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Effect of Fibrous Concrete Layers on Behavior of Self-Compacting Concrete Slabs under Uniform Load

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Abstract

This research study the effect of using fibrous concrete layers on behavior of two way Self-Compacting Concrete slabs with ratio (length/width) ≈1.618 [golden ratio] using steel fiber. The experimental work can be divided in two groups, each group having steel fiber–volume fractions of 0.4% and 0.8%, moreover both groups having two concrete slabs one with two fibrous layers (bottom + top) and the other with one fibrous layer (bottom), in additional to concrete slab without steel fiber(reference slab). All the testing was done under uniform load.
The experimental work result found, that when using fibrous one layer (bottom) or fibrous two layers (bottom + top) with having steel fiber –volume fraction of 0.4%, 0.8%, the ultimate strength is significantly increased and the mode of failure changed from bending to shear. Also for the same amount of steel fiber, the effect of distribute in one layer (bottom) was higher than the distribute in two layers (bottom + top)

Keywords: Concrete slabs, uniform load, fibrous concrete layers, Self Compact Concrete, steel fiber.

Introduction

Steel fibers reinforced concrete (SFRC) is a composite material consisting of concrete matrix containing a random dispersion of steel fiber [ACI Committee 544)]

The use of fibers to reinforce a brittle material can be traced back to Egyptian times when asbestos fiber was used to reinforce clay pots about 5000 years ago [(Mehta, 2006)]. However, the modern development of fiber reinforced concrete in the concrete industry may have begun around the early 1960s [(Li, 2002)]

Addition of steel fibers can increase compressive, tensile, and flexural strengths of concretes along with the post-cracking ductility. Furthermore, the steel fibers raise the resistance of concrete to cracking. The use of steel fiber increases impact resistance and provides ductile failure under compression, flexure and torsion, besides increase in fatigue resistance [R. B. Abdul-Ahad and O. Q. Aziz. 1999].

In general, a comparison between SFRC and plain concrete shows that SFRC exhibits superior mechanical properties, such as increased flexural capacity, toughness, post failure ductility and crack control [Edgington *et al.*, 1974]. In addition, it has been reported [Ding, 2000] that fiber reinforcement in concrete significantly increases the compressive ductility, toughness and energy absorption at early ages, and higher shear strength [F. Minelli, and F. Vecchio,2006]. The improved of mechanical properties of SFRC can be attributed to the localized reinforcing effect of steel fibers enhanced by either ,(1)resistance to crack extension provided near a crack tip because steel fibers possess much higher strength than their surrounding concrete [F. Parker,1974] or (2) after cracking , crack bridging effect attributed to steel fiber transmitting stress across the crack[Bekaert,1999].consequently, the dependent on fiber matrix and steel fiber properties (i.e texture ,strength and end shape),content ,and orientation with respect to the direction crack propagation would favor the use of the material for ground slab application [Aldossari, 2014]

The use of fibers in industrial slabs allows the transfer of forces through cracks and openings, thus generating a ductile behavior. Because of the capacity of large rotations with simultaneous significant bearing capacity, investigations of SFC slabs are necessary for the behavior in bending, punching effect and crack openings [Ellouze et al, 2010]

In this research using Self-Compacting Concrete (SCC) was developed in Japan in the late 1980's and allows concrete to be placed fully

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compacted without segregation and with no additional energy (vibration)[Ragab,2013], this type of concrete that does not require external or internal compaction, because it becomes leveled and compacted under its self –weight. SCC can spread and fill every corner of the formwork purely by means of its self –weight, thus eliminating the need of vibration or any type of compacting effort [Okamura, 1998]

Experimental Work

Materials

Cement

Ordinary Portland local cement (Type –I) from Tasluja factory was used in all mixes throughout this research.

Fine Aggregate

Fine aggregate (sand), which has been selected for present work, was obtained from Al-Ukhaidher area. The fine aggregate has 4.75mm maximum size with rounded particle shape and smooth texture and Specific gravity (2.6). The obtained results from physical and chemical tests indicate that the fine aggregate grading and the sulfate content were within the Iraqi specification No. 45/1984. In all concrete batches the sand was dried in air before being used.

Coarse Aggregate

Coarse aggregate were mostly of round shape and maximum size of (10 mm) with Specific gravity (2.63) was used. It was brought from AL-Nabai region. The grading of coarse aggregate were within the limits specified by ASTM C33.The grading of coarse aggregate was within this specification, and it has been found that the sulfate content was within the Iraqi specification No. 45/1984 .

Admixtures (Superplasticizer)

In this work, a "SikaViscoCete-PC 20" was used as a superplasticizer with dosage of 3.5 liter per 100kg of cement, this dosage was recommended after many trail mixes. This admixture improves the mix in:

- Extremely powerful water reduction, resulting in high density, high strength and reduced permeability for water
- Excellent plasticising effect, resulting in improved flowability, placing and compacting behavior
- Especially suitable for the production of Self Compacting Concrete (SCC)

The properties of the superplasticizer are presented in Table (1).

Table (1) Properties of the superplasticizer*

No.	property	The description
1	Commercial name	SikaViscoCete-PC 20
2	Chemical Base	Modified polycaboxylates based polymer
3	Form	liquid
4	Color	Light brown
5	Relative density	1.09-1.13 kg/l @ 20°C
6	pH	3 - 7
7	Chlorides	Free from chlorides

*Supplied by the manufacturer.

Steel Fibers

Hooked end steel fibers which are known commercially as Dramix-Type ZC, was used in this work. Properties of steel fibers are presented in Table (2).

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Table (2) Properties of steel fibers*

Commercial name	Configuration	Property	Specifications
Dramix ZC 50/0.5	Hooked ends 	Density	7860 kg/m^3
		Ultimate strength	1130 MPa
		Modulus of Elasticity	$200x10^3$MPa
		Strain at proportion limit	5650 $x10^{-6}$
		Poisson's ratio	0.28
		Average length	50 mm
		Nominal diameter	0.5 mm
		Aspect ratio (L_f/D_f)	100

*Supplied by the manufacturer

Mixing water

Ordinary potable water was used for mixing and curing to all concrete mixes in this study

Limestone Powder (LSP)

This material is locally named as “Al-Gubra”. It is a white grinding material from lime-stones excavated from different regions in Iraq, and usually used in the construction processes. In this work, a fine limestone powder that grinded by blowing technique, had been used.

