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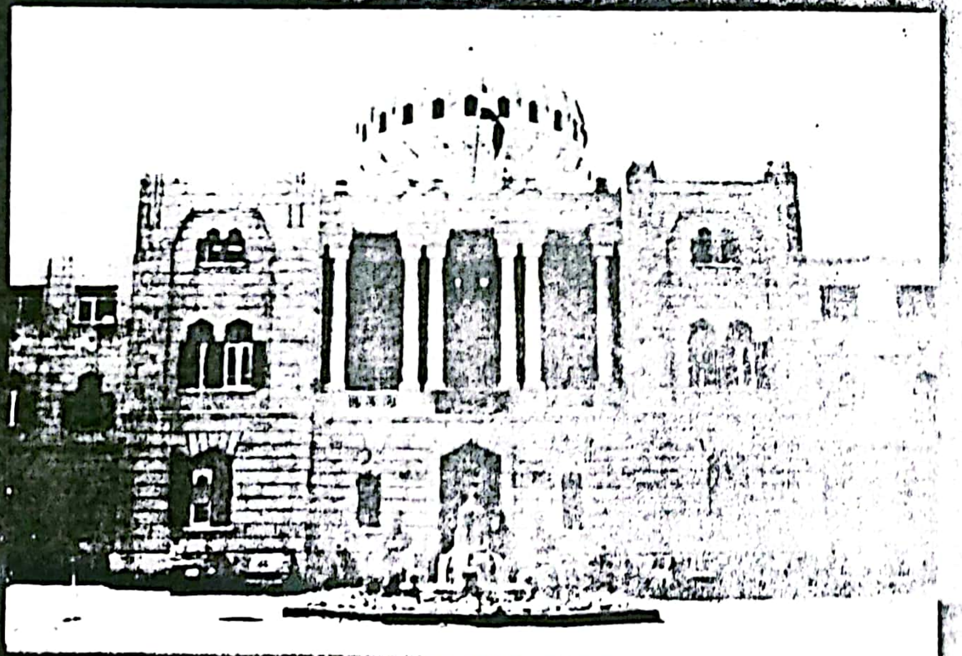

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A COMPARATIVE EXPERIMENTAL STUDY ON RECTANGULAR ONE WAY CONCRETE SLABS REINFORCED USING STEEL REBARS , FIBERS AND POLYPROPYLENE STRIPS

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ABSTRACT

The benefits of using Polypropylene sheets and fibers in structural applications have been well recognized and are growing at a very rapid rate. It is specifically recognized that the high tensile strength , low density, excellent corrosion resistance coupled with non - conductive magnetic characteristics of advanced materials are very beneficial to architecture and infrastructure, particularly in construction of reinforced concrete . The combination of Polypropylene sheets, fibers and concrete structural elements can provide new architectural designs when considering the complementary physical properties of each material .The benefits of Polypropylene sheets and fibers are both near term, in saving construction costs, and long term, in extending the useful life of concrete structures .

The repair and seismic upgrading of reinforced and unreinforced slabs are urgently needed. In response to such a need, a comprehensive research program has been initiated at Zagazig University (Faculty of Engineering-Shoubra) to investigate the effectiveness of Polypropylene strips and fibers as a repair and strengthening technique for reinforced and unreinforced concrete slabs.

This paper describes an investigation of the behavior and ultimate flexural strength of concrete slabs reinforced by Polypropylene strips with fibers and/or reinforcing rebars. A total of eighteen 1/10 scale slabs were constructed and tested under vertical uniform loads. The slabs are simply supported along the long direction and tested under uniformly distributed loads through a tree loading system. Based on the observed behavior, the ultimate flexural strength is determined and some concluding remarks have been drawn.

Keywords : Experimental ; Reinforced Concrete Slabs ; Polypropylene; Strips; Fibers; Strengthening ; Retrofitting ; Rehabilitation .

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INTRODUCTION

Carbon, Glass and Polypropylene can be used to reinforce concrete in the form of discontinuous fibers. The most typical application of this, is a method for crack control. Randomly but uniformly distributed fibers embedded in a concrete mix will have the tendency to resist any tensile forces in the concrete section, thus preventing the propagation of cracks, or rather, minimizing the crack widths (Hosny 1994). Carbon Fiber Reinforced Concrete, (CFRC) has been used in Japan and worldwide for a large number of different projects, most notably in the use of curtain wall panels for high-rise buildings. However, future uses of CFRC will definitely include free access floors, dry-bagged premix repair mortars, and permanent forms for columns and beams (Hosny 1996). The benefits of Polypropylene sheets and fibers are both near term, in saving construction costs, and long term, in extending the useful life of concrete structures (Policelli 1994).

How Fibers Stop Cracks ?

When fibers are introduced into the concrete, and when micro-cracks begin to form and reaches a fiber, it is prevented from further growth. The tiny micro-crack remains in its initial small size. Somewhere adjacent to the first crack, another micro-crack appears and it is also intersected by another fiber and prevented from further growth. In this manner the micro-cracks are not allowed to develop into cracks which could create a reduction in the concrete's integrity (Mashima 1990).Polypropylene fiber reinforcement is considered to be an effective method for providing a good crack control mechanism improving toughness (ductility) properties and impact resistance of concrete materials. The volumetric ratio of fibers being used was 0,10 and 20 percent.

The Role of Fibers in Concrete

Polypropylene fibers are considered to be the best type of fibers to be placed in concrete due to the following : 1) It is inert, and it is not affected by either acids or the alkalis found in concrete ; 2) It will not degrade in concrete ; 3) It is not subject to any form of corrosion ; 4) It is light, with a specific gravity of 0.90 and, therefore, there is a large volume of fibers for a given weight ; 5) It is strong, with a tensile strength of over 1.0 GPa ; and 6) It is an economical fiber and so can be used in adequate quantities without a large expenditure of money (ACI 1991).

Normally, for slabs and other horizontal concrete flat work, Polypropylene fibers are found to be more satisfactory in use than wire mesh or other steel members used as a secondary reinforcement and for these reasons can replace these steel units. Also, it has to be noted that, the fibers cannot replace primary steel reinforcement (Soroushia 1992). Today, you don't have to settle for the wire mesh method and gamble on it being in the right place. Technology has developed fibermesh fibers, a far superior system of engineered secondary reinforcement which provides automatic high-tech protection in concrete's plastic as well as hardened state.

Fibers in concrete have two major functions. The first is to prevent plastic shrinkage cracking. The second is to reduce the segregation of the components of the concrete. There are a number of other physical properties which are improved by the addition of fibers to concrete. The reduction in permeability of the concrete is an attribute of prime importance with regard to the protection against corrosion. The high toughness index, which is the ability of concrete to sustain a load after initial crack, is also important as it relates both to spalling and to a continuing bound to the steel reinforcement.

The use of Fibermesh substantially reduce the formation of plastic settlement and shrinkage cracks by increasing the tensile strain capacity of plastic concrete. These fibers are uniformly distributed throughout the concrete in all directions, providing effective secondary reinforcement for shrinkage crack control. As the concrete hardens and shrinks, microscopic cracks develop. When the micro-cracks intersect a Fibermesh strand, they are blocked and prevented from developing into micro-cracks and causing potential problems. The addition of Fibermesh fibers throughout the concrete also serves to minimize the width and length of those cracks that may appear in the hardened state. Also, fibrillated Polypropylene fibers reduce the rate and amount of bleeding as well as increasing the extensibility of plastic concrete and therefore have a twofold beneficial effect on plastic settlement cracks (Kraai 1994).

