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Using Mortar Infiltrated Fiber Concrete as Repairing Materials for Flat Slabs

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Abstract

This search aims to study and test the effect of using a new material (mortar infiltrated fiber concrete) as repair material in crucial regions that need a special type of repair like (deck of bridges, pavements, and defense structures). This work consisted of three stages: the first stage; testing the engineering properties of slurry infiltrated fiber concrete (compressive, splitting tensile, flexural and bond strengths), by using different types of fibers (End hooked steel fiber, Micro steel fiber, Polypropylene fiber, and Synthetic fiber), in five different types of mortar infiltrated fiber concrete mixes (with a volumetric ratio of fiber 6%), and the age of test was 28 days. After studying the behavior of these mixes in these tests, the second stage of this study was concluded casting reference slab with dimensions 900×900×80 mm from normal strength concrete and repairing two sets of damaged slabs (with dimensions 900×900×50 mm, the first set consist of five slabs damaged in the compression zone, and the second set consist of five slabs damaged in tension zone), the two sets repaired with repair layer from mortar infiltrated fiber concrete with thickness 30 mm. The third stage of the study was testing the effect of the repair material (mortar infiltrated fiber concrete) on the flexural behavior of the repaired slab specimens in (flexural strength, deflection characteristics, and ductility), through using a hydraulic jack with a four-point load system. The results of testing slab specimens indicated significant improvement in the flexural behavior of the repaired slab when compared with the reference slab, the slabs repaired in the compression zone recorded increasing in range 2-39% in ultimate load and the slabs that repaired in tension zone recorded 4-71% increasing in ultimate load .also recorded better deflection values through testing the slabs specimens that repaired. The ductility of the repaired slab specimens increased significantly from 25 to 91% compared with the reference slab specimens. These results indicated excellent effect mortar infiltrated fiber concrete as a perfect repair material for slabs that damaged in compression and tension zones.

Keywords: Mortar Infiltrated Fibre Concrete; Flexural; Repair; Slab; Damage; Deflection; End Hooked Fiber; Hybrid.

1. Introduction

Despite many advantages in using ultra-high-performance concrete, like increasing the compressive strength, the material still brittle, the fibers in general increased the tensile strength plus increasing ductility. The volume of fibers in fiber reinforced concrete ranging from 1 to 3%, due to the problems that initiated from the interlock of high quantity of fibers [1].

Rapid structural failures, which depending on several reasons, necessitated the urgent need to develop a durable material capable of repairing, retrofitting, and restoration workings. As a solution, experimentalists have created mortar infiltrated fiber concrete [2].

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Mortar infiltrated fiber concrete was created in 1979 in the USA, through insertion high amounts of steel fiber in molds to procedure a very compact network of fibers. the Quantities from cement and sand that used generally for making mortar infiltrated fiber concrete are (1:1, 1:1.5 (or) 1:2), Water cement ratio differs between 0.3 to 0.4 Ratio of superplasticizers differs from 2 to 5% from mass of cement. The ratio of fibers by volume can be everyplace from 4 to 20% even though the existing practical ranges from 4 to 12%. In usual fiber reinforced concrete (FRC), where fibers are mixed with other ingredients of concrete, this ratio is limited to about 2% in real workability aims [3]. Mortar infiltrated fiber concrete has a very good potential for use in areas where resistance to impact and high ductility are needed especially in designing the seismic retrofit, in the structures under impact and explosive effects and repair of the structural reinforced concrete element [4]. mortar infiltrated fiber concrete exhibits better spall-reducing performance than normal concrete and other fiber-reinforced [5].

Since the properties like crack resistance, ductility, impact resistance and penetration, are found to be excessive for Mortar infiltrated fiber concrete when compared to other materials; it can be considered as a potential material for use in the following areas [6]: Seismic and Earthquakes resistance by using the precast Mortar infiltrated fiber concrete flexural hinges to advance the seismic resistance of reinforced concrete, it was shown that precast Mortar infiltrated fiber concrete hinges can show better performance than reinforced concrete hinges [7]. Development in rehabilitation and repair of bridge decks/ overlay systems [8] Resist the effect of explosive loading in structures due to its high flexural and high ductility combined with great compressive strength. Mortar also showed excellent resistance to the penetration of projectiles [9], and Mortar infiltrated fiber concrete considered as one of the new concrete technology applications that get increased significance for repairing and retrofitting technique is mortar infiltrated fiber concrete [10]. Douglas (1989) established that new development in rehabilitation and repair of bridge decks/ overlay systems is a unique high fiber volume called mortar infiltrated fiber concrete and its ability to be fabricated in very thin patches, as well as in large huge sections, allow mortar infiltrated fiber concrete to be a workable material alternative in certain applications in which increased strengths and high ductility are needed [8].

Mortar infiltrated fiber concrete can be used in strengthening the compressive zone (Fritz et al., 1993) tested several reinforced concrete beams (rectangular and T-sections) in which a mortar infiltrated fiber concrete matrix was applied and contained 4.3-8.8% of hooked steel fibers. Specimens were tested and a comparison was made created on a ductility index and the deflection. The beams with a mortar infiltrated fiber concrete matrix all failed in a ductile manner. The main advantage appears to be that stirrups can be omitted completely when a mortar infiltrated fiber concrete matrix is used. Moreover, the width of the cracks decreased significantly and was found to be an order of magnitude reduced than in conventional reinforced beams [11].

Kumar (2001) investigated the effect of mortar infiltrated fiber concrete on the flexural response of slabs by testing 14 mortar infiltrated fiber concrete slabs with of size 500×120×25 mm, with a various volume ratio of discrete steel fiber 2.5, 5, 7.5 and 10%. He shows that the inclusion of mortar infiltrated fiber concrete in the specimens can significantly improve its flexural strength. Furthermore, a reduction in crack width with a large number of cracks is observed in specimens contain SIFCON compared to control specimens [12].

Hameed et al. (2019) investigated some of the mechanical properties of Mortar infiltrated fiber concrete and its role in improving the suitable life of normal concrete by testing a composite section of normal concrete and Mortar infiltrated fiber concrete mix, through using the volumetric ratio of 6% from hooked end steel fiber and dissimilar thicknesses of Mortar infiltrated fiber concrete in the layer, the results revealed that the flexural strength of Mortar infiltrated fiber concrete was greater than four times the reference mix and the results showed that the rise of thickness for the layer of Mortar infiltrated fiber concrete would improve the mechanical properties of the composite section [13].

Repairing structure can be represented as a three-stage composite structure: substrate, overlay, and bond region, the bond region need be accomplished for repelling the stresses on the structure [14]. Exclusive problems in the concrete slabs in the construction and the repair; due to their various uses and the conditions that contact with the concrete slabs. When these problems are predicted and reflected before the construction, then using the slab along with service life [15]. Due to the lack information about using mortar infiltrated fiber concrete as a repair material for defected flat slabs, this research study the mechanical properties for mortar infiltrated concrete and using it in repair damaged slabs under four-point load. This research consists of the theoretical aspect in terms of the study of the mortar infiltrated fiber concrete and its mechanical properties as well as the practical aspect in terms of casting, repairing the damaged specimens with mortar infiltrated fiber concrete, then testing the specimens under four-point load to study the effect of repairing.

2. Experimental Work

The experimental work includes initialization and test of raw materials and making trail mixes right up to the required mix of normal concrete and mortar, after that eleven slab specimens were cast for the purpose of test them and studying the effect of using mortar infiltrated fiber concrete, as shown in the following flowchart Figure 1.