Concrete mix

In this work, to produce a nonfibrous concrete, the following mixing proportion was used: [cement: Limestone Powder: sand: aggregate] was [1:0.1:1.9:2] by weight and the water –cement ratio was 0.44 with superplasticizer of 3.5 liter per 100kg of cement. This mix was based on several trial mixes in order to obtain the most suitable mix.

Steel Fiber Reinforced Concrete was obtained by adding steel fibers with volume fractions to the fresh nonfibrous concrete, then remixed. There are three mixture of steel fiber reinforced concrete depending on the volume fraction of steel fiber (0.0%,0.4%and 0.8%)

This mixing has tended to British practice which has generally relied to high sand content (more than 50% by weight of aggregate) with maximum aggregate size of 10 mm[Hannant1978]. The workability of the mix and uniform dispersion of the fibers, are important factors that affect the quality of fibrous concrete.

Mixing procedure

The mixing procedure is an important factor for obtaining the self-compact concrete which satisfy criteria of filling ability, passing ability and segregation resistance. The good dispersion of fibers prevents fiber clumping. The concrete was mixed by hand by using a pan. The interior surface of the pan was cleaned and moistened before placing the materials. The fresh concrete was mixed until a homogeneous fresh concrete was obtained. To avoid balling and to distribute the steel fibers uniformly, the required amount of steel fibers was uniformly added to the mix by hand sprinkling. The fresh concrete was then mixed until a good dispersion of the fiber was obtained.

This procedure is briefly stated in the following points:

1. Initially the fine, filler and coarse aggregates were poured and mixed for several minutes in the pan and then the cement was added .The materials were mixed until a uniform color was obtained
2. Afterward 50% of the water of 0.4 w/c ratio(which divided the w/c ratio=0.4+0.04) was added to the mix and all components were remixed for a few minutes
3. Then, the (superplasticizer +20% of the 0.4 w/c ratio were mixed together) and pouring it into the pan and remixing ,after that the mixture is left for about five minute
4. Then, the remaining 30% of the 0.4 w/c ratio was added and mixed until a homogeneous fresh concrete was obtained
5. Finally the 0.04of w/c ratio was added and remixed

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6. For the mixes that contain steel fiber, to avoid balling and to distribute the steel fibers uniformly, the required amount of steel fibers was uniformly added to the mix by hand sprinkling. The fresh concrete was then mixed until a good dispersion of the fiber was obtained.

Reinforced concrete slabs
Details of tested slabs

The experimental program include testing five reinforced concrete slabs having the full dimensions [(660 mm length ×430 mm width) with thickness of 40mm] and net dimensions of b=610 mm length, and a=377mm width, with 40mm thickness [consist from two layers (bottom and top)] which led to (b/a) ratio≈1.618 (golden ratio) $=\left[\frac{\sqrt{5}+1}{2}\right]$ [R. Knott. Fibonacci]

After exception slab (N) (without steel fiber in all layers, top and bottom) which using as a reference, the other slabs can be divided into two groups, each group consist two concrete slabs. First group contain concrete slabs 4F and N/4F which adding volume fraction of steel fiber = 0.4% in two layers (top and bottom) and one layer (bottom) respectively. Second Group having concrete slabs (8F) and (N/8F) which adding volume fraction of steel fiber = 0.4% in two layers (top and bottom) and one layer (bottom) respectively, the experimental work explain in diagram shown in Fig. (1).