Also, within the commonly employed dosages of Fibermesh, the viscosity of the fresh concrete, i.e., its ability to become worked into the desired position by vibration, is essentially unaffected by the addition of Fibermesh to the fresh concrete.

The normal dosage of Polypropylene fibers is 0.9 Kg per cubic meter of concrete. The fiber length is usually 18 mm . The fibrillated bundles of fibers prevent balling during mixing and it is separated into individual fibers and become evenly distributed throughout the concrete. There are approximately 7 million fibers per cubic meter or about 7 fibers per cubic centimeter (Kraai 1994).

Physical Properties of Polypropylene Fibers and Sheets (Kraai 1994)

1. Absorption	- Nill
2. Specific Gravity	- 0.9
3. Fiber Length	- 3 , 12 , 18 , 38 mm
4. Thermal Conductivity	- Low
5. Electrical Conductivity	- Low
6. Workability	- High
7. Water-Cement Ratio	- 0.50 - 0.60 (Normal)
8. Acid and Salt Resistance	- High
9. Weight of the Sheets / m^2	- 0.3, 0.4 , 0.6 Kg / m^2
10. Flame Retardancy	- Self Extinguishing

Mechanical Properties of Polypropylene Sheets

1. Young's Modulus	- 35 GPa
2. Elongation at Break	- 25 % ~ 35 %
3. Tensile Strength	- 1.0 ~ 1.2 GPa

Comparison Between Fibermesh and Secondary Reinforcement

Features	Fibermesh	Wiremesh
1. Reinforces against plastic shrinkage crack formation	Yes	No
2. Holds cracks together	Yes	Yes
3. Reinforces against impact forces	Yes	No
4. Reinforces against shattering	Yes	No
5. Reinforces against abrasion	Yes	No
6. Reinforces against water migration	Yes	No
7. Rustproof and corrosion resistant	Yes	No
8. Non-magnetic	Yes	No
9. Minimum required concrete cover	- 0-	25 mm
10.Three dimensional residual strength	Yes	No
11. Always positioned in compliance with codes	Yes	No
12. Safe and easy to use		

EXPERIMENTAL PROGRAM

Significance of Research

The tests reported in this paper is intended to find the best and most economic way to replace and/or strength the reinforcing steel in concrete slabs. There is no published experimental data exist for such slabs reinforced by Polypropylene strips in addition to Polypropylene fibers. This combination can be adequate for reinforced concrete elements due to it high performance which indicated in the previous section. Also, basic knowledge is needed on the effect of the addition of the randomly oriented fibers on the behavior of reinforced concrete slabs.

A scale factor of ten is selected for this experimental program to model the slab specimens. The selection of scaling is based on the success of previous studies using this scale (William 1966, Gajana 1985, ACI 1970). The choice of this scale factor was primarily based upon the fact that the space and capacity available of the Universal Testing Machine (UTM) used in the experimental program is limited and also loading facilities can be much more manageable and less costly at this scale. Also These tests are used as a comparative case studies between each other under the same conditions.

Eighteen slab specimens were casted and tested (as shown in Figs.1,2 and 3). The major parameters included, the volumetric ratio of fibers, the width, spacing and number of Polypropylene strips (Table 1) were considered.This paper provides the effect of the studied parameters on the behavior and the strength of concrete slabs. Then the factors studied during this investigation were:

1- Studying the effect of Polypropylene fiber doze (0.9, 1.8 Kg/m^3) on the flexural strength of plain concrete slabs (Specimens numbers (1,3,4) or (A,C,D) Table 1).
2- Studying the effect of Polypropylene fiber doze (0.9, 1.8 Kg/m^3) on the flexural strength of reinforced concrete slabs (Specimens numbers (2,5,6) or (B,E,F) Table 1).
3- Investigating the effect of width and spacing of Polypropylene strips on the flexural strength of reinforced concrete slabs (Specimens numbers (5,7,8) or (E,G,H) Table 1).
4- Studying the effect of number, width and spacing of Polypropylene strips on the flexural strength of slabs (Specimens numbers (7 to 18) or (G to R) Table 1).
5- Studying the effect of Polypropylene strips as an alternative material instead of using steel rebars (Specimens numbers (9 to 18) or (I to R) Table 1).

Test Specimens and Materials

Details of eighteen prototype One-way concrete slabs, reinforced by conventional steel rebars and/or Polypropylene strips and fibers are given in Table 1 . Five specimens were reinforced by conventional steel rebars with/without Polypropylene strips and fibers. The dimensions of all specimens are 400 by 200 mm, which were kept constant throughout the study. According to the requirements of the Egyptian code of practice (1995) and ACI requirements (1992) , the thickness of all slabs was 20 mm.

The test specimens were divided into six groups. These groups are : 1) Plain concrete ; 2) Reinforced concrete ; 3) Plain concrete with Polypropylene fibers ; 4) Reinforced concrete with Polypropylene fibers ; 5) Plain concrete with Polypropylene strips and fibers ; and 6) Reinforced concrete with Polypropylene strips and fibers. All specimens have the same dimensions (400 x 200 x 20 mm) , and they are simply supported on the short edge. Table 1 shows the classification of the specimens.

The concrete mix used was made of ordinary Portland cement of 400 kg/m^3 content. All material size and fibers are scaled down. The aggregate used was coarse sand to simulate the scale factor. Mix proportions by weight were 1:1.875 for cement and coarse sand respectively. The water / cement ratio was 0.58 by weight. The concrete compressive strength measured at 28 days was 21.1 MPa. Tension tests were conducted on rebars and coated Polypropylene samples to determine the yield strength of the steel rebars , ultimate tensile strength and elongation for both of them. Mechanical properties of reinforcing steel and Polypropylene strips are given in Table 1.

Slabs were casted from the same batch, cured for a period of 28 days and then strengthened by the Polypropylene strips after curing and were allowed to dry for 7 days before testing. A strengthening Polypropylene strips of intensity 0.3 Kg/m^2 of dimensions as shown in Fig.4 and Table 1 were cut and attached to the slab surface with epoxy adhesive meeting the requirements of ASTM (C234, C39,C496,C4476).

Application of the Polypropylene Strips on the Specimens

The pieces of Polypropylene strips were cut. The Polyester resin was then placed in a plastic or glass bowl and mixed with styrenes as a catalyst at a ratio of 10 : 1. The two components were mixed very well. It should be noted that , great care has to be taken during applying , handling and using this material due to its harm effect on the skin of the user when using carelessly . A first coat of the resin was applied on the surface of the slab by using a small hand brush to insure uniform distribution of the resin on the surface of the slab followed by the attachment of the Polypropylene strips. A second coat of the resin was then applied on the top of the strips within half an hour later and before the first coat started to set as shown in Fig.5. A roller was used to insure complete wetting of the strips and inter mix the resin from both coating. Great care was paid to prevent trapping air gaps under the mat which can affect the interface bond condition between the strips and specimen.

Test Procedure

The slabs were tested as a simply supported plate through the long direction and subjected to monotonically increasing uniform vertical load with a displacement control rate of 0.145 mm/sec. The uniform vertical load was applied through a typical tree loading system using a lever arm and a steel ball of diameter 20 mm as shown in Figs.1,2 and 3. This system of loading has been used to simulate the actual uniform loads in practice. During the analysis of results, the weights of the waffle tree loading system has been neglected due to its negligible value and because of these experimental study is a comparative one and the applied vertical load is the target of this tests. The vertical load was applied through the 100 KN Universal Testing Machine (UTM) which has sensitive load cell and internal Linear Variable Differential Transducer (LVDT) to monitor the slab response during testing. All measurements were made in the SI system of units. Measurements for mid point deflections were taken throughout the test by both the internal LVDT of the (UTM) and a dial gage with 0.01 mm accuracy .