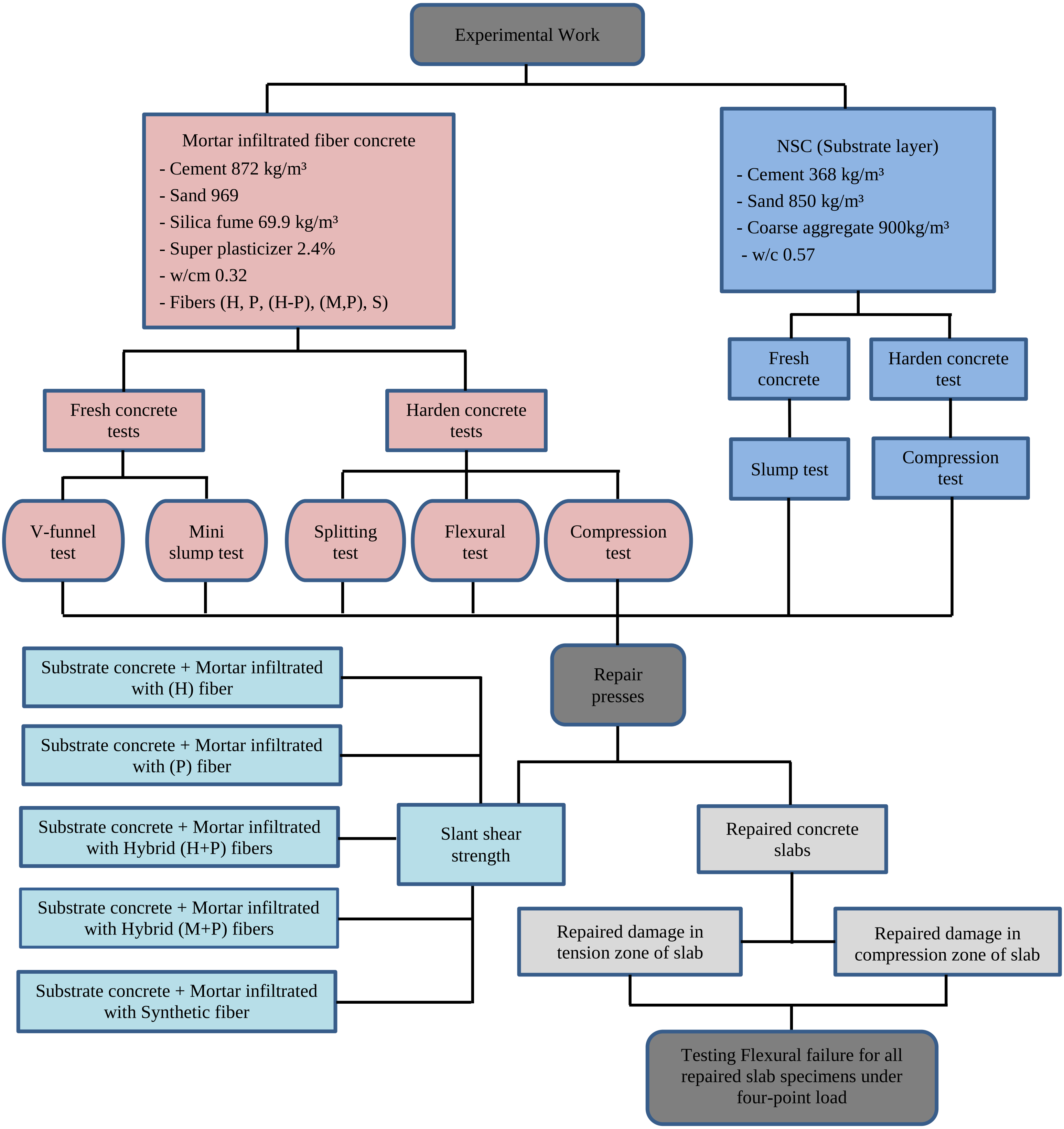

Figure 1. Flow chart of the experimental programs

2.1. Materials used for Casting Substrate Layer for Slab Specimens (Normal Strength Concrete)

The normal strength concrete was design according to the (ACI Committee 211.1-91) [16]. The target concrete strength f'c was 25 MPa.

- The cement used the Portland limestone cement (CEM II/A-L- 42.5 R) factory-made in Iraq named (Karasta), that cement act in accordance with the (EN 197-1:2011) (EN, 2011) [17].

- Natural local sand follows to the limits of Iraq specification (IQS No.45/1984) [17], Zone (2). Figure 2 shows the grading curve of the natural sand after sieving.

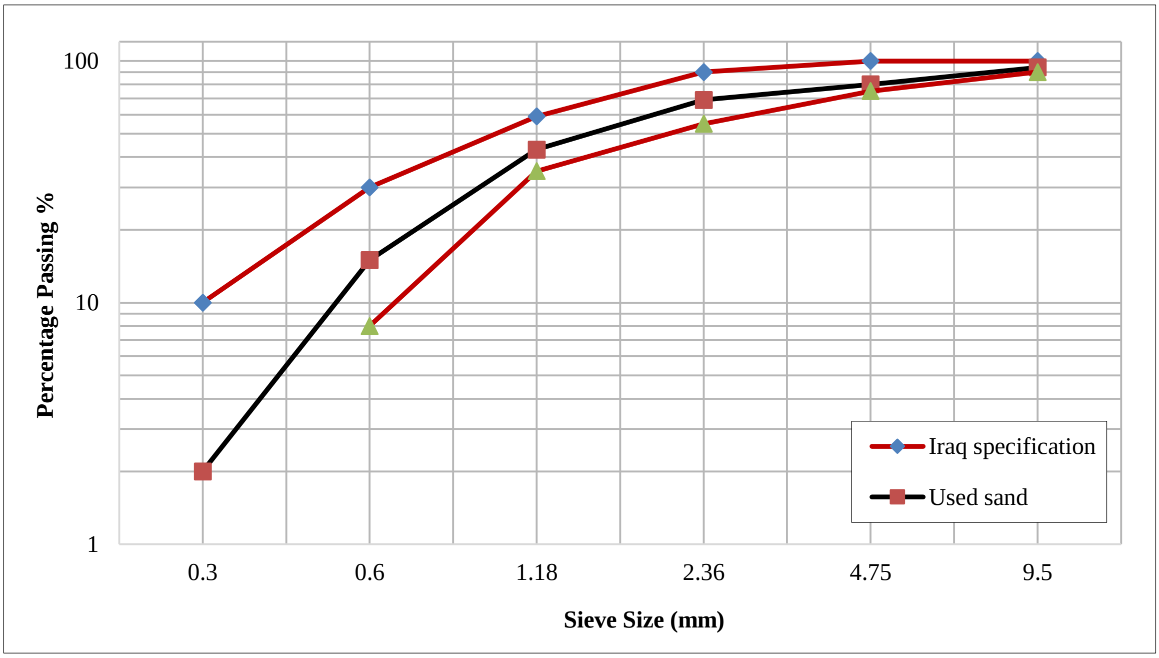

Figure 2. Grading curves for fine aggregate

- The coarse aggregate used was natural rounded gravel with maximum size of 10mm as shown in the grading curve. Mechanical and chemical properties meet the requirements of (ASTM C33 /86) [18]. Figure 3 shows the grading curve of the natural gravel.

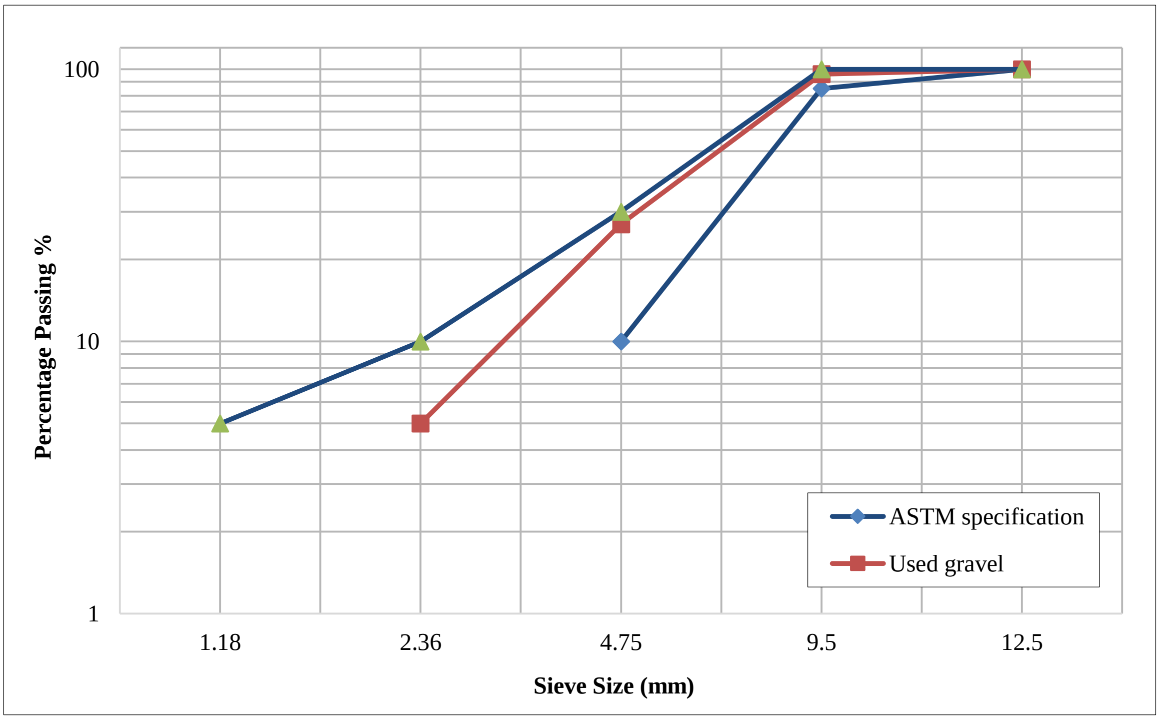

Figure 3. Grading curves for coarse aggregate

- Deformed steel bars were used as flexural reinforcement for NSC slabs specimens. For slabs (reference and that repaired with mortar infiltrated fiber concrete in compression face, bars with 6 mm diameter was used in tension zone thickness of layer 50 mm, also 4 mm diameter deformed steel bars were used in compression zone thickness of layer 30 mm, while for slab that repaired with mortar in tension face, bars with 4 mm diameter was used in tension zone thickness of layer 50 mm, also 6 mm diameter were used in compression zone thickness of layer 30 mm. steel reinforcement bars tested according to ASTM A615 [19] and the results given in Table 1.

Table 1. Test results of steel reinforcement bars used

Nominal diameter (mm)	Measured diameter (mm)	Yield stress* (MPa)	Ultimate Strength (MPa)
6	5.75	560	607
4	3.89	415	599

2.2. Materials Used for Casting Repaired Layer for Specimens

- The cement used in mortar infiltrated fiber concrete was the same type that used in item.
- Extra fine sand (Natural sand taken from Al-Ukhaider in Iraq), it has to be small enough to ensure whole access through the dense steel fiber devoid of congestion and which was sieved through (600 µm sieve), Zone (3) [17]. Figure 4 shows the grading curve after sieving process.