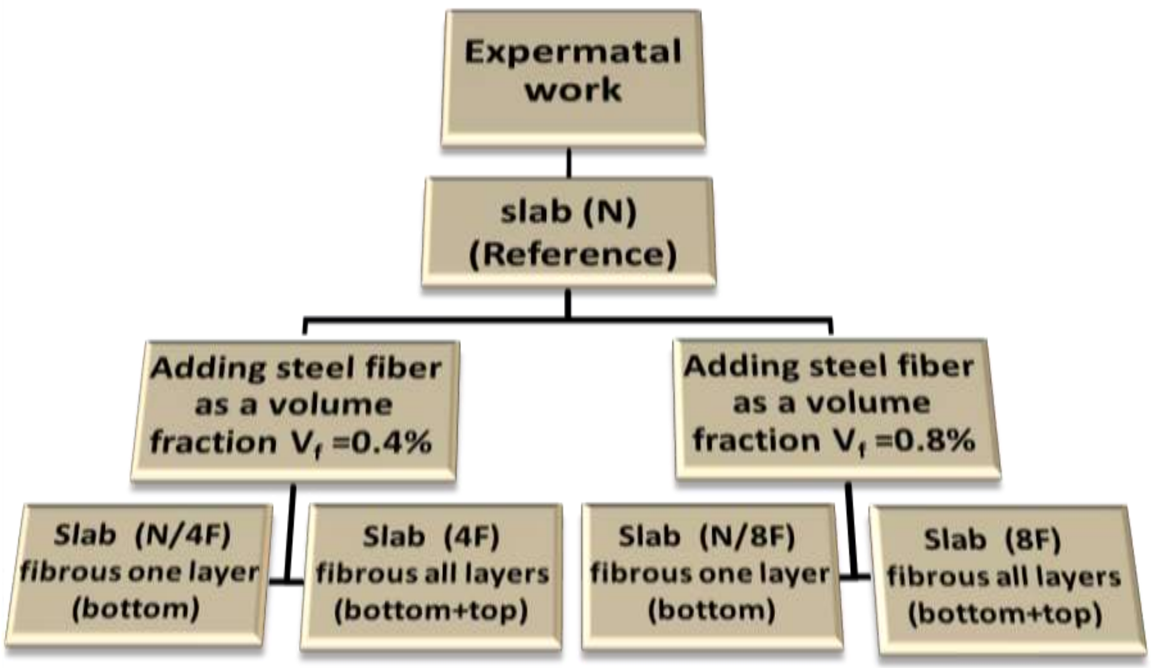

Fig. (1) Diagram explain the experimental work

Details of the Mold

Fig. (2) shows the wood form that was used in the fabrication for all concrete slabs. They made from playwood of (18mm) with inside dimensions [length (b=660 mm), width(a=430 mm)]. Thickness of the slab (h = 40 mm) divided in two layers, (bottom and top), each one (h/2) equal 20mm, this wooden form for casting concrete slabs (N/4Fand N/8F). But the wooden form which casting concrete slabs (N, 4F and 8F) shown in Fig. (2-A) that have thickness(h=40 mm) as a one layer. In addition wood forms 100 mm cubes and (100×200) cylinders are used for control specimens.

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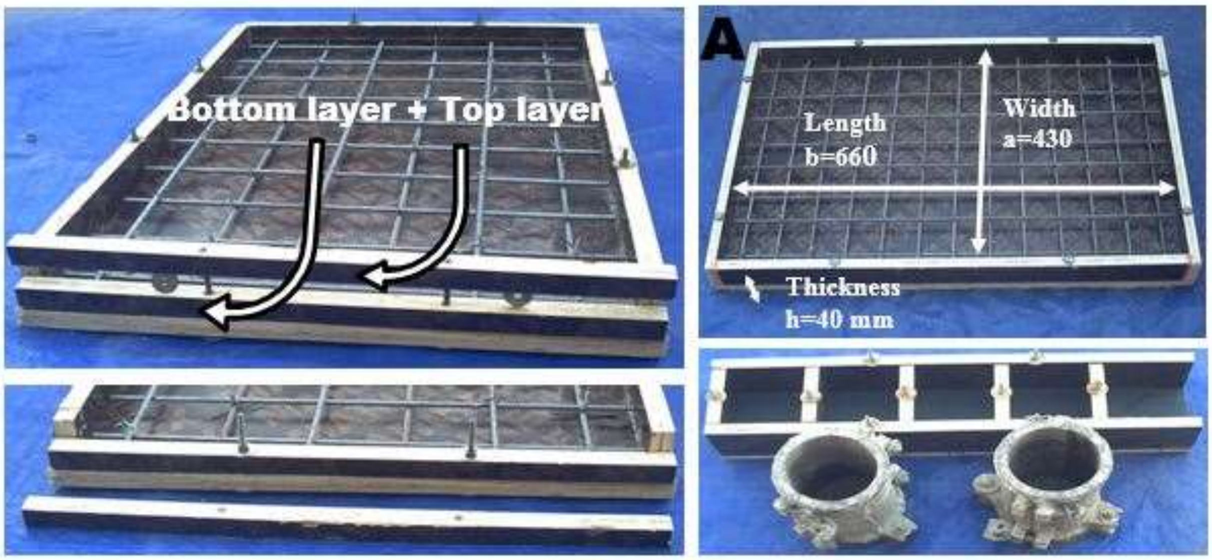

Fig. (2) Details of wooden form used concrete slabs, and wooden cubic forms and cylinders

Details of Steel Reinforcement

All concrete slabs were reinforced with deformed bars having nominal diameter of 5 mm, they were used as a mesh with spacing of 70 mm center to center in each way. The bars parallel to the length were arranged in sequence below and up of the bars parallel to the width, this type of arrangement led to make the distance (d) was equal in each way as shown in Fig. (3). All deformed bars having $Fy = 708\ Mpa$ and $Fu = 1164\ Mpa$. The deformed bars were connected together by using (1 mm) steel wire.

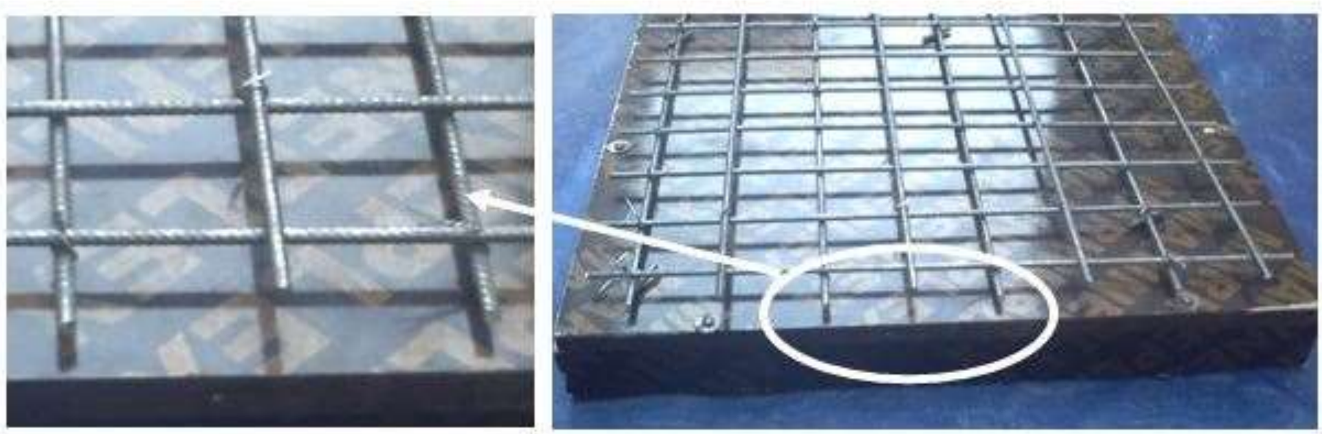

Fig. (3) Details of mesh reinforcement

Details of fabrication and curing

For fabrication of a typical slab, the wooden form was cleaned and oiled before casting. The required reinforcement mesh was placed horizontally using five supports (small piece of plain bars having nominal diameter of 2mm), one in each corner and in center, in order to keep the cover uniformly during fabrication.