RESULTS AND DISCUSSIONS

Deflections

The deflection-load rates for slabs reinforced by Polypropylene strips are nearly 0.85 to 1.17 times that for slabs reinforced by conventional steel reinforcement, which are suitable to serviceability conditions (as shown in Table 1). Figure 6 shows the finite element mesh used to simulate the tested slabs to find the analytical deflection.

Crack Patterns and Failure Modes

In case of slabs strengthen by Polypropylene, the failure modes can be classified to these groups : 1) Yield of rebars ; 2) Rupture of rebars ; 3) Flexural failure; 4) Bond failure of steel rebars; 5) Splitting of the compression zone; 6) Crushing of concrete; 7) Rupture of Polypropylene layers ; and 8) Bond failure of the Polypropylene layers (as shown in Table 1).

Figure 7 shows the observed crack patterns of all specimens at failure. The failure mode of slab specimens strengthen by Polypropylene strips is characterized by the rupture of strips followed by the formation of an inclined cracks in the tension side with / without crushing and spalling in the compression side. The final failure taking place either simultaneously with or subsequent to the formation of this inclined crack and/or rupture of Polypropylene strips. Therefore, the use of Polypropylene strips as a strengthening material for concrete slabs changes the cracking pattern of such slabs as shown in Fig.7 and Table 1.

Behavior of the Specimens

From the analysis of the test results and from Tables 1 and 2 it can be noted that:

1- The ultimate strength of the reinforced concrete slabs with 0.9 Kg/m^3 Polypropylene fibers increases by about 11 % more than the slabs having zero percent fiber content .
2. The ultimate strength of the reinforced concrete slabs with 1.8 Kg/m^3 Polypropylene fibers increases by about 25 % more than the slabs having zero percent fiber content .
3. The use of Polypropylene strips as a strengthening material for plain concrete slabs increases its ultimate carrying capacity by about 4.1 to 10.4 times.
4. The use of Polypropylene strips as a strengthening material for reinforced concrete slabs increases its ultimate carrying capacity by about 2.36 to 2.67 times.
5. The ultimate strength of slabs reinforced by Polypropylene strips, increases with the increase of strips number and width , while decreases with the increase of strips spacings.

ANALYTICAL RESULTS

Analytical study using finite shell element as shown in Fig. 6 has been curried out in the linear stage (up to the first crack occurs) using layered element . The ratio of the predicted and experimental deflection was 0.97. Then, the analytical and experimental results are very close and largely self explanatory.

SUMMARY AND CONCLUSIONS

The work illustrated here was mainly concerned with predicting the experimental and theoretical behavior of concrete slabs strengthen by Polypropylene strips and fibers. From the results in Tables 1 and 2 and from the discussion in the previous sections, the conclusions obtained from this study may be bought out in the following points :

1. Presents of fibers prevent hair cracks after casting concrete due to initial settings and chemical contraction of cement. Also the use of Polypropylene fibers give a smooth surface.
2. Polypropylene fibers improve ductility characteristics of concrete slabs.
3. The ultimate strength of the reinforced concrete slabs with 0.9 Kg/m^3 Polypropylene fibers increased by about 11 % more than the slabs having zero percent fiber content.
4. The ultimate strength of the reinforced concrete slabs with 1.8 Kg/m^3 Polypropylene fibers increased by about 25 % more than the slabs having zero percent fiber content.
5. The use of Polypropylene strips as a strengthening material for plain concrete slabs increases its ultimate carrying capacity by about 4.1 to 10.4 times.
6. The use of Polypropylene strips as a strengthening material for reinforced concrete slabs increases its ultimate carrying capacity by about 2.36 to 2.67 times.
7. The ultimate strength of slabs reinforced by Polypropylene strips, increases with the increase of strips number and width, while decreases with the increase of strips spacings.
8. The use of Polypropylene strips as a strengthening material for concrete slabs change the cracking pattern of such slabs as shown early. The crack width is relatively small, then the use of polypropylene as strengthening material is suitable for serviceability conditions.
9. The deflection-load rates for slabs reinforced by Polypropylene strips are nearly 0.85 to 1.17 times that for slabs reinforced by conventional steel reinforcement, which are suitable to serviceability conditions.
10. The finite element model used in this study, successfully simulated the behavior of slabs reinforced by Polypropylene strips.
11. Based on the previous results, the strengthening by using Polypropylene strips is considered to be an efficient and relatively cheaper method to increase the load carrying capacity and ductility of the slabs than any other methods of retrofitting.
12. Future studies have to be done on higher ratios of Polypropylene fibers to obtain economic solutions with higher strength and ductility.
13. Further research should be pursued prior to allowing the use of Polypropylene strips and fibers as reinforcement for concrete slabs.
14. The benefits of Polypropylene sheets and fibers are both near term, in saving construction costs, and long term, in extending the useful life of concrete structures. Further studies have to be done on the mechanical properties of polypropylene sheets through a long time to study its creep and shrinkage characteristics.

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Table (1) Dimensions, Details and Test Results of the Tested Specimens

Specimen No.	Specimen Symbol	Bottom Steel in the Two Directions	Intensity of Fibers (Kg/m3)	Strips of Polypropylene in the Short Direction: No. of Strips (L)	Strips of Polypropylene in the Short Direction: Spacing S (mm)	Strips of Polypropylene in the Short Direction: Width of Strips T (mm)	Strips of Polypropylene in the Short Direction: No. of Strips (N)	Strips of Polypropylene in the Short Direction: Spacing (S (mm)	Strips of Polypropylene in the Short Direction: Width of Strips T (mm)	Failure Load (KN)	Failure Displacement (mm)	Deflection Load Rate (mm/KN)	Failure Mode	Notes
1	A	-	-	-	-	-	-	-	-	1.20	1.20	1.00	Flexural Failure	Control Specimen
2	B	10 Φ 2	-	-	-	-	-	-	-	5.86	8.20	0.71	Flexural Failure	Control Specimen
3	C	-	0.9	-	-	-	-	-	-	1.58	1.50	0.95	Flexural Failure	
4	D	-	1.8	-	-	-	-	-	-	1.78	1.20	0.67	Flexural Failure	
5	E	10 Φ 2	0.9	-	-	-	-	-	-	6.52	6.50	0.99	Flexural Failure	
6	F	10 Φ 2	1.8	-	-	-	-	-	-	7.33	5.90	0.80	Flexural Failure	
7	G	10 Φ 2	0.9	5	20	20	5	40	40	15.66	8.70	0.56	Flexural - Crushing Failure	Single Spacing
8	H	10 Φ 2	0.9	5	27	13	5	53	27	13.84	7.70	0.56	Flexural - Rupture Failure of Poly. Strips	Double Spacing
9	I	-	0.9	1	-	400	1	-	200	13.36	8.00	0.60	Flexural - Crushing Failure	One Sheet 400x200
10	J	-	0.9	3	33	33	3	67	67	9.20	5.90	0.64	Flexural - Rupture Failure of Poly. Strips	Single Spacing
11	K	-	0.9	5	20	20	5	40	40	10.30	7.10	0.69	Flexural - Rupture Failure of Poly. Strips	Single Spacing
12	L	-	0.9	7	14	14	7	29	29	12.50	8.70	0.70	Flexural - Rupture Failure of Poly. Strips	Single Spacing
13	M	-	0.9	3	44	22	3	89	45	5.56	4.40	0.79	Flexural - Rupture Failure of Poly. Strips	Double Spacing
14	N	-	0.9	5	27	13	5	53	27	7.78	5.90	0.76	Flexural - Rupture Failure of Poly. Strips	Double Spacing
15	O	-	0.9	7	19	9	7	38	19	10.38	8.40	0.81	Flexural - Rupture Failure of Poly. Strips	Double Spacing
16	P	-	0.9	3	50	17	3	100	33	4.94	3.90	0.79	Flexural - Rupture Failure of Poly. Strips	Triple Spacing
17	Q	-	0.9	5	30	10	5	60	20	7.04	5.40	0.77	Flexural - Rupture Failure of Poly. Strips	Triple Spacing
18	R	-	0.9	7	21	7	7	43	14	9.60	8.00	0.83	Flexural - Rupture Failure of Poly. Strips	Triple Spacing