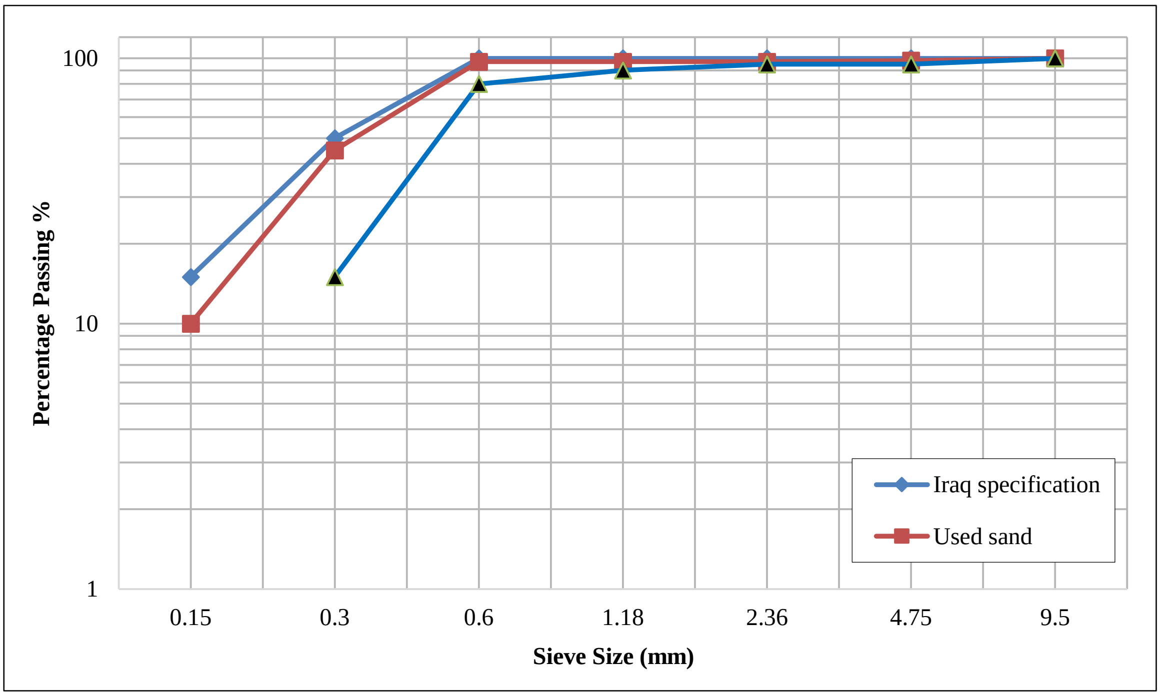

Figure 4. Grading curves for extra fine aggregate

- High range water reducing admixture was needed to advance the flowability of the Mortar infiltrated fiber concrete which is branded commercially as (Hyperplast PC200) from (DCP) company was used as a HRWR and it is freed from chlorides and conforms with (ASTM C494 / C494M, 2017) [20].
- Micro Silica Fume (SF), it can reveal both pozzolanic and cementitious possessions, its particle size ranges from 0.1 to 1 µ m, it improves the microstructure of the cement and makes it more confrontation to any type of exterior effect, which is known as Mega Add MS (D) from (CONMIX), and the (SF) used in this study obeys to the requirement of (C1240) [21], and Drinkable tap water free from pollutions used in the mix of concrete.

2.3. Fibers used in the Work

The first type of fiber was End hooked steel fibers; the hooked fiber was provided from JATLAS in Turkey. The second type of fiber was Synthetic fiber. This type of fiber was supplied from the Sika Company in Zurich, Switzerland. The third type was macro polypropylene fiber (twisted polypropylene), the polypropylene fiber was supplied from FORTA CONCRETE FIBER in the U.S.A. The fourth type was (micro steel fiber), this type of micro steel fibers was manufactured by the (Guangzhou Daye Metallic Fibers Co., Ltd, China). The fourth types of fibers following the ASTM A820/A820M-04 [22]. Figure 4 shows the fourth type of used fibers. And the physical and technical properties for the fibers used in this study were listed in Table 2.

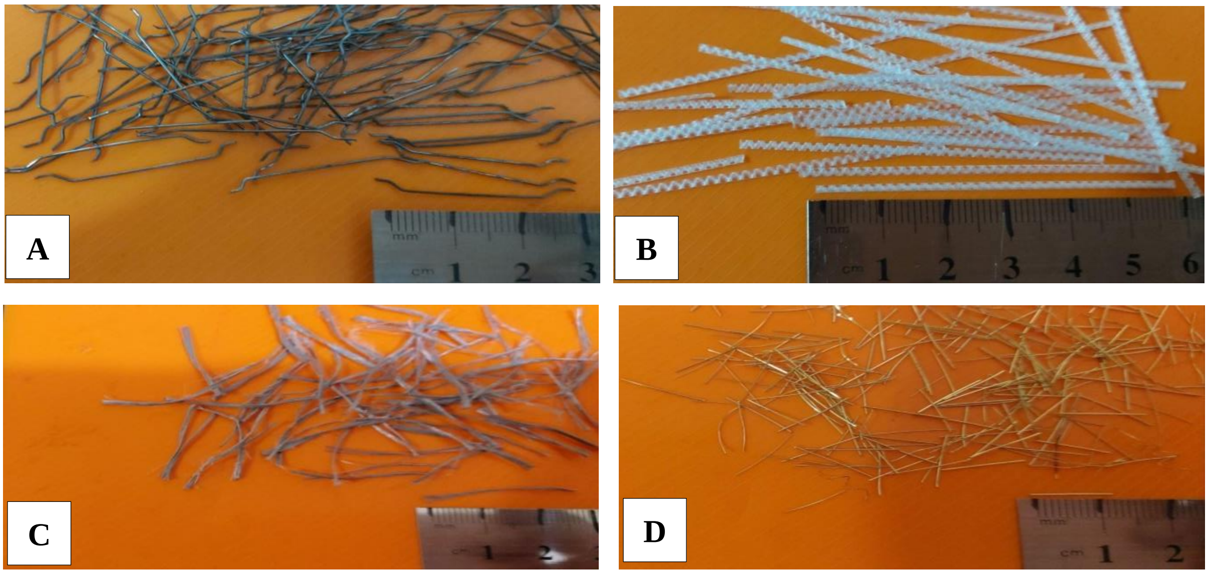

Figure 5. The fibers used: A) End hooked steel fiber, B) Synthetic fiber, C) Polypropylene fiber, and D) Micro fiber

Table 2. Physical and technical properties of fibres used in this study

Description	Results of End Hooked fibre	Results of Synthetic fibre	Results of Micro steel fiber	Results of polypropylene fiber
	Deformed shape	Deformed shape	Straight steel fiber	Twisted-bundle monofilament fiber
Appearance	Bright and clean wire	White fibre	Brass coated	Grey colour
Length (l), mm	30	60	13	27
Diameter (d), mm	0.5	0.84	0.2	0.27
Aspect ratio (l/d)	60	71.42	65	100
Density (kg/m^3)	7800	910	7825	910
Tensile strength (MPa)	1100	430	2400	(570-660)

- Tap water was used for making and curing of concrete specimens in the investigational work of this research. The temperature of water was maintained was 25±2 °C.

2.4. Mix Proportions

2.4.1. Mix Proportions for Normal Strength Concrete (NSC) for Substrate Layer for Slab Specimens

According to the mix design, the quantities of materials used were in unit (kg/m^3): 368 for cement, 900 for Gravel, 850 for Sand, 208 for water and the W/c ratio was 0.57.

2.4.2. Mix Proportions for Mortar Infiltrated Fiber Concrete

Since there is not any standard specification for mortar infiltrated fiber concrete mix design yet; many trail mixtures were carried out to find a proper mix that has the optimal possessions in the fresh state concerning viscosity, fluidity, and filling ability without bleeding and segregation in the fiber system that causes a decrease in mechanical properties of mortar infiltrated fiber concrete. The literature review findings, relieved in the design of mortar infiltrated fiber concrete mixes. It can be seen that the percentage of (sand: cement) by weight in utmost cases is equal to 1:1, so this value was accepted in this study. Used cement content range starting 800 to 1000 kg/m^3 and suggested using W/C ratio below 0.4 (by weight) for the production of the mortar matrix. Therefore, after many trails, ordinary Portland cement of (872) kg/m^3 content was used in this search, while the water/binder ratio was saved constant as 0.32 (by weight). In this research fibers were used in five different mixes with a different volumetric ratio of the fiber as listed in Table 3.

Table 3. Mix proportions for mortar infiltrated fiber concrete used in this study

Mix symbol	The Description	Proportions of mix (kg/m³)						
		Fiber used	Cement	Sand	Water	Silica Fume 10% rep.	W/b	Super Plasticizer by wt. of Cementious (%)
H	End Hooked fiber with Vf 6%	471.9	872.1	969	471.9	96.9	0.32	2.4
H.P	Hybrid (End Hooked fiber with Vf 3% + polypropylene fiber with Vf 3%)	235.95 + 27.3	872.1	969	471.9	96.9	0.32	2.4
M.P	Hybrid (Micro steel fiber with Vf 3% + polypropylene fiber with Vf 3%)	235.95 + 27.3	872.1	969	471.9	96.9	0.32	2.4
P	Polypropylene fiber with Vf 6%	54.6	872.1	969	471.9	96.9	0.32	2.4
Y	Synthetic fiber with Vf 6%	54.4	872.1	969	471.9	96.9	0.32	2.4

2.5. Casting of Specimens

2.5.1. The Casting of Specimens for Testing Mechanical Properties of Mortar Infiltrated Fiber Concrete

Steel molds were used to study the properties for each mix of mortar infiltrated fiber concrete, before casting each mixture; the molds were washed and oiled to prevent linkage between concrete and molds. Casting the samples was carried out according to (three-layer technique) which involved initial placing and packing of the fibers in the (cylinder, cube, and prism) molds only up to a one-third depth of the mold, followed by infiltration of the mortar up to this level, the contents were then vibrated. The process was repeated until the entire mold was filled and compacted in three layers to cover the fibers in this layer and compacted by hand by using compacted stick mortar. After finishing the casting process, leveling the surface by using a steel trowel and left for 24hrs in the laboratory and after 24hrs was removed from the mold and cured 28 days in the natural water chamber.