Each slab was cast with mixed according to the mixing procedure mentioned before. For slab (N/4F) and (N/8F), the fresh concrete was placed in the wooden form of the slab by two layers (according to the variation of volume fraction of steel fiber), each layer (represent half of concrete slab) was hammered by rubber driver, at the sides and the base of the wooden until the casting was completed. The fresh concrete of the top layer was placed in the wooden

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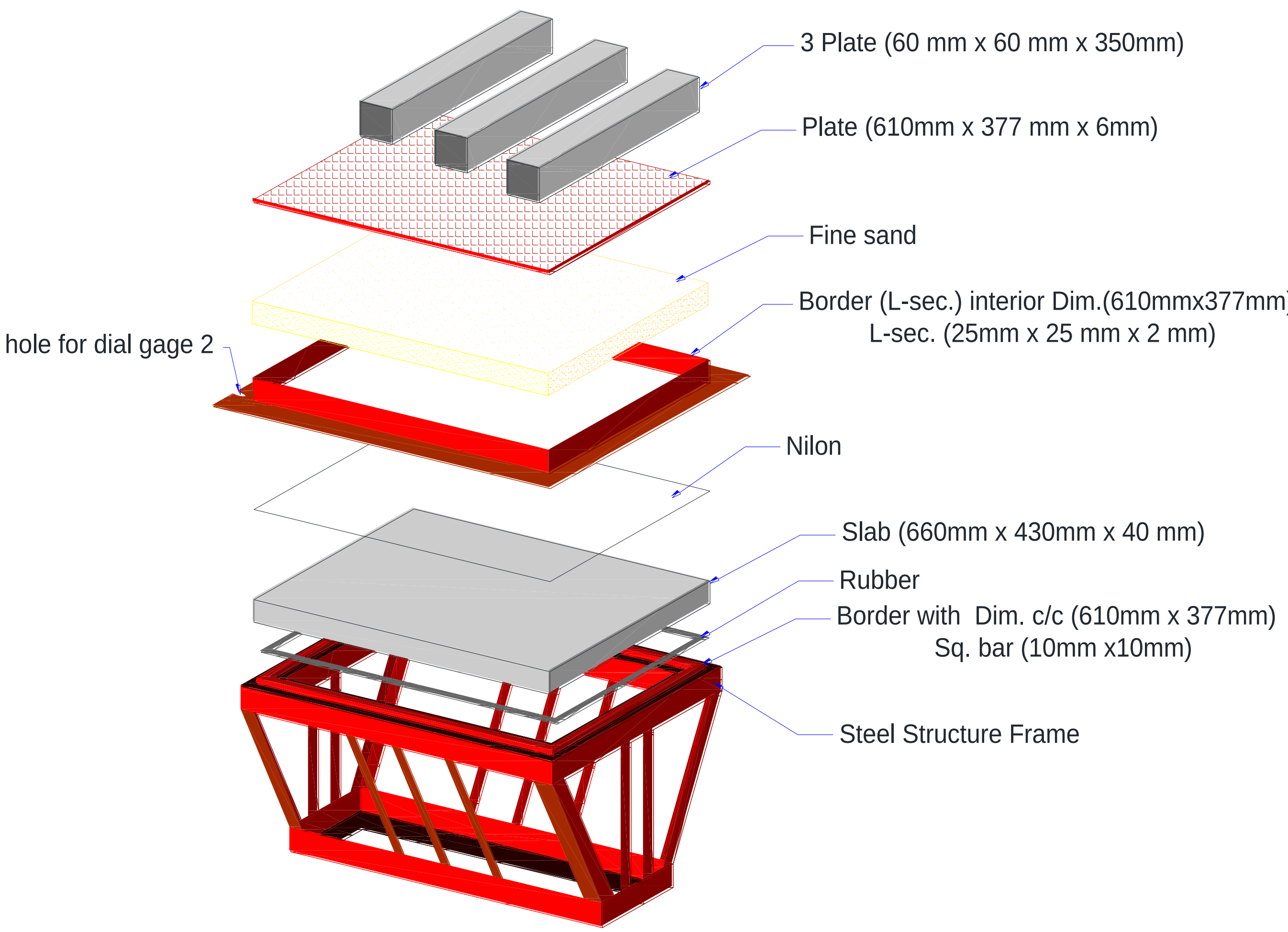
form after period about five minute since completed of casting fresh concrete of bottom layer. Also the control specimens (cubes and cylinders) were casting as the same method for each types of fresh concrete. But the other slabs (N,4F,8F),the fresh concrete was placed in the wooden form of the slab as a layer and also were hammered by rubber driver, at the sides and the base of the wooden until the casting was completed.

The control specimens and wooden form were covered with a plastic sheet to prevent evaporation of water. After (24) hours, the slabs and control specimens were stripped from the molds and cured in a water bath for about one month. To keep the temperature about 25º to 30º, two heaters were used which modified for ornamental fish ponds and water pump to distributed the heat in the water bath.

Then they were taken out from the water bath, and then the slabs, control specimens were tested.

Testing procedure

Slab specimens were placed on the steel frame of the testing machine and covered with fine sand and plate in order to distribute stress on testing slab and adjusted so that the centerline, line of supports, point load on the sand and dial gauges were fixed at their correct and proper locations. Loading was applied in small increments of (2kN) (stress equal to load divided by area of the slab [(2kN/(610mm×377mm)]). At each stress stage the deflection readings at the center and at the support region were recorded. After the first crack appeared the cracking depth and cracking width were gradually increased with increasing stress. The loading increments were applied until failure occurred. Fig. (4) shows details of the testing concrete slabs.