Properties of Concrete : fcu = 21.1 MPa

Properties of Steel :

Φ = 2 mm As = 3.14 mm2

fy = 1.27 GPa Yield Strain = 0.016

fu = 1.28 GPa Ultimate Strain = 0.039 Es = 80 GPa

Properties of the Polypropylene Sheets Coted By Epoxy :

Type	Intensity (Kg / m2)	Strength (GPa)
I	0.3	1

Properties of Fibers Thread :

f = 0.76 GPa Ultimate Strain = 0.049

In the Long Direction: N * T + N * S = 400 mm, Then T + S = 400 / N

In the Short Direction: L * T + L * S = 200 mm, Then T + S = 200 / L

Where

N, L are the number of strips in the long and the short directions.

S is the spacing between strips (mm) & T is the strip width (mm)

S = T in case of single spacing

S = 2T in case of double spacing

S = 3T in case of triple spacing

Polypropylene strips were made from Polypropylene sheets of intensity 0.3 Kg/m2

Table (2) Analysis of the Test Results

(1) The Effect of Fibermesh Doze on the Strength of Plain Concrete

Specimen	A	C	D
Load (KN)	1.2	1.58	1.78
Ratio Related to A	1.000	1.317	1.483
Ratio Related to C	-	1.000	1.127

(2) The Effect of Fibermesh Doze on the Strength of Reinforced Concrete

Specimen	B	E	F
Load (KN)	5.86	6.52	7.33
Ratio Related to B	1.000	1.11	1.25
Ratio Related to E	-	1.000	1.124

(3) The Effect of Polypropylene Strips on the Strength of Reinforced Concrete

Specimen	E	H	G
Load (KN)	6.52	13.84	15.66
Ratio Related to E	1.000	2.123	2.402
Ratio Related to H	-	1.000	1.132

(4) The Effect of Polypropylene Strips (Number, Width and Spacing) on the Strength

(a) Effect of Width

Three Strips

Specimen	J	M	P
Load (KN)	9.2	5.56	4.94
Ratio Related to J	1.000	0.604	0.537
Ratio Related to M	-	1.000	0.888

Five Strips

Specimen	K	N	Q
Load (KN)	10.3	7.78	7.04
Ratio Related to K	1.000	0.756	0.683
Ratio Related to N	-	1.000	0.905

Seven Strips

Specimen	L	O	R
Load (KN)	12.5	10.38	9.6
Ratio Related to L	1.000	0.83	0.768
Ratio Related to O	-	1.000	0.925

Table (2) Analysis of the Test Results (Cont.)

(b) Effect of Spacing (Number of Strips)

For specimen (I) (one strip 400 x 200 mm) the strength was 13.36 KN which is 11.13 and 2.28 times of the specimens (A) and (B) respectively. λ = 100 %

S = T (Single Spacing , Spacing = Width) λ = 50 %

Specimen	J	K	L
Load (KN)	9.2	10.3	12.5
Ratio Related to J	1.000	1.12	1.359
Ratio Related to K	-	1.000	1.213

S = 2 T (Double Spacing , Spacing = Double The Thickness)

Specimen	M	N	O
Load (KN)	5.56	7.78	10.38
Ratio Related to M	1.000	1.4	1.867
Ratio Related to N	-	1.000	1.334

S = 3 T (Triple Spacing , Spacing = Triple the Width) λ = 25 %

Specimen	P	Q	R
Load (KN)	4.94	7.04	9.6
Ratio Related to P	1.000	1.425	1.943
Ratio Related to Q	-	1.000	1.364

(5) Comparison of Strength (Specimens Having Reinforcing Steel and/or Polypropylene Strips)

Specimen	A	B	I	J & K & L	M & N & O	P & Q & R
Load (KN)	1.2	5.86	13.36	9.2 to 12.50	5.56 to 10.38	4.94 to 9.6
Ratio Related to B	0.200	1	2.28	1.57 to 2.13	0.95 to 1.75	0.84 to 1.64

(6) Comparison of Steel Rebar and Polypropylene Costs (Specimens Having Reinforcing Steel and/or Polypropylene Strips)

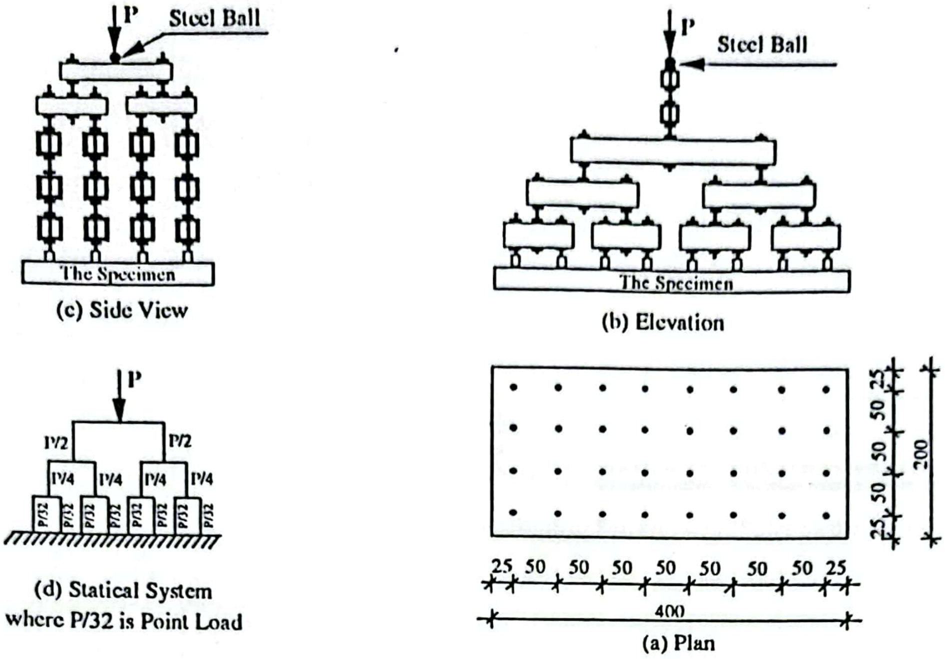
Specimen	A	B	I	J , K & L	M , N & O	P , Q & R
Ratio Related to B	-	1	3	1.5	1	0.75

Where :

S is the spacing between Polypropylene strips

T is the width of the Polypropylene strips

$$\lambda = \frac{\text{Surface area of Polypropylene strips}}{\text{Surface area of the specimen}}$$