2.5.2. The Casting of Specimens for Testing the Bond of Mortar Infiltrated Fiber Concrete

The specimen was a composite cylinder with dimensions 75×150 mm that had a slant elliptical surface inclined with angle 30˚ from the vertical axis used with plastic molds. If the angle greater than30˚, test results as a compressive strength test since the compressive component have more effect [14]. The plastic molds were cleaned and oiled, then cylinder wood was inserted inside plastic molds, after casted normal strength concrete in layers, each layer should be compacted by stick compaction to reduce air voids, then levelled the surface by using a steel trowel and left for 24hrs in the laboratory. Concrete specimens after 24hrs were removed from the molds and treated for 28days in the tap water chamber. After 28 days, the specimens take it out of the water then left a period to get specimens saturated and surface dry. The inclined surface was roughing by a screwing to make groves [23], then insert these concrete specimens in the molds again and cast by overlay different types of Mortar infiltrated fiber concrete used in the study. Figure 6 shows the preparing for slant shear test.

Figure 6. Preparing for slant shear test

2.5.3. Casting Slab Specimens

Casting the slab specimens done in two stages: the first stage casting the (NSC) as substrate layer and the second stage casting the mortar infiltrated fiber concrete as repair material (overlay layer). For all slabs (control and repaired), after finishing the process of preparation of the molds, the steel reinforcement was placed in the mold (and circular plastic spacers with a size 15 mm were used.

For the reference specimen; (Slab with dimensions 900×900×80 mm, reinforced with (6 mm diameter in the tension zone and 4 mm diameter in the compression zone), after completion of the casting process with NSC, the surface of the specimen is leveled and left to harden for 24 hours. then, the slab specimen was removed from the mold and cured for 28 days by covering the surface of the slab with wet burlap. For the remaining slabs, the procedures can be classified according to the two sets of the slabs.

2.5.3.1. Casting Set 1 (Slabs that Damaged in Compression Zone)

The same preparation of the reference slab, the reinforcement with (6mm diameter in the tension zone with a thickness of 50 mm) cast with NSC, and the surface of the specimen are leveled and left to harden for 24 hours. After 24hours, slab specimen was removed from the mold and cured for 28 days, After the curing time was finished, the slabs lifted period to get slabs surface saturated and surface dry, the surface was roughing by a screwing to make groves, then the surface reinforced with (4 mm diameter with thickness 30 mm) cast with mortar infiltrated fiber concrete as layers to ensure infiltrating the mortar through the fibers.

2.5.3.2. Casting Set 2 (Slabs that Damaged in Tension Zone)

The same preparation of the reference slab, the slab reinforcement with 4mm diameter in the compression zone with a thickness of 50 mm cast with NSC. After the curing time was finished, the slab surface saturated and surface dry, the surface was roughing by a screwing to make groves, then the surface reinforced with (6 mm diameter with thickness 30 mm) cast with mortar infiltrated fiber concrete as then cured for 28 days. Figure 7 shows preparing the surface of the substrate layer of the slab specimen (made groves).

Figure 7. Preparing the surface of the substrate layer of the slab specimen (made groves)

2.5.4. Description and Identification of the Tested Slabs Specimens

To facilitate the comparison between the slabs, each slab specimen is identified by symbols. Slab specimens casting with NSC only were tested as reference specimens. The other slabs that were repaired with mortar infiltrated fiber concrete according to the zone of damage. The present study consists of three parts: first part refers to the type of the specimen, the second part refers to the fiber/fibers used and the third part refers to the location of the repaired zone. Table 4 shows the identification of the slab specimens.

Table 4. Identification of the slab specimens

Symbol	Discription of the slab	Symbol	Discription of the slab
N	Cast with only NSC (No fiber) (80 mm thickness)		
	Set 1		Set 2
S-H-C	50 mm NSC in tension zone + 30 mm (H) mix. in compression zone	S-H-T	50 mm (H) mix. in tension zone + 30 mm NSC mix. in compression zone
S-H.P-C	50 mm NSC in tension zone + 30 mm (H.P) mix. in compression zone	S-H.P-T	50 mm (H.P) mix. in tension zone + 30 mm NSC mix. in compression zone
S-H.P-C	50 mm NSC in tension zone + 30 mm (M.P) mix. in compression zone	S-H.P-T	50 mm (M.P) mix. in tension zone + 30 mm NSC mix. in compression zone
S-P-C	50 mm NSC in tension zone + 30 mm (P) mix. in compression zone	S-P-T	50 mm (P) mix. in tension zone + 30 mm NSC mix. in compression zone
S-Y-C	50 mm NSC in tension zone + 30 mm (Y) mix. in compression zone	S-Y-T	50 mm (Y) mix. in tension zone + 30 mm NSC mix. in compression zone

2.5.5. Test Methods

2.5.5.1. Compressive Strength Test

This test was agreed to BS1881-116 using 100 mm cubes tested at age 28 days for mortar infiltrated fiber concrete specimens, and 150 mm cubes for normal strength concrete. The specimen was loaded uniaxially by the universal compressive machine type CONTROLS, the loading rate was applied at (0.3 N/mm^2 per second) according to BS.1881: part 116. The average of three cubes was recorded for each variable in this test [24].

2.5.5.2. Flexural Strength (Modulus of Rupture)

This test was agreed by ASTM C1609-12(61), beams with dimensions 100 ×100 ×40 mm tested at age 28 days while recording the average of two specimens under two-point loads with a constant rate of loading about 0.015 Mpa/sec. The average of three prisms was recorded for each flexible in this test [25].

2.5.5.3. Splitting Tensile Strength

The indirect tensile strength test is carried out on mortar infiltrated fiber concrete specimens by ASTM C496-79. Tests are made on specimens 150×300 mm cylinders, after curing the specimens by immersion in a water tank inside the laboratory for 28 days and an average outcome of two samples. The loading rate was applied at o.3 MPa per second. The average of three cylinders was recorded for each variable in this test [26].

2.5.5.4. Bond Strength Test

Cylinders were made according to ASTM C882-05 an average outcome of two samples was tested according to ASTM C39-14 at 28 days by a digital hydraulic compression machine with a capability of 1900 KN and rate of load 0.3 kN/sec.

2.5.5.5. Test Flexural Behavior of Slab Specimens

Slab specimens must prepare to test before the testing day, the wet burlap on the surface of slabs was removed, the slabs were washed and highlighted with white paint on together surfaces, to achieve perfect visibility of cracks during testing. The slabs were characterized and carefully located along the edges on simple supports. All slabs were tested in a universal testing machine with an ability of 400 KN under monotonic load up to the ultimate load. Some modifications were made to the machine to fit the ceiling model's slabs specimen. The instrumentations used were Dial gauges with accuracy 0.01mm with interval 30mm were put downward of slabs, four cameras were used, three of them were oriented towards dial gages to record the motion of the dial gauges, this motion was used to compute deflection value. The rest cameras were put toward the load device to record it. The recorders were used to draw the stress-deflection diagram, and Crack meter to measure the width of the crack in the surface of the tested slabs.

2.5.5.6. Loading and Support Condition

All slabs were tested until failure occur as simply supported slab by using four of (roller hinge) with 20 mm diameter. Bearing steel plate of 90×90×25 mm was inserted between the steel roller and concrete, to avoid local failure at the loading points and supporting, and a piece of rubber in the bottom of the steel bearing plate. All slab specimens were tested under four concentrated loads at the center for each case. Then, recording the initial reading of the deflection due to self-weight between strain gauges. Loaded the slabs with a constant rate of loading about 0.05 KN/sec, loads will be increased with similar increments, the deflection was recorded at each increment of loading in addition to record the first crack load and load at failure, cracking patterns and the failure mode was checked visually, then photos were taken to the specimens crack. Figure 7 shows the universal machine, four roller hinge, cameras, and dial gauges used in slab specimens testing.

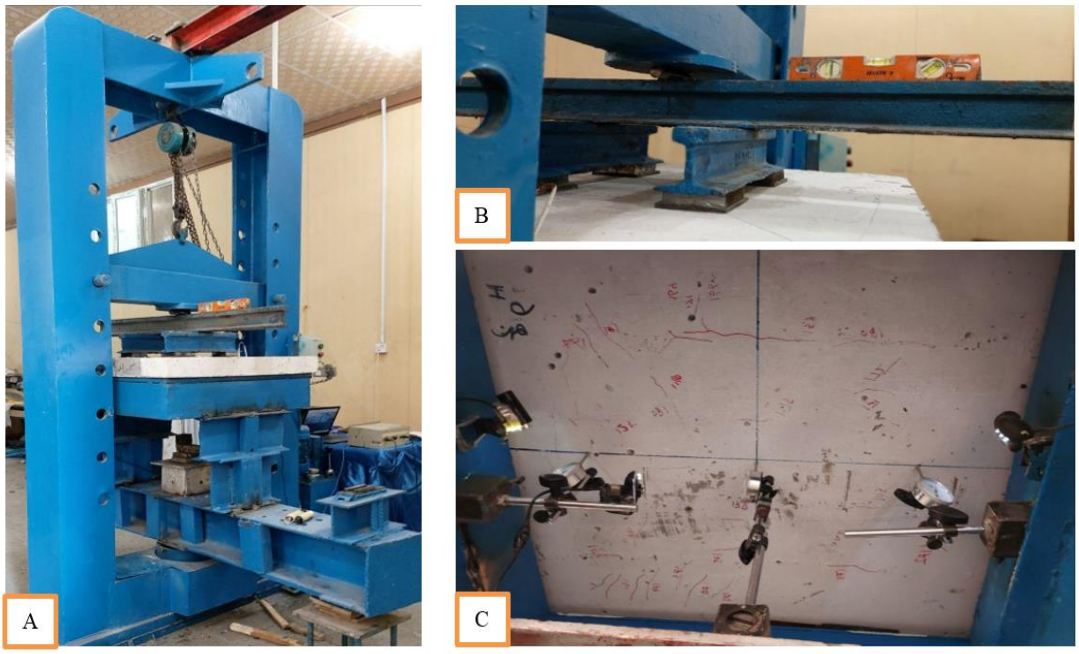

Figure 8. A) Universal machine, B) Four roller hinge, C) Dial gauges and cameras used in test

3. Results and Discussion

3.1. Results of Testing Mortar Infiltrated Fiber Concrete Specimens

The result of compressive strength, splitting tensile strength, flexural strength and Bond Strength of mortar infiltrated fiber concrete are tabulated in Table 5.

