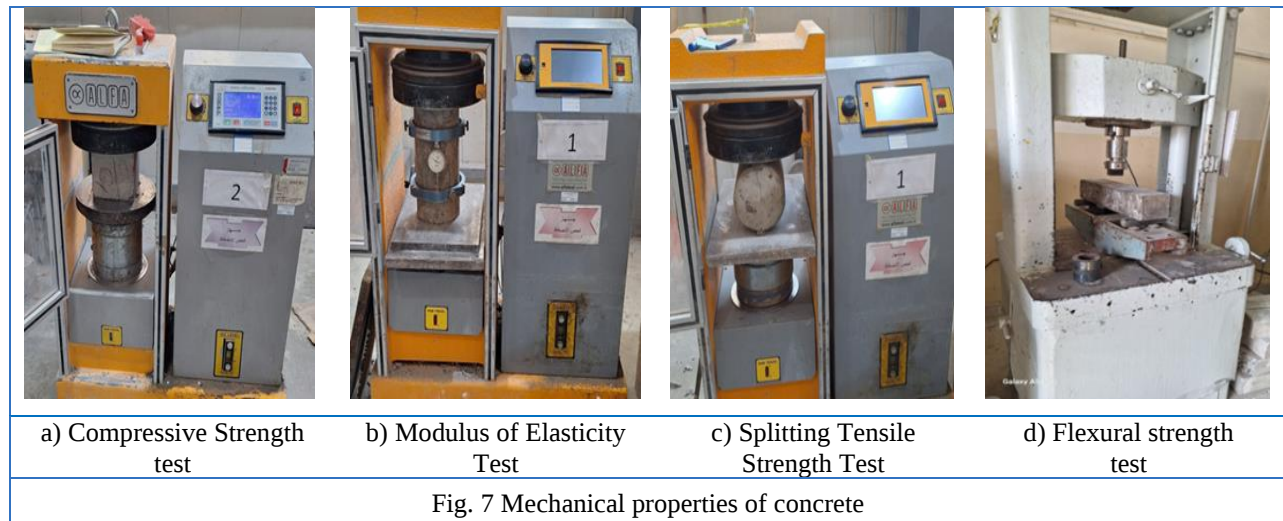
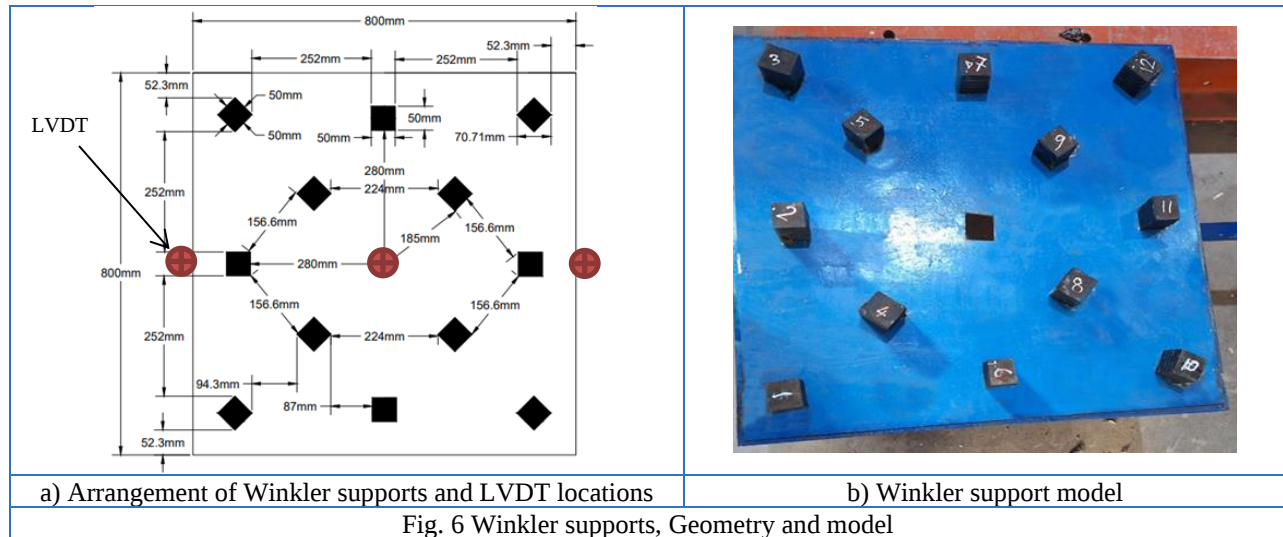