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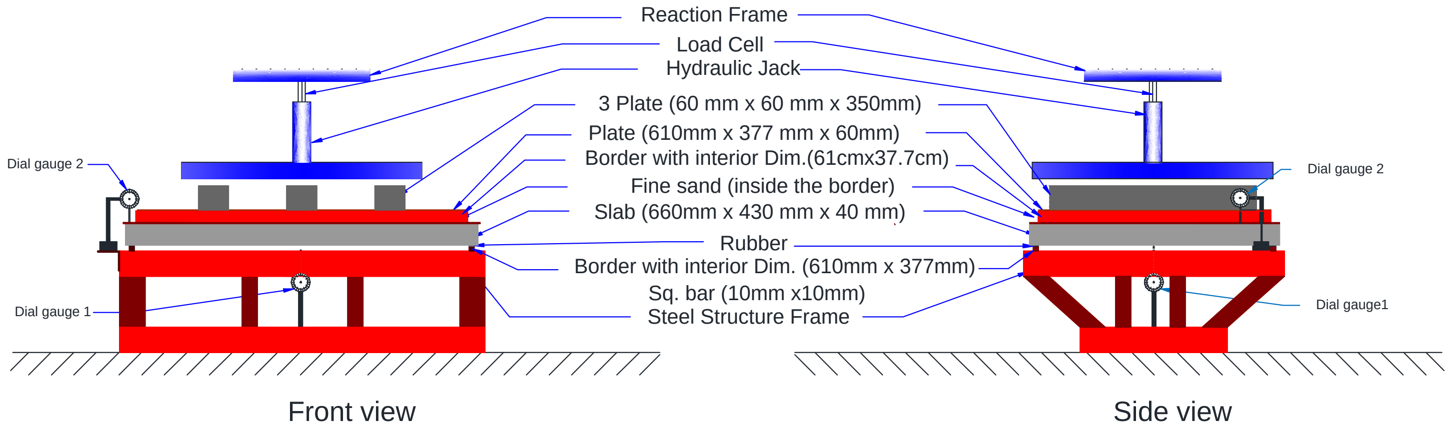

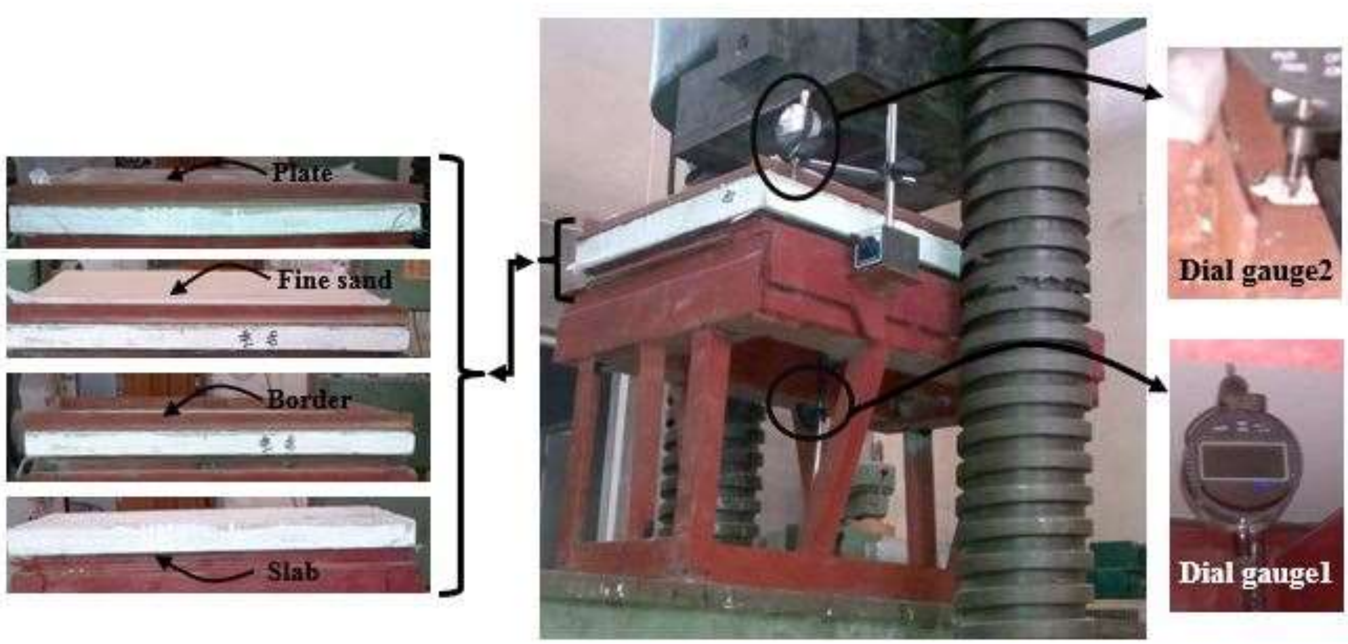

Fig. (4) Slab specimen setup

Experimental Results

The following paragraphs contain the result of the standard tests that were carried out on the fresh concrete, and hardened concrete.

Slump Flow Test and T50cm Test

The slump flow test is used to assess the horizontal free flow of self-compacting concrete. It is the most commonly used test, and gives a good assessment of filling ability. It may give some indication of resistance to segregation. T50cm test is also the measure of the speed of flow and hence the viscosity of SCC [EFNARC, 2002]. This test, which was developed in Japan, was originally used to measure underwater concrete and has also been used to measure highly flowable concretes [Al-Jabri, 2005]. The slump flow test is used to determine filling ability and can indicate segregation resistance of SCC to an experienced user (Al-Jabri, 2005). Table (3) shows the results of slump flow tests. The values of (D) represent the maximum spread (slump flow final diameter), while the values of T50 represent the time required for the concrete flow to reach a circle with 50 cm diameter)[Fig.(5)]. Table (3) shows that the results were acceptable with criteria for Self-Compacting Concrete (JSCE, 1999), and illustrated that the filling ability decreased when adding steel fibers to the concrete.