Table 5. Summary of compressive strength, splitting tensile strength, flexural strength and Bond Strength for Mortar infiltrated fiber mortar mixes tests values.

Item	Average compressive strength (N/mm²)	Average Splitting Tensile Strength (N/mm²)	Average flexural strength (N/mm²)	Average Bond Strength (N/mm²)
0% Control	41.6	5.2	14.5	9.6
H-F6	92.9	15.6	40.13	14.4
H.H-F6	68.3	9.6	20.5	15.9
H.M-F6	80.84	10.2	30.8	16.2
P.P-F6	66.92	5.8	16.74	15.2
S-F6	61.5	8.7	16.7	14.3

From Table 5, it is observed that the compressive strength increased in range 48-123% comparing with control specimen, the splitting tensile strength increased in range 12- 200%, flexural strength increased in range 15-176% and the mortar infiltrated concrete specimens enhanced bond strength in the range 49-69%. most of the highest results obtained when using End hooked fiber (as single fiber or as combined with polypropylene fiber), this is due to that steel fiber has high elastic modulus and tensile strength, which are needed fiber properties for guiding crack width as well as growing tensile, flexural and compressive strength in concrete [27]. Steel fibers increase the characteristics of cement-based matrices in the hardened state; they can bond cracks, spread stress across a crack, and counteract crack growth [28]. the pull-out peak load increased with the increase in the embedded length of steel fiber, the peak load of hooked-end steel fibers was higher than those of smooth steel fibers and bonding toughness of hooked-end fibers increased much more than those of smooth steel fibers A high value was obtained for almost tests that carried on mortar infiltrated fiber concrete mixes [29]. The other types of fibers show good results when comparing to the control specimen and could use them in many applications as low cost of them when comparing to steel fiber and according to easy to get them in the different countries.

3.2. Results of Testing Slab Specimens

The test results of these slabs involved the first crack load, ultimate load, load deflection curves, ductility and crack pattern as well as mode of failure data are presents in Table 5.

Table 6. Results for slab specimens testing

	Slab specimen type	First seen crack load (KN)	Ultimate load (KN)	Increase in ultimate load %	Ultimate deflection at mid span (mm)	Ductility index μ Δ	Mode of failure
Set 1	N	28	120.42	-	13.67	1.2	Flexural
	S-H-C	36	167	39%	4.90	1.67	Flexural
	S-H.P-C	33	140	16%	12.98	2.3	Flexural
	S-M.P-C	30	123	2%	13.50	1.76	Flexural
	S-P -C	29	127.54	6%	12.61	1.5	Flexural
	S-Y-C	30	123.18	2%	12.95	1.42	Flexural
Set 2	S-H-T	105	199	65%	8.33	1.65	Flexural
	S-H.P-T	110	207	71%	16.02	1.88	Flexural
	S-M.P-T	46	125.4	4%	12.24	1.74	Flexural
	S-P-T	45	199	65%	18.33	2.08	Flexural
	S-Y-T	80	147.56	22%	10.75	1.5	Flexural

In this study, eleven slab specimens were cast and tested, the first was the reference slab (N) while the rest of the slabs as repaired slab specimens with mortar infiltrated fiber concrete with a 6% volumetric ratio of fibers. The four-point load test is applied to the reinforced concrete slab specimens and investigations have been carried out at room temperature and as per standards.

The load-carrying capacity revealed the ultimate applied load that can be exposed to the tested slab specimens. After that, a descent in machine reading appeared with a quick deformation on the slab, which named as a load failure. The growth of cracks and the period at which they appeared spread in all slab specimens were noticed through testing to measure the behavior of the mortar infiltrated fiber concrete slab specimens.

The first crack load refers to the load where the first signs of cracking occur on the side of the test specimen. The cracks were patent with a colored marks pen indicates the partition of evolution in the path of failure from the beginning of loading up to failure, then photos were taken to the crack pattern. At greater loads, more flexural cracks were formed gradually and extended as the loading increase. To investigate the effect of repairing with mortar infiltrated fiber concrete on the load-carrying capacity and other characteristics of slab specimens, the behavior of mortar infiltrated fiber concrete slab specimens and reference slab specimen need be studied and shortened as follows:

3.2.1. Compression Zone (Set 1)

From Table 6, it can be observed that all the repaired slab specimens show the highest first crack load than the reference slab specimen. Among the repaired slabs, the (S-H-C) specimen was recorded the highest first crack load of 36 KN, this is mainly due to the high steel fiber content presented in this slab. The percentage increment of first crack load in repaired slab specimens, when compared with (N slab), was in the range of 3.5 to 28.5% for different repaired slabs. For the ultimate load, it can be observed that the maximum ultimate load of 167 KN has been obtained from (S-H-C), slab. The ultimate load of the repaired specimens was 2 to 39% higher when compared to (N slab).

Three from repaired slabs (S-H.M-C, S-P-C, and S-Y-C) recorded ultimate load close to the ultimate load of (N slab) as 122, 127.92, and 122.18 respectively. The results of central deflection values for different slab specimens are presented in Table 6. It can be observed from this Table that the central deflection of all repaired slab specimens is less when compared to (N slab) at any given load. This is due to the increased stiffness of repaired slabs. The maximum deflection of 13.5 mm is observed for (S-M. P-C) slab, which is highest than other repaired slabs. The enhancement of the value for the repaired slabs was in range 1.5-64%. From this, it is observed that the repaired slab specimens have quite well over the (N slab). The maximum deflection was 13.5 mm observed for (S-M. P-C) slab, which is highest than other repaired slabs. The enhancement of the value for the repaired slabs was in range 1.5-64%. From this it is observed that the repaired slab specimens have quite well over the (N slab). Crack patterns of different slabs. The crack patterns were almost similar in all the repaired slabs while conducting the study, it is observed that the first crack originated at the points load on the tension face of slabs. The failure of repaired slabs was very gradual and the slabs were intact even after ultimate load reached, the propagation of cracks was observed to be fast in (N slab) specimen. The crack pattern in repaired slabs of the testing consisted from four trapeziums and one rectangle, similar observation can be made even for (N slab). Slight cracks have propagated from bottom face to top face of some repaired slabs when the load exceeds 100 KN on the slab specimens. Figures 9 to 14 show the load-deflection curve and crack pattern of the (N slab) and repaired slab specimens in set 1.

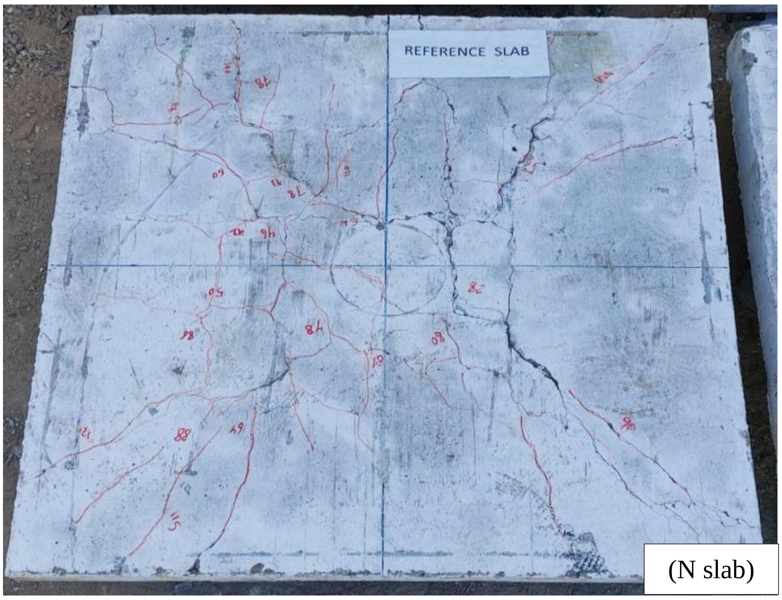

Figure 9. The final shape for (N slab) specimen shows the crack pattern and flexure perimeter