Fig. 4 Experimental specimen form

3.5 Subgrade reaction calculations

As shown in Fig. (6b), (12) rubber supports were positioned beneath the slab to reproduce a Winkler foundation. These supports are installed on a square steel plate that is (800 x 800) mm in size and 10 mm thick [30]. A representation of a continuous Winkler soil is given by these rubber supports. Each item underwent compression testing to assess its rubber stiffness, with an average value of (7500) kN/mm, when the effect area of each rubber piece (50×50) mm was taken into. The Winkler constant (k_s) was (28) N/mm³, which is equivalent to a uniform loose sand soil in accordance with ASTM classification [31]. (12) rubber supports were chosen to simulate the Winkler model which represents a loose sand soil according to the modules subgrade reaction value. The number of supports and their sizes were chosen based on the behavior of the rubber material. If another system such as springs had been used to represent that type of soil, the size and number of springs would have been different depending on the spring stiffness, also to allow for clear deformation of the slab.



4 Test results and discussions

By applying the load to the center of the slab, six concrete slabs strengthened with various types of fiber meshes were put to the test. The load was gradually increased until failure occurred. Six categories of crack patterns and ultimate load, load-deflection behavior, first cracking and ultimate load, toughness of slab, ductility index, and stiffness of slab are used to discuss the data in order to better understand the structural behavior of the slabs.

4.1 Crack patterns and ultimate load

The increasing applied load was applied to each specimen until the first crack showed. The first crack load and ultimate failure of the specimen are presented in Table (11). As shown in Figure (9), the fracture resulting from the applied load is the formation of linear cracks at the slab bottom surface (Control slab, GL, PP, CR, GG, and WR), among the specimen strengthened with two layers of fiber mesh. According to these results the polypropylene fiber meshes strengthened slab has the lowest bearing strength, its maximum bearing strength was (45.5) KN, which is near to the strength capacity of control slab, which was equal to (43.9) kN. Unlike other fibers, polypropylene does not have a high tensile strength [24]. Because of the high tensile strength of the carbon fibers, the specimen strengthened with two layers of carbon fiber meshes has the highest bearing strength of all the specimens, reaching (66.3) kN. This shows that in comparison to the control specimen, the carbon fiber mesh significantly improved the specimen by (51%). Tahwia [24] and Rasheed [32] examined the slab at ground under static loads, and their findings are in line with our findings.