All Dimensions Are in mm

Fig. (1) Schematic View of the Loading System

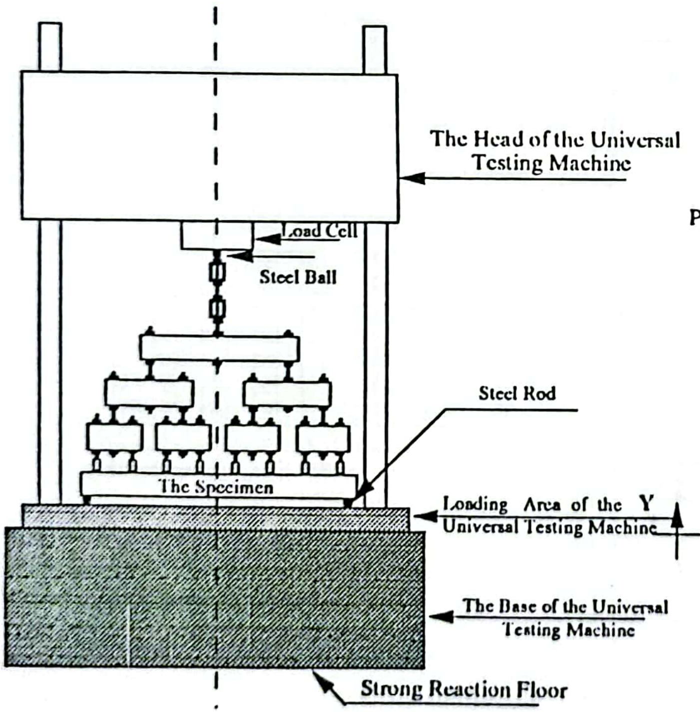
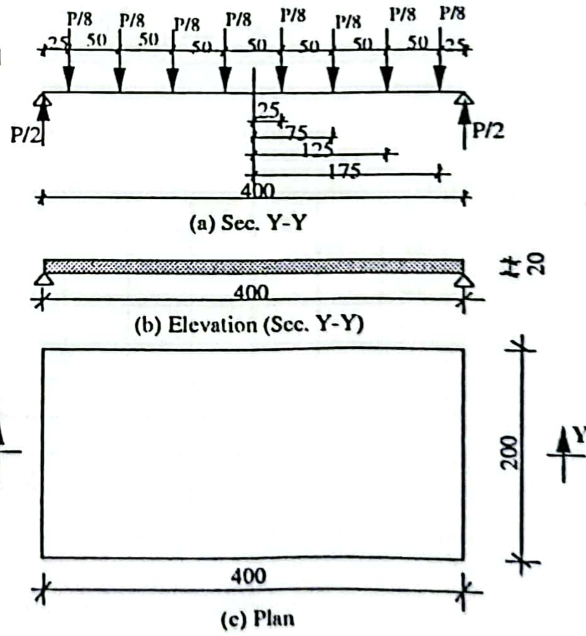