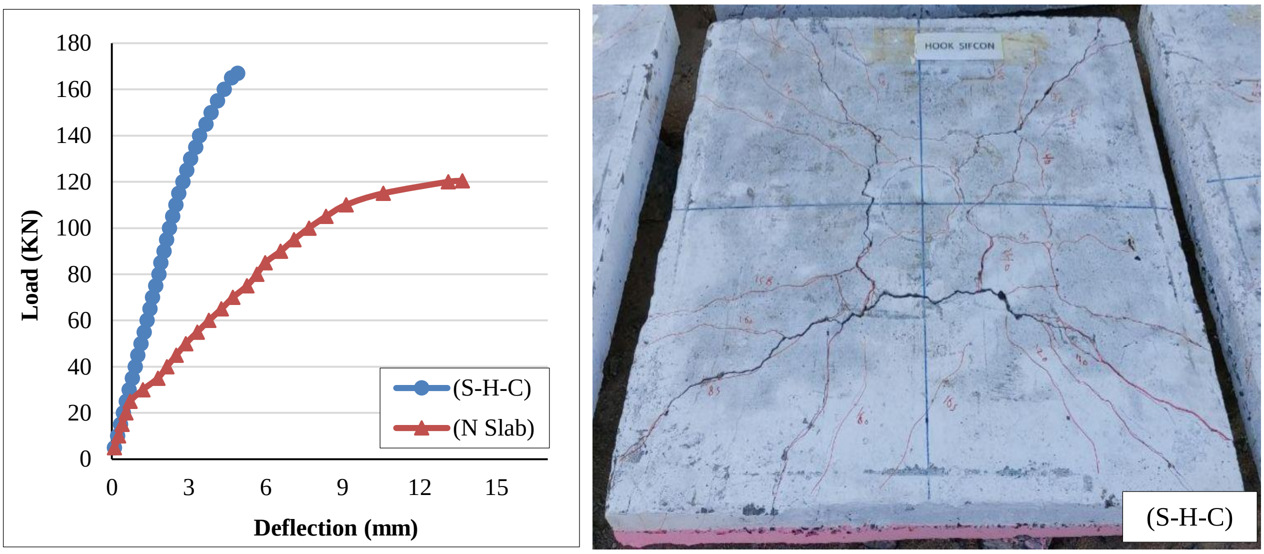

Figure 10. Load- Deflection curve compared with (N slab) and the crack pattern for the (S-H- C) slab

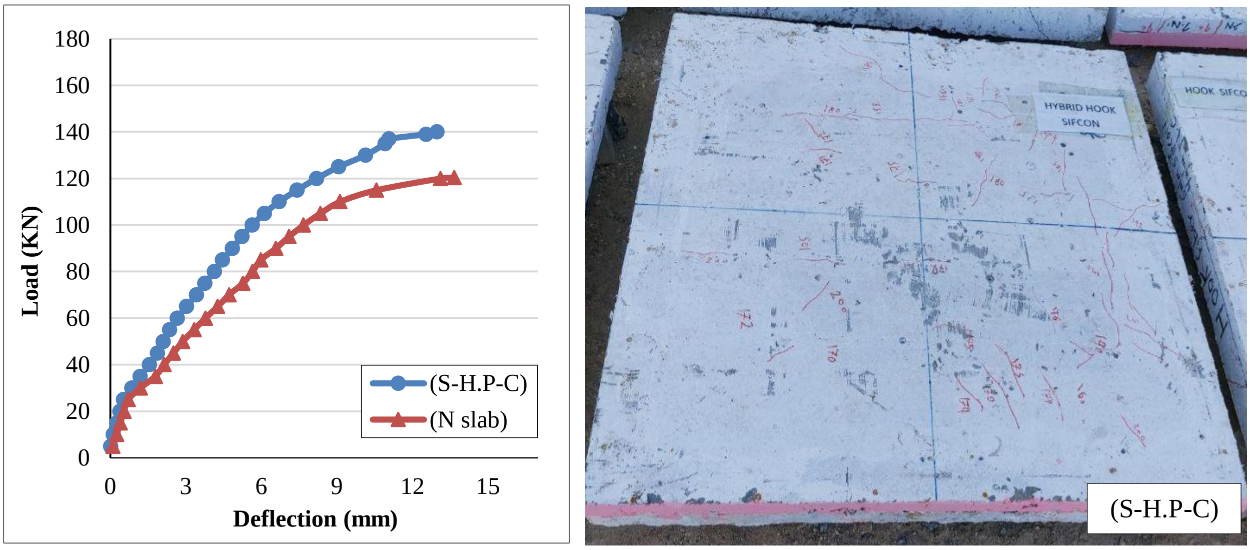

Figure 11. Load- Deflection curve compared with (N slab) and the crack pattern for the (S-H.P- C) slab

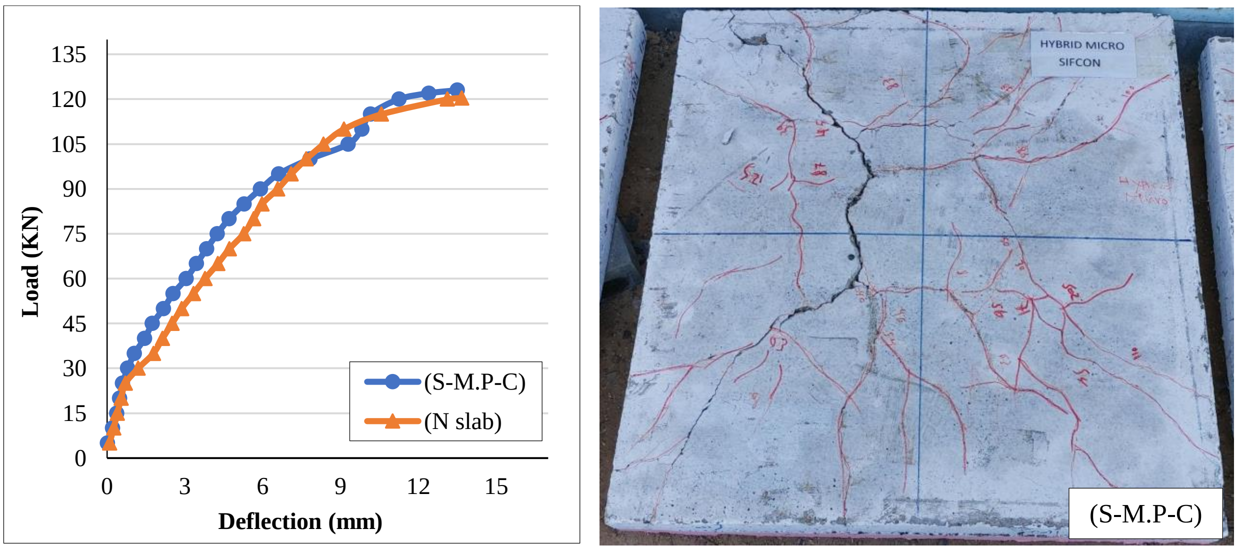

Figure 12. Load- Deflection curve compared with (N slab) and the crack pattern for the (S-M.P- C) slab

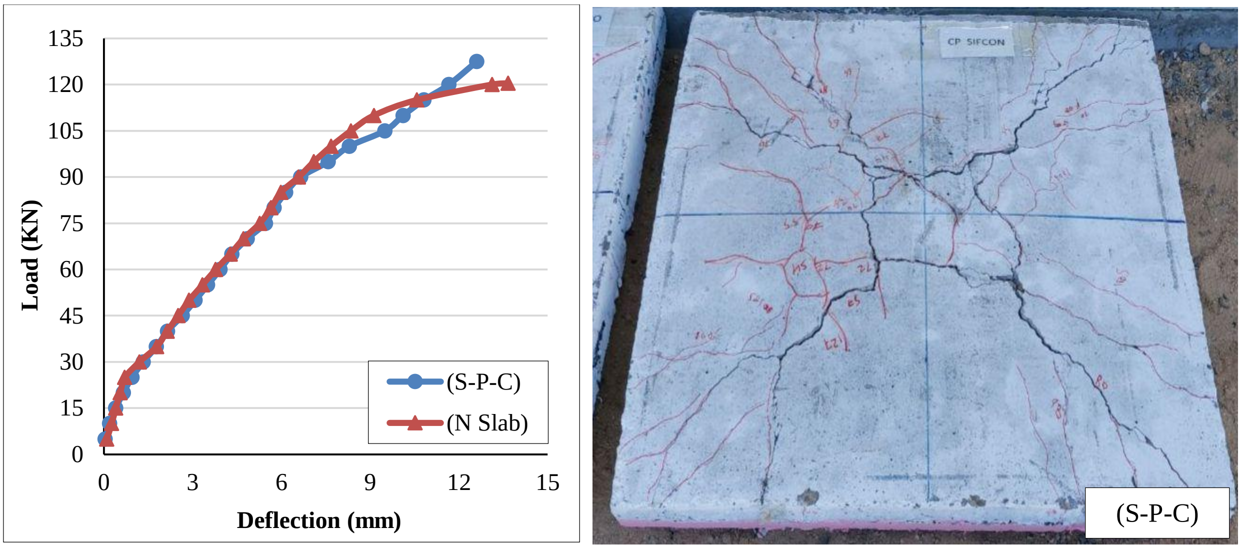

Figure 13. Load- Deflection curve compared with (N slab) and the crack pattern for the (S-P- C) slab

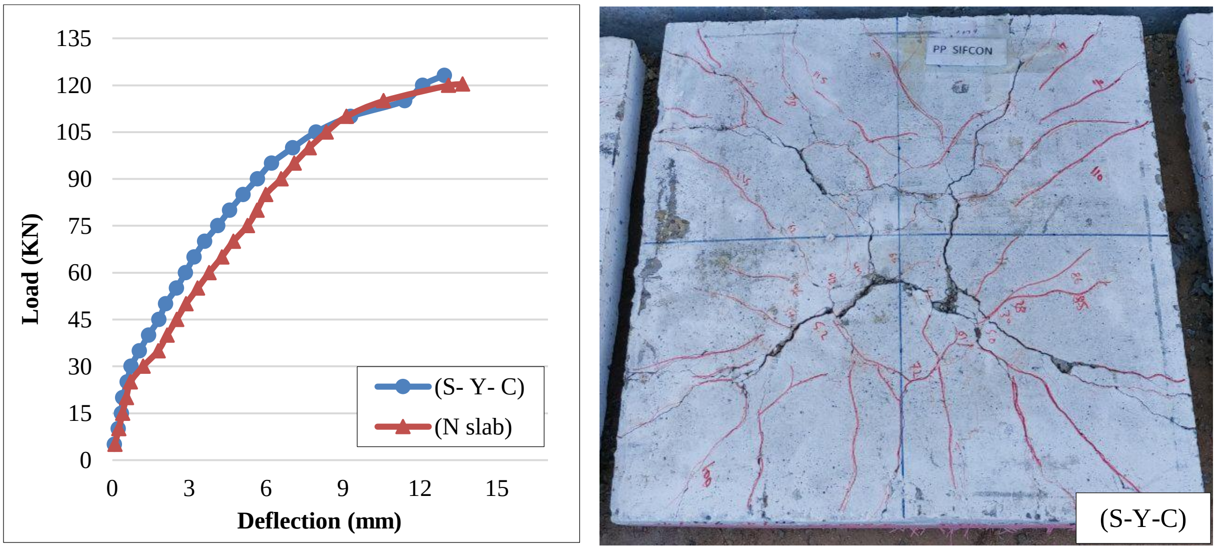

Figure 14. Load- Deflection curve compared with (N slab) and the crack pattern for the (S-Y- C) slab

3.2.2. Tension Zone (Set 2)

From Table 6, it can be observed that the reference slab (N slab) recorded lower first crack load 28 KN than repaired slabs; due to the absence of fibers that arrest the formation of cracks, while the repaired slabs recorded first crack in range of 45-110 KN, the percentage increase of first crack load in repaired slabs in this set when compared with first crack load in (N slab) specimen, with increment increase in the range of 60 to 292%.