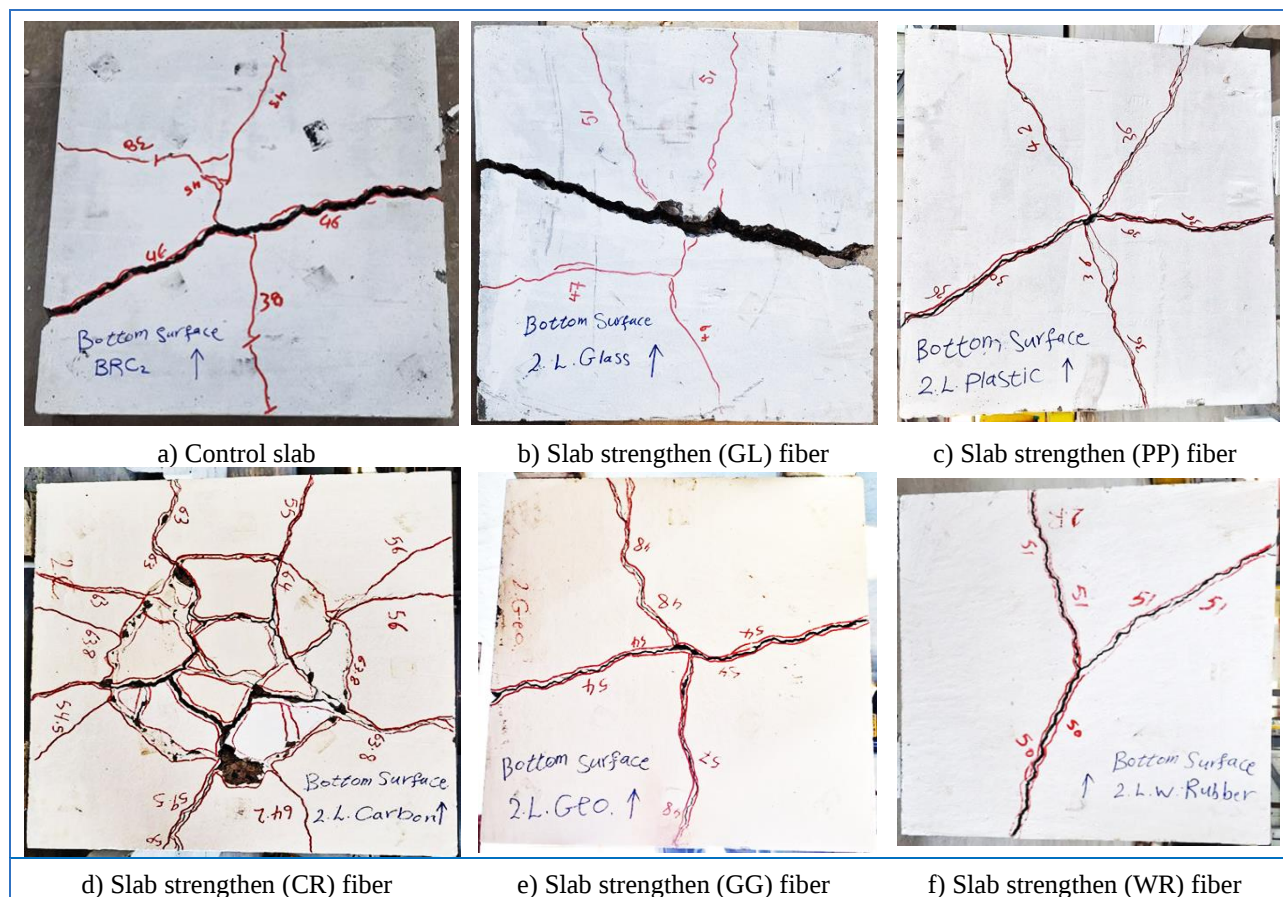


Fig. 9 Concrete slab failure and crack patterns for center load

4.2 Load–deflection behavior

The observed response of concrete slabs (BRC, GL, PP, CR, GG, and WR) under a central load is supported by the load-deflection curve shown in Figure (10). A decline in strength and ductility is shown in the slab's abrupt loss of load-bearing capability and failure to fracture after reaching its maximum load. Throughout the test process, the sensor recorded (LVDT) the deflection at the center of the concrete slab, as shown in Fig. (6a), at each load increment, the elastic area exhibits many unique phases throughout the incremental loading process. The deflection rate then quickens when cracks start to appear and spread [32]. This pattern persists until the steel mesh tensile stress hits the yield point. This is when the deflection curve slope starts to drop. Ultimately, the test is stopped when the deflection keeps rising without the applied load increasing at the same time. The load-deflection curves are in three stages. The first stage (the non-cracked stage) has almost linear load-deflection curves. The second stage, sometimes referred to as the pre-yield stage, occurs between the cracking load and the yield load. As shown in Fig. (10), flexural cracks appear on the slab tensile side at this point, and the mesh fiber material begins to rupture, all samples passed this stage. The last step is sometimes referred to as the post-yield stage. The load starts to drop as the specimen's deflection and crack openings increase after it has reached its maximum bearing strength. The specimen eventually comes dangerously close to total collapse. And presence of fiber meshes has a major impact on the curve slope. To compare the behavior between all fiber meshes strengthened in the tension and compression regions in terms of response, Fig. (11) shows the differences between the response of these slabs, where the highest response is for the slab strengthened by carbon fibers and the lowest response is the slab strengthened by polypropylene fibers, noting that the highest was the deflection in the slab strengthened with carbon fibers, while the lowest deflection was in the slab strengthened with glass fibers.