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Fig. (5) Slump flow test

Table (3) Slump Flow Test and Acceptance criteria for Self-Compacting Concrete

V_f %	T50 (Sec.)	D (mm)	Acceptance criteria for Self-compacting Concrete			
			Typical range of values			
			Slump flow by Abrams cone		T50cm slump flow	
			Max. (mm)	Min. (mm)	Max. (Sec.)	Min. (Sec.)
			D=800	D=600	T50= 25	T50=3
0.0	6	630				
0.4	7	620				
0.8	9	610				

Testing of Hardened Concrete

Compressive Strength

The compressive strength test was carried out according to BS 1881: part 116:1989. This test was measured on 100 mm cubes using electrical testing machine with capacity of 2000 kN.(Fig. (6a))

Splitting Tensile Strength

The splitting tensile strength test was performed according to ASTM C496-86. (100×200)mm cylindrical concrete specimens were used. (Fig. (6b))

Unit weight (density)

The unit weights of concrete, with three steel fiber –volume fraction were measured (Fig. (6c)), using the following equation.

$$Density = \frac{W_A}{W_A - W_W} \quad \text{---- [1]}$$

Where: W_A = weight in air, W_W = weight in water

The compressive strength, splitting tensile strength and unit weight, were obtained by using 100 mm cubes and (100mm×200mm) cylinder. The effect of steel fiber was slightly significant in density. However, the result of present study showed that adding steel fiber significantly increased the compressive strength. On the other hand the effect of increasing steel fiber were very significant in splitting tensile strength.

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(Fig. 6a) Compressive strength test

(Fig. 6b) Splitting tensile strength test

(Fig. 6c) Unit weight (density) test

Experimental Results for concrete slab
Effect of fibrous concrete layers

The effect of fibrous concrete layers on the ultimate strength of concrete slab with groups (1) and (2) that having steel fiber –volume fraction of 0.4% group (1) and 0.8% group (1), are shown in Fig. (7) and Fig. (8) respectively. These slabs of each group had one fibrous layer(bottom) and two fibrous layers(bottom + top) in each group.

The percentage of increases in the ultimate strength when using fibrous one layer (bottom) and fibrous two layers (bottom + top), with steel fiber –volume fraction of 0.4%, 0.8% according to reference slabs (N) are shown in Table (4).This table illustrates that when using fibrous concrete layers(either one layer or two layers), the ultimate strength is significantly increased. The percentage of increases in ultimate strength value was increased with increasing fiber contain.

The increase in ultimate capacity of slabs with fibrous concrete layers , may be attributed to the role of steel fibers in improving the properties of reinforced concrete in resisting additional bending and shear stress.

The higher percentage of increases in ultimate stress when using fibrous concrete layers, essentially one fibrous concrete layer , may be due to the type of orientation of steel fiber, as most of steel fiber were distributed horizontally with vertically small slop because the small thickness that contain steel fiber.

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Table (4) Effect of fibrous concrete layer on ultimate strength of Self-Compacting Concrete slabs with two steel fiber –volume fraction (V_f) %

Name	Type of layer	V_f %	f_{cu} MPa	ft MPa	Density Kg/m3	Pu kN	Stress (MPa)	Percentage of increase	
N	All layer	0.0	30.5	3.2	2336	74	0.321781	-------	
4F	All layer	0.4	35.5	4.3	2377	126	0.547898	70.2	V_f =0.4 %
N/4F	Top layer	0.0	30.5	3.2	2336	104	0.452233	40.5	
	Bottom layer	0.4	35.5	4.3	2377				
8F	All layer	0.8	38.1	5.3	2405	206	0.887072	178	V_f =0.8 %
N/8F	Top layer	0.0	30.5	3.2	2336	148	0.643562	100	
	Bottom layer	0.8	38.1	5.3	2405				

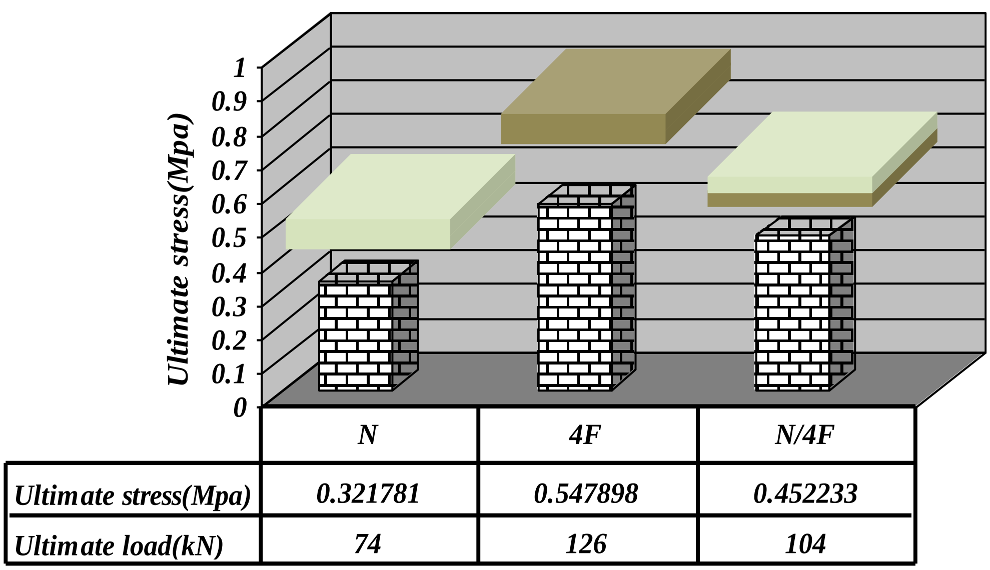

Fig. (7) Effect of fibrous concrete layer on ultimate strength of Self-Compacting Concrete slabs with steel fiber –volume fraction (V_f) =0.4%