Among the slab specimens, the (S-H.P-T) slab, recorded first crack load of 110KN, which is the highest among all the specimens; this could be due to higher volume fraction of steel fiber presented in this slab, with increment increase of range 292% and there was similarity between the first crack load of (S-H-T) slab was 105 KN and (S-H.P-T) slab, this similarity indicated the strong effect of steel fiber in arresting formation cracks failure in slab specimens. slight effect of polypropylene fiber in flexural strength when combined with steel fiber in (S-H.P-T) slab, this action of polypropylene fiber seems clearly with first crack load of (S-P-T) slab specimen that recorded (45 KN) and ultimate load deflection of 199 KN.

It can be observed that all repaired slabs recorded ultimate load higher than the ultimate load of (N slab), due to result of fiber in arresting and bridging the cracks on the face of the slab tested, with increment when compared to (N slab) was 4-72%. Three of the repaired slab specimens had recorded convergent results of ultimate load (S-H.P-T) slab, (S-H-T) slab and (S-P-T) slab as 207, 199 and 199 KN, while the lowest results recorded with (S-M.P-T) slab.

The central deflection of repaired slabs was less when compared to the reference slab specimen at any given load, this is due to the increased stiffness of repaired slabs. The maximum deflections were observed in (S-P-T) slab and (S-H.P-T) slab specimens as 18.33 and 16.02 mm respectively, which were higher than the (N slab) specimen that recorded 24.05 mm deflection, this results were normal according to the high first crack load and high ultimate load that regards (S-H.P-T) slab. It is important to mention that at the first crack load, the (N slab) specimen show a deflection of 0.05 mm, while the specimen (S-H.P-T) slab recorded the 0.01mm which is considered lowest than all repaired slabs in this set. It is observed from the Table 6, that all repaired slab specimens (repaired and reference slabs) have the same failure mode (flexural failure mode), and this mode proved the excellent reinforcement that used in reinforced the slab specimens that prevent another failure mode like bunching shear failure mode that happened suddenly.

3.2.3. Cracking and Failure Pattern

It can be seen that the crack pattern is not similar in all mortar infiltrated fiber concrete slab specimens in this set due to effect of different fibers used in the study. It is observed from test results many indications of the behavior of tested slab specimens, for the repaired slab specimens, flexural failure happened and the cracks firstly formed from the point loads on the tension face of the slabs and exuded to the edges.

When loading continued, the cracks lengthways the diagonals extended with additional slight cracking starting at positions near the older cracks. At higher loads, further flexural cracks were formed progressively and widened, then the failure occurred and the peak load recorded as the ultimate load, crack propagation of mortar infiltrated fiber concrete presents irregular multi crack phenomenon and the density of crack increase with the growth of fiber content conspicuously. Figures 15 to 19 show the load-deflection curve for the slabs in this set compared with (N slab), also crack pattern of the slab specimens. One can be seen from Figure 15, which the load on the slab increased normally while the deflection increased very slowly at some points on the curve; this act attributed to distribution of the fibers used in the slab specimen more homogenous and behaved as reinforcement that led to significant increase in strength of the slab specimen.

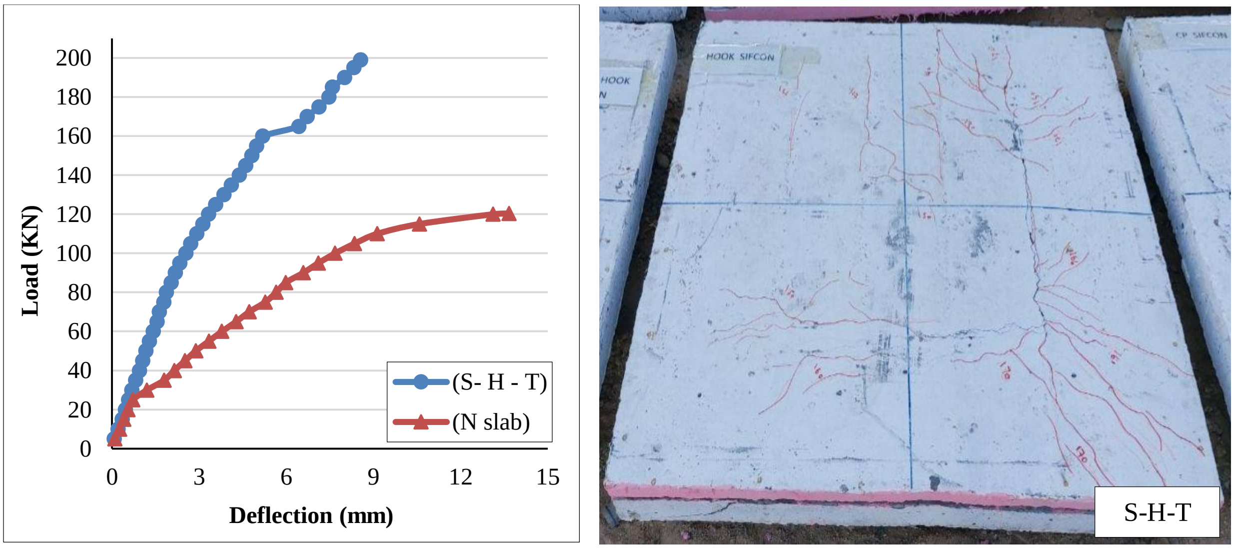

Figure 15. Load- Deflection curve compared with (N slab) and the crack pattern for the (S-H-T) slab

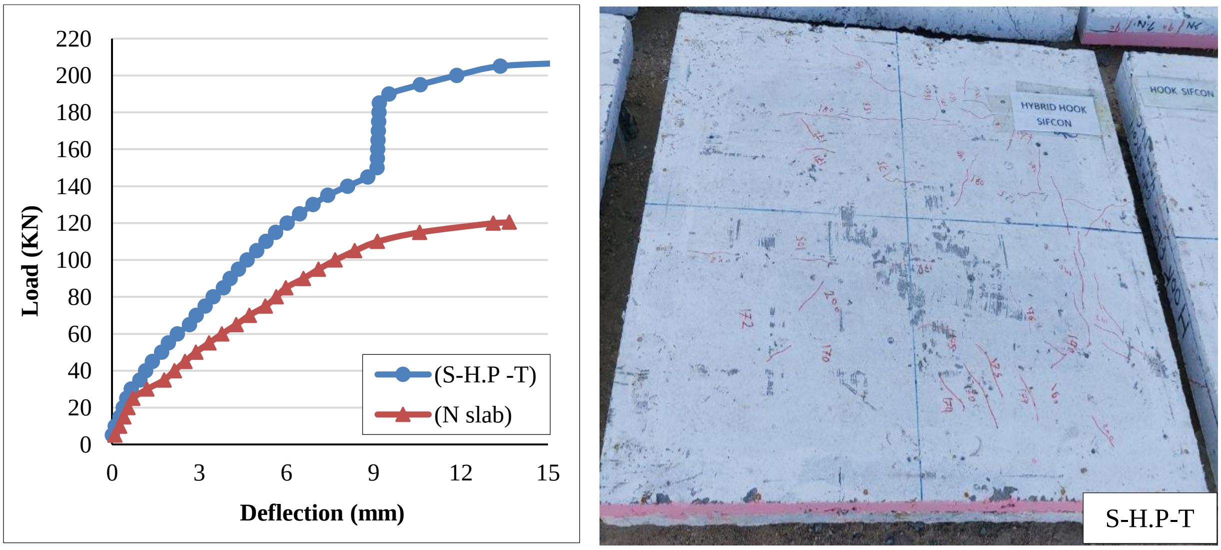

Figure 16. Load- Deflection curve compared with (N slab) and the crack pattern for the (S-H.P-T) slab