4.3 First cracking and ultimate load

Each specimen was examined up to the first fracture brought on by the increase in applied load. Table 10 shows the specimen of the first crack load and the ultimate failure that the specimen could bear. As shown in Figure (10) the cracks resulting from the applied load are the formation of linear cracks at the bottom surface of the slabs. The polypropylene-strengthened slab had the lowest bearing strength and was almost the same as the control slab because polypropylene fibers don't have the same high tensile strength as other fibers, (45.5) kN was its maximum bearing strength, However, because of the high tensile strength of carbon fibers, the slab strengthen with carbon fiber mesh has the highest bearing strength of all the specimens, reaching (66.3) kN. This indicates that it greatly enhanced the specimen by 51% as compared to the control slab. Showed the polypropylene fiber strengthened specimen had early first cracking that was near first cracking to the control slab by a 5.5% improvement rate. Specimens strengthened with fiberglass, geogrid, carbon, and waste rubber meshes showed improvements in first cracking compared to the control slab by 37.9%, 37.3%, 45.1%, and 46.2%, respectively.

4.4 Toughness of slab

The toughness, also known as the total absorbed energy, was determined by calculating the area under the load and deflection curve of the concrete slabs, as indicated in Table (11) and Figure (12). It was revealed through the results that there was an improvement in the specimens compared to the control slab due to the high stiffness that each specimen gained from the fiber mesh added to it, as the specimens (GL, PP, and GG) have a percentage of improvement (54.5, 22.1 and 79.4)%, respectively, compared to the control slab. Because carbon fiber mesh has a high tensile strength, the specimen strengthened with two carbon fiber meshes demonstrated a notable improvement over all other specimens. Comparing the specimen (CR) to the control slab, the improvement rate was 331.8%. This significant rise may be attributed to the specimen's high endurance force, which was acquiring from the carbon fiber mesh. This caused the specimen to undergo significant displacement throughout the test, which also resulted in an

instance of punching shear, the rubber fiber mesh gave a significant improvement to the specimen during the test, which was also characterized by high flexibility and led to a large displacement, as it gave an improvement rate of (114.1%) compared to the control slab.

Table 11 Load at first crack and ultimate failure with deflections of test specimens

Slab code	First crack		Ultimate failure		Toughness kN.mm	Increasing in Toughness %
	Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)		
BRC	34.6	4.64	43.9	5.52	371.45	—
GL	47.7	4.57	56.1	9.91	573.71	54.5
PP	36.5	4.84	45.5	10.5	453.61	22.1
GG.	48.2	4.95	57.5	12.67	666.28	79.4
CR	50.2	5.63	66.3	9.07	1603.94	331.8
WR	50.6	5.42	51.2	10.47	795.14	114.1