Fig. (2) Schematic View of the Test Set Up



All Dimensions are in mm

Fig. (3) Loading System, Dimensions of the Tested Slab

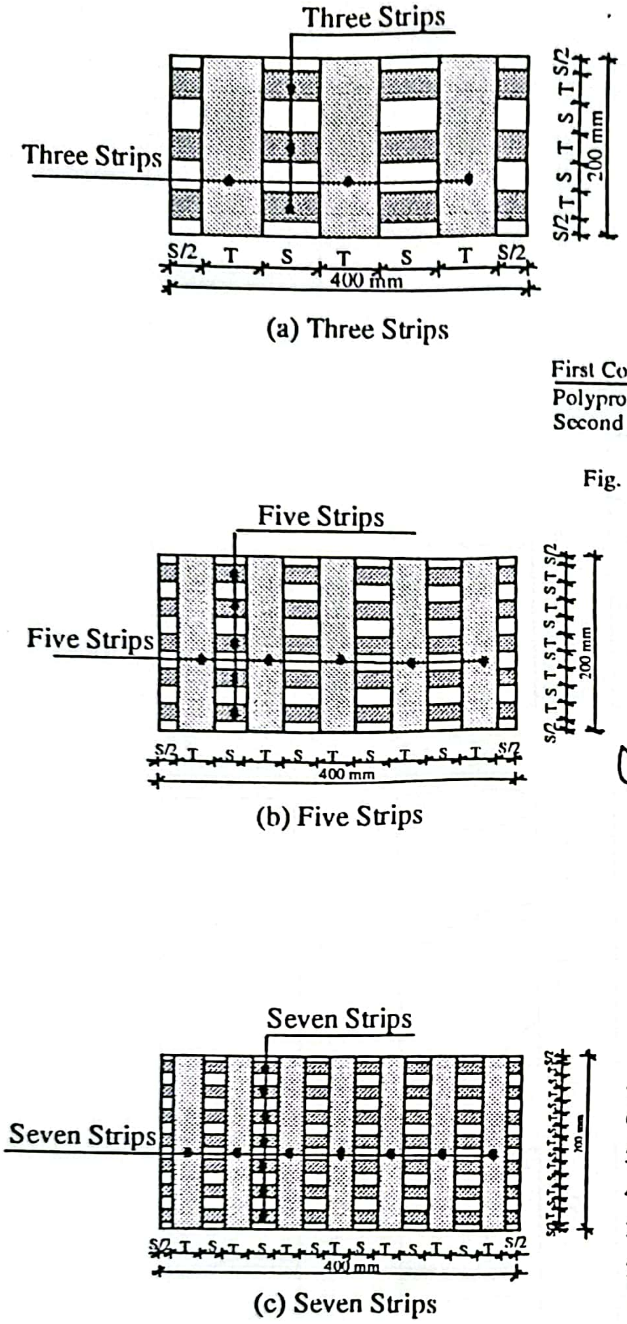


Fig. (4) Strips Arrangements

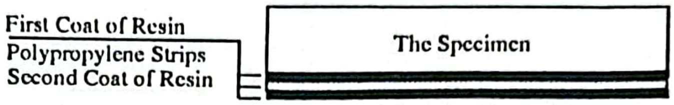


Fig. (5) Application of Polypropylene Strips on the Specimen

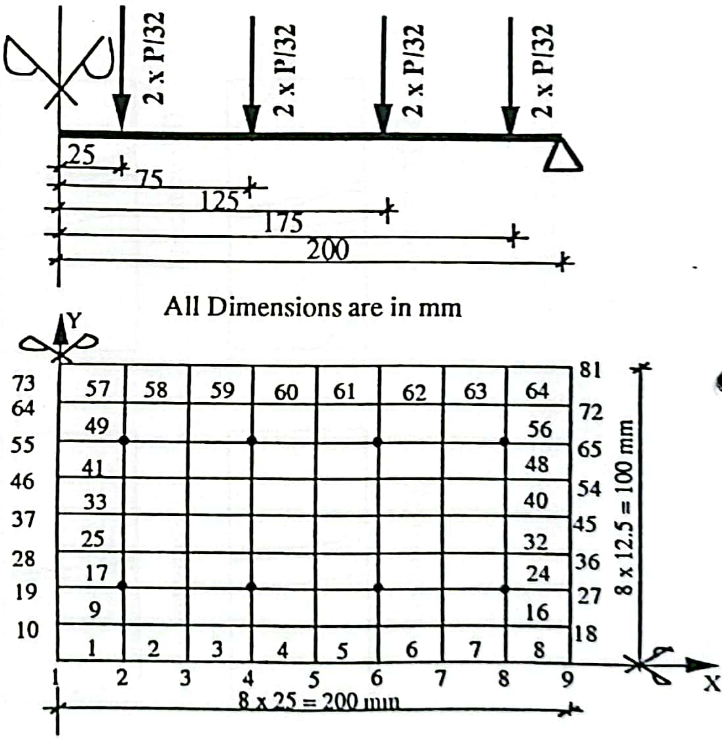


Fig. (6) Loading and Finite Element Mesh of the Quarter the Tested Slab

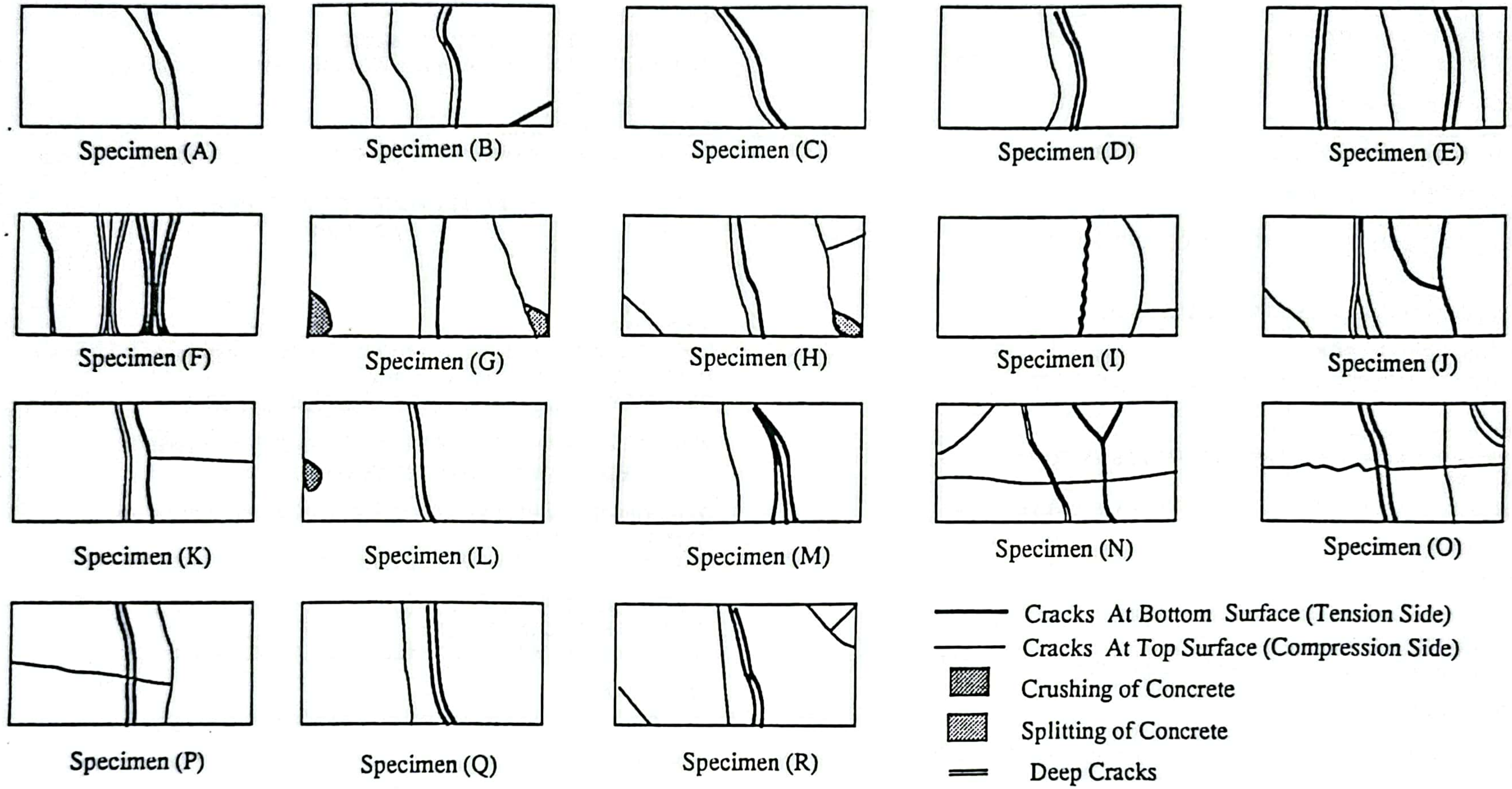


Fig. (7) Schematic View of the Crack Pattern of the Failure Modes

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A COMPARATIVE EXPERIMENTAL STUDY ON RECTANGULAR ONE WAY CONCRETE SLABS REINFORCED USING STEEL REBARS , FIBERS AND POLYPROPYLENE STRIPS

AHMED A. MAHMOUD*

ABSTRACT

The benefits of using Polypropylene sheets and fibers in structural applications have been well recognized and are growing at a very rapid rate. It is specifically recognized that the high tensile strength , low density, excellent corrosion resistance coupled with non - conductive magnetic characteristics of advanced materials are very beneficial to architecture and infrastructure, particularly in construction of reinforced concrete . The combination of Polypropylene sheets, fibers and concrete structural elements can provide new architectural designs when considering the complementary physical properties of each material .The benefits of Polypropylene sheets and fibers are both near term, in saving construction costs, and long term, in extending the useful life of concrete structures .

The repair and seismic upgrading of reinforced and unreinforced slabs are urgently needed. In response to such a need, a comprehensive research program has been initiated at Zagazig University (Faculty of Engineering-Shoubra) to investigate the effectiveness of Polypropylene strips and fibers as a repair and strengthening technique for reinforced and unreinforced concrete slabs.

This paper describes an investigation of the behavior and ultimate flexural strength of concrete slabs reinforced by Polypropylene strips with fibers and/or reinforcing rebars. A total of eighteen 1/10 scale slabs were constructed and tested under vertical uniform loads. The slabs are simply supported along the long direction and tested under uniformly distributed loads through a tree loading system. Based on the observed behavior, the ultimate flexural strength is determined and some concluding remarks have been drawn.

Keywords : Experimental ; Reinforced Concrete Slabs ; Polypropylene; Strips; Fibers; Strengthening ; Retrofitting ; Rehabilitation .

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INTRODUCTION

Carbon, Glass and Polypropylene can be used to reinforce concrete in the form of discontinuous fibers. The most typical application of this, is a method for crack control . Randomly but uniformly distributed fibers embedded in a concrete mix will have the tendency to resist any tensile forces in the concrete section , thus preventing the propagation of cracks, or rather, minimizing the crack widths (Hosny 1994). Carbon Fiber Reinforced Concrete, (CFRC) has been used in Japan and worldwide for a large number of different projects, most notably in the use of curtain wall panels for high-rise buildings. However, future uses of CFRC will definitely include free access floors, dry-bagged premix repair mortars , and permanent forms for columns and beams (Hosny 1996) . The benefits of Polypropylene sheets and fibers are both near term, in saving construction costs, and long term, in extending the useful life of concrete structures (Policelli 1994).

How Fibers Stop Cracks ?

When fibers are introduced into the concrete, and when micro-cracks begin to form and reaches a fiber, it is prevented from further growth. The tiny micro-crack remains in its initial small size. Somewhere adjacent to the first crack , another micro-crack appears and it is also intersected by another fiber and prevented from further growth. In this manner the micro-cracks are not allowed to develop into cracks which could create a reduction in the concrete's integrity (Mashima 1990).Polypropylene fiber reinforcement is considered to be an effective method for providing a good crack control mechanism improving toughness (ductility) properties and impact resistance of concrete materials. The volumetric ratio of fibers being used was 0,10 and 20 percent .