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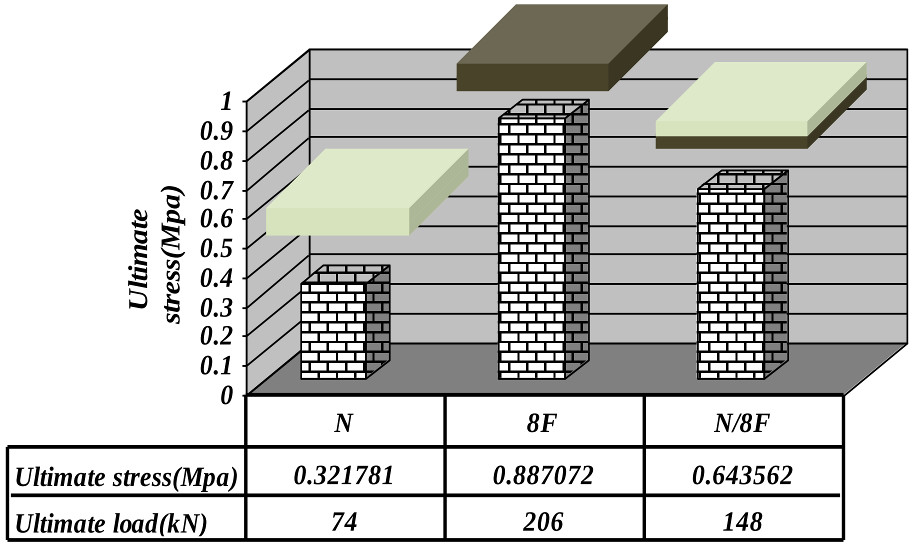

Fig. (8) Effect of fibrous concrete layer on ultimate strength of Self-Compacting Concrete slabs with steel fiber –volume fraction (V_f) =0.8%

Effect of steel fiber distribution

The effect of steel fiber distribution using the same amount of steel fiber, was studied in this work. Fig. (9) shows the effect of distribution the same amount of steel fiber on ultimate strength either in two layers (top and bottom) with volume fraction of steel fiber=0.4% such as concrete slab (4F) or in one layer (bottom) with volume fraction of steel fiber=0.8% such as concrete slab (N/8F), and the percentage of increasing in ultimate strength according to reference slabs (N) are shown in Table (5).This table shows that the slab (N/8F) given ultimate strength higher than the slab (4F), the reason of this behavior may be that the effect of steel on increasing tensile strength was very higher than the effect of steel fiber on increasing compression strength ,so that all the steel fiber in the slab (N/8F) was available in one layer (bottom) which represented the tension zone. The second reason might be to that when the thicknesses which contain steel fiber decreased, the type of orientation or the angle of steel fiber with respect to horizontal plane decreased. The small thickness make the almost (or all) of steel fiber was distributed horizontally with vertically small, this type of distribution increased the effect of steel fiber.

Table (5) Effect of steel fiber distribution on ultimate strength of Self-Compacting Concrete

Name	Type of layer	V_f %	f_{cu} MPa	ft MPa	Density Kg/m3	Pu kN	Stress (MPa)	Percentage of increase
N	All layer	0.0	30.5	3.2	2336	74	0.321781	-------
4F	All layer	0.4	35.5	4.3	2377	126	0.547898	70.2
N/8F	Top layer	0.0	30.5	3.2	2336	148	0.643562	100
	Bottom layer	0.8	38.1	5.3	2405			

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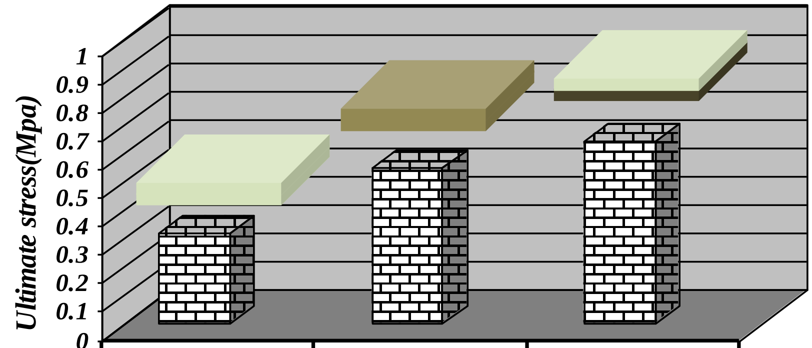

	N	4F	N/8F
Ultimate stress(Mpa)	0.321781	0.547898	0.643562
Ultimate load(kN)	74	126	148

Fig. (9) Effect of steel fiber distribution on ultimate strength of Self-Compacting Concrete slabs

Load – deflection response

Fig (10) shows the stress –deflection curves of the tested of concrete slab at the center of the slab and support region at all stages of loading up to failure The net deflection at center of the slab is obtained by subtracting the deflection that measured by the dial gauge at the support region [reading of dial gauge 2] from the deflection that measured by the dial gauge at mid span [reading of dial gauge 1] as shown in Fig.(4) [at every stage of loading], this method is carried out in this study because the deflection that was measured at support region gives a large value corresponding to the deflection of the concrete slabs. Fig. (10A) shows that when using fibrous concrete layers (one or two layers), the ultimate strength of slabs increases and the deflection was decreased, these behaviors are present for two steel fiber – volume fraction (V_f) (0.4% and 0.8%).