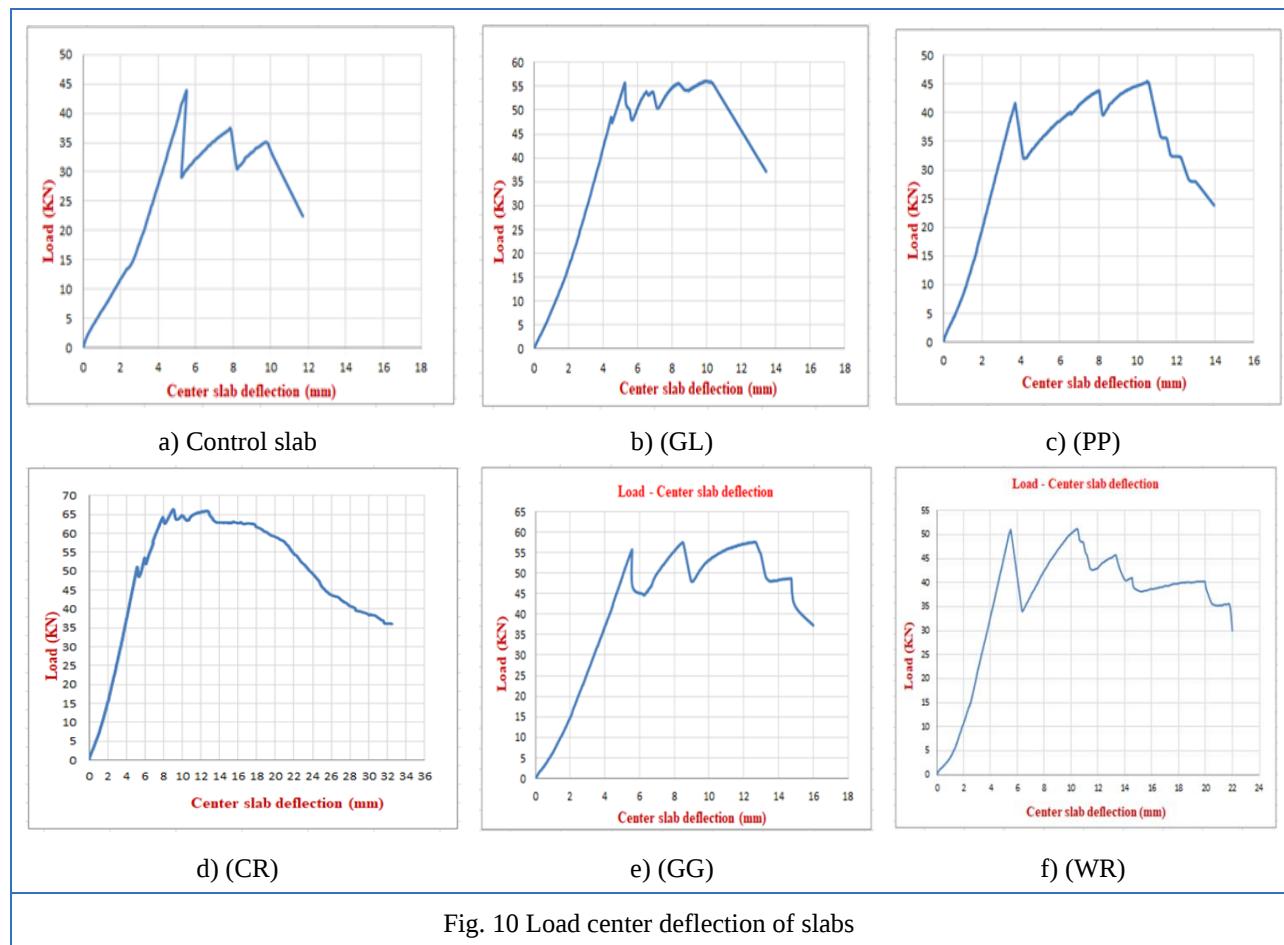


Fig. 10 Load center deflection of slabs

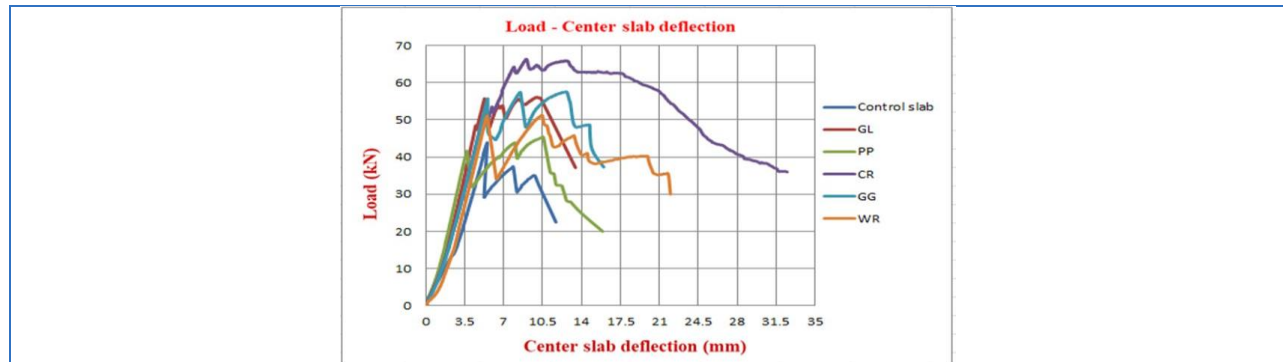


Fig. 11 Comparison of the behavior of slabs strengthened by 2-layer of fiber meshes

4.5 Ductility index

Each slab's yield point, central deflections, and ductility index are displayed in Table (12). The ductility index is characterized as the capacity of a structural member to endure the massive deformations it is subjected to during loading and is determined by dividing the deflection at the point of failure by the deflection at the yield point. According to the results, the specimen strengthened with two carbon fiber meshes has a ductility index value of 4.76, with a 117% improvement rate, compared to the control slab. This is thought to be the highest value obtained through experimental testing. In contrast, the ductility rates for the slab strengthened with two-layer polypropylene fiber meshes have the lowest value obtained (1.90), and were nearly equal to the control slab ductility index value.