The Role of Fibers in Concrete

Polypropylene fibers are considered to be the best type of fibers to be placed in concrete due to the following : 1) It is inert , and it is not affected by either acids or the alkalis found in concrete ; 2) It will not degrade in concrete ; 3) It is not subject to any form of corrosion ; 4) It is light, with a specific gravity of 0.90 and, therefore, there is a large volume of fibers for a given weight ; 5) It is strong, with a tensile strength of over 1.0 GPa ; and 6) It is an economical fiber and so can be used in adequate quantities without a large expenditure of money (ACI 1991).

Normally, for slabs and other horizontal concrete flat work, Polypropylene fibers are found to be more satisfactory in use than wire mesh or other steel members used as a secondary reinforcement and for these reasons can replace these steel units. Also, it has to be noted that , the fibers cannot replace primary steel reinforcement (Soroushia 1992) . Today, you don't have to settle for the wire mesh method and gamble on it being in the right place. Technology has developed fibermesh fibers, a far superior system of engineered secondary reinforcement which provides automatic high-tech protection in concrete's plastic as well as hardened state.

Fibers in concrete have two major functions. The first is to prevent plastic shrinkage cracking. The second is to reduce the segregation of the components of the concrete. There are a number of other physical properties which are improved by the addition of fibers to concrete. The reduction in permeability of the concrete is an attribute of prime importance with regard to the protection against corrosion. The high toughness index, which is the ability of concrete to sustain a load after initial crack, is also important as it relates both to spalling and to a continuing bound to the steel reinforcement.

The use of Fibermesh mix substantially reduce the formation of plastic settlement and shrinkage cracks by increasing the tensile strain capacity of plastic concrete. These fibers are uniformly distributed throughout the concrete in all directions, providing effective secondary reinforcement for shrinkage crack control. As the concrete hardens and shrinks, microscopic cracks develop. When the micro-cracks intersect a Fibermesh strand, they are blocked and prevented from developing into micro-cracks and causing potential problems. The addition of Fibermesh fibers throughout the concrete also serves to minimize the width and length of those cracks that may appear in the hardened state. Also, fibrillated Polypropylene fibers reduce the rate and amount of bleeding as well as increasing the extensibility of plastic concrete and therefore have a twofold beneficial effect on plastic settlement cracks (Kraai 1994).

Also, within the commonly employed dosages of Fibermesh, the viscosity of the fresh concrete, i.e., its ability to become worked into the desired position by vibration, is essentially unaffected by the addition of Fibermesh to the fresh concrete.

The normal dosage of Polypropylene fibers is 0.9 Kg per cubic meter of concrete. The fiber length is usually 18 mm . The fibrillated bundles of fibers prevent balling during mixing and it is separated into individual fibers and become evenly distributed throughout the concrete. There are approximately 7 million fibers per cubic meter or about 7 fibers per cubic centimeter (Kraai 1994).

Physical Properties of Polypropylene Fibers and Sheets (Kraai 1994)

1. Absorption	- Nill
2. Specific Gravity	- 0.9
3. Fiber Length	- 3 , 12 , 18 , 38 mm
4. Thermal Conductivity	- Low
5. Electrical Conductivity	- Low
6. Workability	- High
7. Water-Cement Ratio	- 0.50 - 0.60 (Normal)
8. Acid and Salt Resistance	- High
9. Weight of the Sheets / m^2	- 0.3, 0.4 , 0.6 Kg / m^2
10. Flame Retardancy	- Self Extinguishing

Mechanical Properties of Polypropylene Sheets

1. Young's Modulus	- 35 GPa
2. Elongation at Break	- 25 % - 35 %
3. Tensile Strength	- 1.0 - 1.2 GPa

Comparison Between Fibermesh and Secondary Reinforcement

Features	Fibermesh	Wiremesh
1. Reinforces against plastic shrinkage crack formation	Yes	No
2. Holds cracks together	Yes	Yes
3. Reinforces against impact forces	Yes	No
4. Reinforces against shattering	Yes	No
5. Reinforces against abrasion	Yes	No
6. Reinforces against water migration	Yes	No
7. Rustproof and corrosion resistant	Yes	No
8. Non-magnetic	Yes	No
9. Minimum required concrete cover	- 0-	25 mm
10. Three dimensional residual strength	Yes	No
11. Always positioned in compliance with codes	Yes	No
12. Safe and easy to use		

EXPERIMENTAL PROGRAM

Significance of Research

The tests reported in this paper is intended to find the best and most economic way to replace and/or strength the reinforcing steel in concrete slabs. There is no published experimental data exist for such slabs reinforced by Polypropylene strips in addition to Polypropylene fibers. This combination can be adequate for reinforced concrete elements due to it high performance which indicated in the previous section. Also, basic knowledge is needed on the effect of the addition of the randomly oriented fibers on the behavior of reinforced concrete slabs.

A scale factor of ten is selected for this experimental program to model the slab specimens. The selection of scaling is based on the success of previous studies using this scale (William 1966, Gajana 1985, ACI 1970). The choice of this scale factor was primarily based upon the fact that the space and capacity available of the Universal Testing Machine (UTM) used in the experimental program is limited and also loading facilities can be much more manageable and less costly at this scale. Also These tests are used as a comparative case studies between each other under the same conditions.

Eighteen slab specimens were casted and tested (as shown in Figs.1,2 and 3). The major parameters included, the volumetric ratio of fibers, the width, spacing and number of Polypropylene strips (Table 1) were considered.This paper provides the effect of the studied parameters on the behavior and the strength of concrete slabs. Then the factors studied during this investigation were:

1- Studying the effect of Polypropylene fiber doze (0.9, 1.8 Kg/m^3) on the flexural strength of plain concrete slabs (Specimens numbers (1,3,4) or (A,C,D) Table 1).
2- Studying the effect of Polypropylene fiber doze (0.9, 1.8 Kg/m^3) on the flexural strength of reinforced concrete slabs (Specimens numbers (2,5,6) or (B,E,F) Table 1).
3- Investigating the effect of width and spacing of Polypropylene strips on the flexural strength of reinforced concrete slabs (Specimens numbers (5,7,8) or (E,G,H) Table 1).
4- Studying the effect of number, width and spacing of Polypropylene strips on the flexural strength of slabs (Specimens numbers (7 to 18) or (G to R) Table 1).
5- Studying the effect of Polypropylene strips as an alternative material instead of using steel rebars (Specimens numbers (9 to 18) or (I to R) Table 1).

Test Specimens and Materials

Details of eighteen prototype One-way concrete slabs, reinforced by conventional steel rebars and/or Polypropylene strips and fibers are given in Table 1 . Five specimens were reinforced by conventional steel rebars with/without Polypropylene strips and fibers. The dimensions of all specimens are 400 by 200 mm, which were kept constant throughout the study. According to the requirements of the Egyptian code of practice (1995) and ACI requirements (1992) , the thickness of all slabs was 20 mm.

The test specimens were divided into six groups. These groups are : 1) Plain concrete ; 2) Reinforced concrete ; 3) Plain concrete with Polypropylene fibers ; 4) Reinforced concrete with Polypropylene fibers ; 5) Plain concrete with Polypropylene strips and fibers ; and 6) Reinforced concrete with Polypropylene strips and fibers. All specimens have the same dimensions (400 x 200 x 20 mm) , and they are simply supported on the short edge. Table 1 shows the classification of the specimens.

The concrete mix use(s made of ordinary Portland cement of 400 kg/m^3 content. All material size and fibers ... scaled down. The aggregate used was coarse sand to simulate the scale factor. Mix proportions by weight were 1:1.875 for cement and coarse sand respectively. The water / cement ratio was 0.58 by weight. The concrete compressive strength measured at 28 days was 21.1 MPa. Tension tests were conducted on rebars and coated Polypropylene samples to determine the yield strength of the steel rebars , ultimate tensile strength and elongation for both of them. Mechanical properties of reinforcing steel and Polypropylene strips are given in Table 1.