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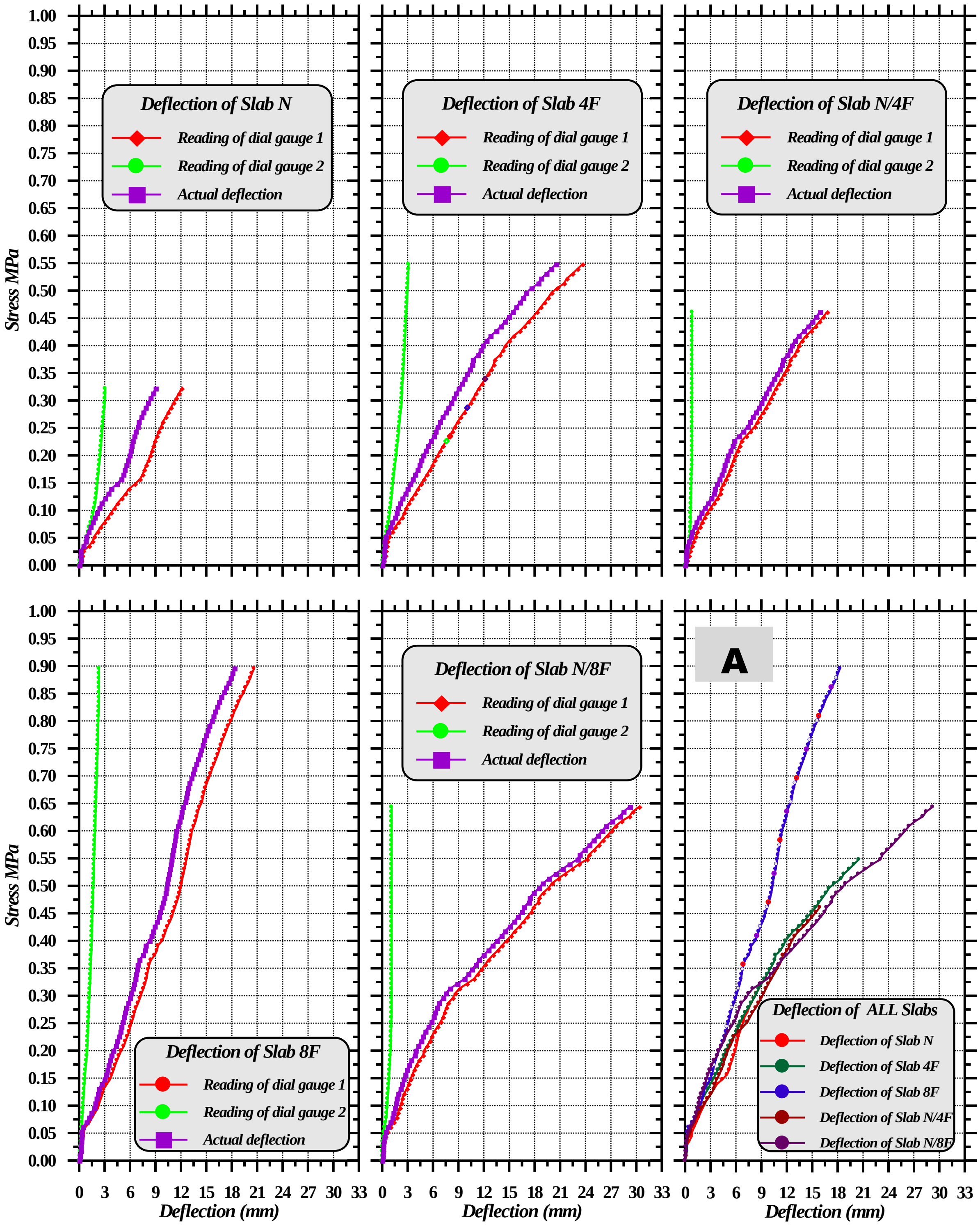

Fig. (10) stress-deflection curves for Self-Compacting Concrete slabs (N), (4F) ,(N/4F), (8F)and (N/8F)

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Crack pattern and mode of failure

Fig. (11) shows the crack pattern for all tested slab specimens, included reference concrete slab(N) with two groups of fibrous concrete, that having steel fiber –volume fraction of 0.4%, 0.8%, (4F,N/4F)and(8F,N/8F) respectively, with one fibrous layer(bottom) and two fibrous layers (bottom + top)

For slabs without steel fiber [reference concrete slab (N)],the most cracks were enclosed after testing, therefore many cracks cannot be recognized by eyes and the crack was marked using Magnifying glass, the mode of failure was bending.

When using fibrous concrete layers (two layers) which had steel fiber –volume fraction equal to 0.4%[slab 4F], the number and width of the cracks were increased, specially shear cracks which led to failure of mode bending-shear.

On the other hand, when using fibrous concrete layers (one or two layers) which had steel fiber –volume fraction equal to 0.8%[slab (8F)and slab (N/8F] and for slab(N/4F)which have fibrous concrete layers (one layer) with steel fiber –volume fraction 0.4%, the shear cracking width were extremely increased and led to failure in shear mode.

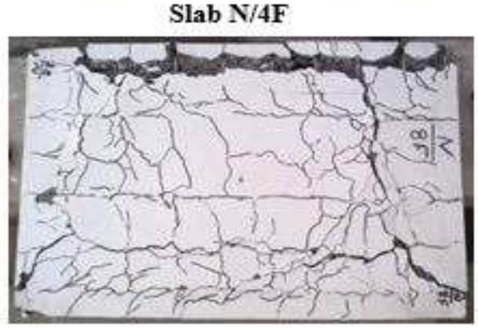
The finding In the present study, that when using fibrous concrete layers (one layer or two layers with steel fiber), the mode of failure changed from bending to shear, and the increasing of this effect when using one fibrous concrete layer (bottom), might be explained by that, when using fibrous concrete layers (one layer or two layers with steel fiber), the resistance of bending stress increased larger than the resistance of shear stress. As any orientation steel fiber in the bending region (at center) will lead to increase resistance of bending stress while near the support (shear region), the steel fibers were parallel the support so they didn't increase shear stress.

Slab N

Slab 4F

Slab N/4F

Slab 8F



Slab N/8F

Fig. (11) Bottom crack patterns at failure for all concrete slabs

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Conclusions

1. The result of present study showed that when using fibrous concrete layers (one or two layers), the ultimate strength was significantly increased. This result for two volume fraction of steel fiber 0.4%and 0.8%.
2. The effect of distribute steel fiber on ultimate strength, in one layer (bottom)was higher than the effect of distribute the same amount of steel fiber , in two layers (bottom +top)
3. When using fibrous concrete layers (one or two layers), the deflection of slab specimen are decreased. These behaviors were found for two volume fraction of steel fiber 0.4%and 0.8%.
4. When using fibrous concrete layers (one or two layers), the resistance of bending stress increased larger than the resistance of shear stress, therefore, the mode of failure changed from bending to shear. this phenomenal increased when using one fibrous concrete layer (bottom)

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4. Ahmed Riyadh [son of my sister].

Reference

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