4.6 Stiffness of slab

Table (13) shows the stiffness of the specimens and the percentage increase in the stiffness of the specimens strengthened with fiber meshes compared to the control slab. The findings showed that the specimens strengthened with rubber, carbon, geogrid, and polypropylene fibers all experienced stiffness increases between (37 and 40)%, while the specimen strengthened with two layers of glass fiber meshes experienced a maximum increase percentage by (44%) than the control slab.

Table 12 Load at yielding and Center deflection at (yield & failure) with ductility index

Slab no.	Load at Yielding (kN)	Center deflection at yield (mm)	Center deflection at failure (mm)	Ductility index
BRC	42.3	5.34	11.70	2.19
GL	53.0	5.04	13.46	2.67
PP	43.1	7.40	13.95	1.90
GG	55.1	7.94	16.00	2.02
CR	57.0	6.83	32.50	4.76
WR	47.6	9.19	22.00	2.40

Table 13 Increasing in the stiffness of slab

Slab code	Stiffness (kN/mm)	Increasing in stiffness (%)
BRC	8.6	----
GL	12.4	44.2
PP	12.1	40.7
GG	11.8	37.2
CR	11.9	38.4
WR	11.8	37.2

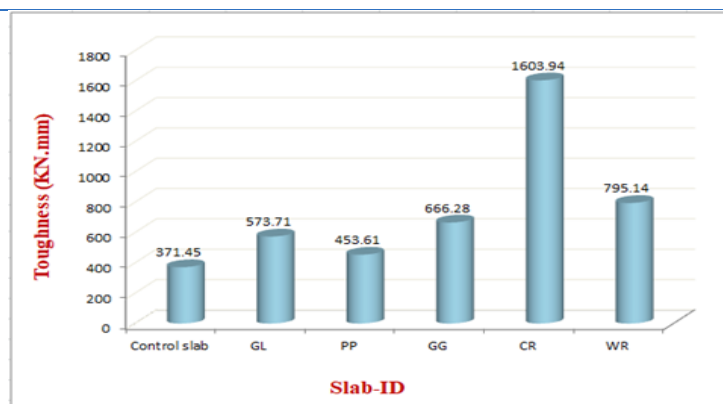


Fig. 12 Toughness of the tested slabs

5 Conclusions

Several tests were carried out to investigate how different types of synthetic fiber mesh affected the stiffness of the slab, ductility index, and toughness of concrete slabs strengthened with fibers based on Winkler foundations. Based on this, the following conclusions have been made:

- 1- Concrete slabs strengthened with synthetic fiber meshes have improved mechanical qualities, strength, and deflection. According to the test findings, fiber meshes not only improve the qualities of concrete slabs but also decrease the breadth of cracks and boost the slab's strength to ultimate failure. These enhancements vary depending on the type of fiber mesh used for strengthening.
- 2- Based on the test results, the use of fiber meshes that bridge the cracks created in the slab during testing greatly boosts the concrete strength because the fiber meshes increase the slab's endurance, which raises the slab's performance during the flexibility stage.
- 3- The presence of strengthened fiber meshes helps reduce crack propagation and growth, particularly in the slab strengthened with carbon fiber mesh, where the percentage increase improvement in load for the first crack appearance reached 51% when compared to the control slab not strengthened with fibers. These fibers also increase the concrete slab's resistance to elastic deformations and tensile stresses.
- 4- Fiber meshes increased the overall toughness of concrete slabs when compared to the control slab, the specimen strengthened with carbon fiber mesh showed the largest increase improvement by 331.8% when compared to the control slab, This was due to the high tensile strength of carbon fibers, which gave a noticeable and high increase to the specimen added to it. The specimen strengthened with polypropylene fiber mesh experienced the lowest increase of the improvement by 22.1% in comparison to the control slab. This was caused by the tensile strength of carbon fibers, which produced a significant and high increase to the specimen added to it.
- 5- According to the test results, there was a notable improvement in the stiffness of the specimens, the percentage increase in the specimens strengthened with glass, polypropylene, and carbon was (44.2, 40.7, and 38.4)% respectively, in comparison to the control slab, while the percentage improvement in the other specimens was equal at 37.2%.

Author Contributions

Mohammed Basheer (M.B.) and Sofyan Ahmed (S.A.) conceived of the presented idea. M.B. developed the theory and performed the computations. M.B. and S.A. verified the analytical methods. S.A. supervised the findings of this work. All authors discussed the results and contributed to the final manuscript.

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