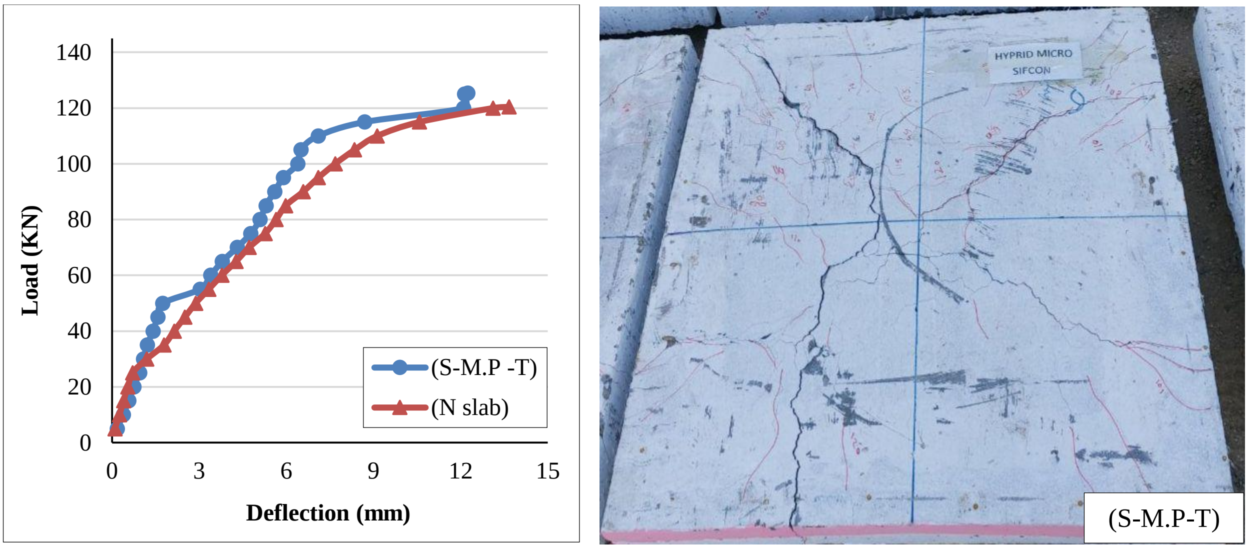

Figure 17. Load- Deflection curve compared with (N slab) and the crack pattern for the (S -M.P-T) slab

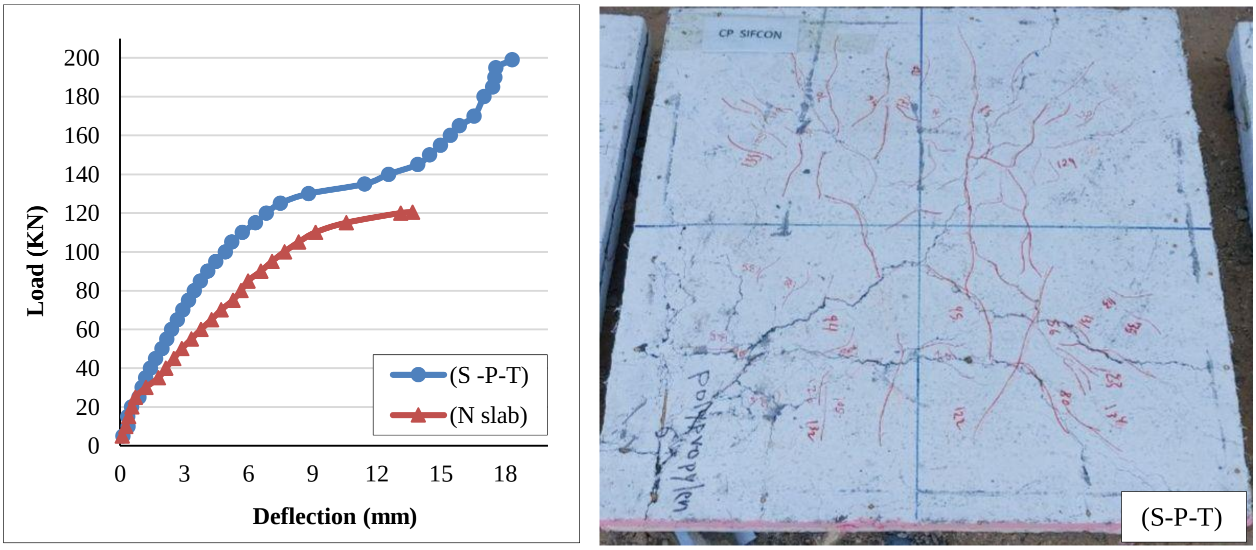

Figure 18. Load- Deflection curve compared with (N slab) and the crack pattern for the (S-P-T) slab

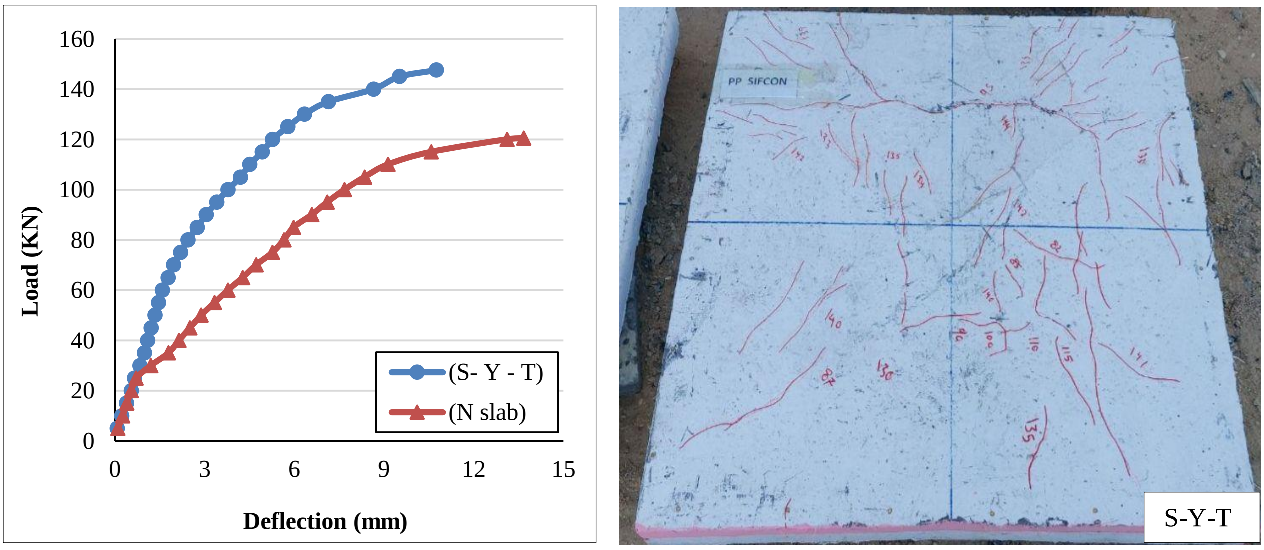

Figure 19. Load- Deflection curve compared with (N slab) and the crack pattern for the (S-Y-T) slab

3.3. Failure Mode

After observation of the slab specimens, found that all of them have the flexural failure mode, due to the perfect reinforcement design for the specimens to avoid another failure mode like punching shear failure that happened suddenly.

3.4. Load-deflection Behavior in Flexure

The load-deflection curve can be distributed into three phases. Firstly, in the elastic phase, a significant number of micro-cracks are formed in the weak location of the concrete under the external load. Secondly, in the initial cracking phase, the bending capability of the matrix reaches the ultimate phase on explanation of the creation of a significant number of micro-cracks, and then, the macro- cracks seem. Finally, in the fracture propagation and failure stage, the load exceeds the matrix strength and the fiber plays a role of bridging the cracks, transmitting internal stress, hindering crack propagation increasing the deformation capacity, and thus enhancing the toughness of concrete.

The load-deflection behavior of mortar infiltrated fiber concrete is quite different from the load-deflection behavior of fiber-reinforced concrete. The curve has a small linear elastic response and a considerable plateau at the peak. The slabs can also sustain a high percentage of peak loads (more than 80% of peak load) even at large deflections.

4. Conclusions

In this study, the effect of the use of different types of mortar infiltrated fiber concrete mixes for the repairing of structural damages in different zones of concrete slabs was presented. Based on the test results, the following conclusions are drawn:

- The test results showed that mortar infiltrated fiber concrete has very high mechanical properties that led to being useful concrete in different structural applications and Using different types of mortar infiltrated fiber concrete resulting in different good options from them to be used in repair slabs according to availability of fibers, types of strength desired, and the cost of the work.
- The compression test for the mortar infiltrated fiber concrete indicated that the enhancement obtained was in range 48-123% comparing with control specimens, the splitting tensile strength test for the mortar infiltrated fiber concrete indicated that the enhancement obtained was in range 12-200% comparing with control specimens, the flexural strength test for the mortar infiltrated fiber concrete indicated that the enhancement obtained was in range 15-176% comparing with control specimen, and the bond strength test for the mortar infiltrated fiber concrete indicated that the enhancement obtained was in range 49-69% comparing with control specimens.
- Hooked steel fiber recorded the highest values in different mechanical tests, therefore it is recommended to use them in repairing damage structures that need for highest ductility and flexural strength, and Hybrid fiber consist of hooked steel fiber and polypropylene fiber recorded high values in different mechanical tests due to combined effect in the bond between fibers that led to enhance the mortar infiltrated mix, Using Hooked steel fiber in repairing damage compression zone in slab specimen recorded 39% increase in ultimate load comparing with reference slab specimen and decrease deflection in center of the slab at ultimate load from 13.67 to 2.4 mm comparing with reference slab specimen.
- One can conclude from test results that using Hybrid fiber consist of hooked steel fiber and polypropylene fiber in the tension zone of, that the ultimate load was increased by about 71% compared with that of reference slab, . Mortar infiltrated concrete has the best behavior in the tension zone than in the compression zone due to the high tensile strength of the fibers used in this study.
- It can be seen that ductility of the repaired slab specimens increased in ranging from 25% to 91% in slabs that repaired in the compression zone, and the ductility increased from ranging 25% to 73% when compared with the reference slab specimen, that ensures the effect of mortar infiltrated fiber concrete as a repair material.

5. Conflicts of Interest

The authors declare no conflict of interest.

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