Slabs were casted from the same batch, cured for a period of 28 days and then strengthened by the Polypropylene strips after curing and were allowed to dry for 7 days before testing. A strengthening Polypropylene strips of intensity 0.3 Kg/m^2 of dimensions as shown in Fig.4 and Table 1 were cut and attached to the slab surface with epoxy adhesive meeting the requirements of ASTM (C234, C39,C496,C4476).

Application of the Polypropylene Strips on the Specimens

The pieces of Polypropylene strips were cut. The Polyester resin was then placed in a plastic or glass bowl and mixed with styrenes as a catalyst at a ratio of 10 : 1. The two components were mixed very well. It should be noted that , great care has to be taken during applying , handling and using this material due to its harm effect on the skin of the user when using carelessly . A first coat of the resin was applied on the surface of the slab by using a small hand brush to insure uniform distribution of the resin on the surface of the slab followed by the attachment of the Polypropylene strips. A second coat of the resin was then applied on the top of the strips within half an hour later and before the first coat started to set as shown in Fig.5. A roller was used to insure complete wetting of the strips and inter mix the resin from both coating. Great care was paid to prevent trapping air gaps under the mat which can affect the interface bond condition between the strips and specimen.

Test Procedure

The slabs were tested as a simply supported plate through the long direction and subjected to monotonically increasing uniform vertical load with a displacement control rate of 0.145 mm/sec. The uniform vertical load was applied through a typical tree loading system using a lever arm and a steel ball of diameter 20 mm as shown in Figs.1,2 and 3. This system of loading has been used to simulate the actual uniform loads in practice. During the analysis of results, the weights of the waffle tree loading system has been neglected due to its negligible value and because of these experimental study is a comparative one and the applied vertical load is the target of this tests. The vertical load was applied through the 100 KN Universal Testing Machine (UTM) which has sensitive load cell and internal Linear Variable Differential Transducer (LVDT) to monitor the slab response during testing. All measurements were made in the SI system of units. Measurements for mid point deflections were taken throughout the test by both the internal LVDT of the (UTM) and a dial gage with 0.01 mm accuracy .

RESULTS AND DISCUSSIONS

Deflections

The deflection-load rates for slabs reinforced by Polypropylene strips are nearly 0.85 to 1.17 times that for slabs reinforced by conventional steel reinforcement, which are suitable to serviceability conditions (as shown in Table 1). Figure 6 shows the finite element mesh used to simulate the tested slabs to find the analytical deflection.

Crack Patterns and Failure Modes

In case of slabs strengthen by Polypropylene, the failure modes can be classified to these groups : 1) Yield of rebars ; 2) Rupture of rebars ; 3) Flexural failure; 4) Bond failure of steel rebars; 5) Splitting of the compression zone; 6) Crushing of concrete; 7) Rupture of Polypropylene layers ; and 8) Bond failure of the Polypropylene layers (as shown in Table 1).

Figure 7 shows the observed crack patterns of all specimens at failure. The failure mode of slab specimens strengthen by Polypropylene strips is characterized by the rupture of strips followed by the formation of an inclined cracks in the tension side with / without crushing and spalling in the compression side. The final failure taking place either simultaneously with or subsequent to the formation of this inclined crack and/or rupture of Polypropylene strips. Therefore, the use of Polypropylene strips as a strengthening material for concrete slabs changes the cracking pattern of such slabs as shown in Fig.7 and Table 1.

Behavior of the Specimens

From the analysis of the test results and from Tables 1 and 2 it can be noted that:

1- The ultimate strength of the reinforced concrete slabs with 0.9 Kg/m^3 Polypropylene fibers increases by about 11 % more than the slabs having zero percent fiber content .
2. The ultimate strength of the reinforced concrete slabs with 1.8 Kg/m^3 Polypropylene fibers increases by about 25 % more than the slabs having zero percent fiber content .
3. The use of Polypropylene strips as a strengthening material for plain concrete slabs increases its ultimate carrying capacity by about 4.1 to 10.4 times.
4. The use of Polypropylene strips as a strengthening material for reinforced concrete slabs increases its ultimate carrying capacity by about 2.36 to 2.67 times.
5. The ultimate strength of slabs reinforced by Polypropylene strips, increases with the increase of strips number and width , while decreases with the increase of strips spacings.

ANALYTICAL RESULTS

Analytical study using finite shell element as shown in Fig. 6 has been curried out in the linear stage (up to the first crack occurs) using layered element . The ratio of the predicted and experimental deflection was 0.97. Then, the analytical and experimental results are very close and largely self explanatory.

SUMMARY AND CONCLUSIONS

The work illustrated here was mainly concerned with predicting the experimental and theoretical behavior of concrete slabs strengthen by Polypropylene strips and fibers. From the results in Tables 1 and 2 and from the discussion in the previous sections, the conclusions obtained from this study may be bought out in the following points :

1. Presents of fibers prevent hair cracks after casting concrete due to initial settings and chemical contraction of cement. Also the use of Polypropylene fibers give a smooth surface.
2. Polypropylene fibers improve ductility characteristics of concrete slabs.
3. The ultimate strength of the reinforced concrete slabs with 0.9 Kg/m^3 Polypropylene fibers increased by about 11 % more than the slabs having zero percent fiber content .
4. The ultimate strength of the reinforced concrete slabs with 1.8 Kg/m^3 Polypropylene fibers increased by about 25 % more than the slabs having zero percent fiber content .
5. The use of Polypropylene strips as a strengthening material for plain concrete slabs increases its ultimate carrying capacity by about 4.1 to 10.4 times.
6. The use of Polypropylene strips as a strengthening material for reinforced concrete slabs increases its ultimate carrying capacity by about 2.36 to 2.67 times.
7. The ultimate strength of slabs reinforced by Polypropylene strips, increases with the increase of strips number and width, while decreases with the increase of strips spacings.
8. The use of Polypropylene strips as a strengthening material for concrete slabs change the cracking pattern of such slabs as shown early . The crack width is relatively small, then the use of polypropylene as strengthening material is suitable for serviceability conditions.
9. The deflection-load rates for slabs reinforced by Polypropylene strips are nearly 0.85 to 1.17 times that for slabs reinforced by conventional steel reinforcement, which are suitable to serviceability conditions.
10. The finite element model used in this study, successfully simulated the behavior of slabs reinforced by Polypropylene strips.
11. Based on the previous results, the strengthening by using Polypropylene strips is considered to be an efficient and relatively cheaper method to increase the load carrying capacity and ductility of the slabs than any other methods of retrofitting.
12. Future studies have to be done on higher ratios of Polypropylene fibers to obtain economic solutions with higher strength and ductility .
13. Further research should be pursued prior to allowing the use of Polypropylene strips and fibers as reinforcement for concrete slabs.
14. The benefits of Polypropylene sheets and fibers are both near term, in saving construction costs, and long term , in extending the useful life of concrete structures . Further studies have to be done on the mechanical properties of polypropylene sheets through a long time to study its creep and shrinkage characteristics.

ACKNOWLEDGMENT

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Table (1) Dimensions, Details and Test Results of the Tested Specimens

Spec imen No.	Symbol	Bottom Steel in the Two Directions	Intensity of Fibers (Kg/m3)	Strips in the Long Direction No. of Strips (L)	Strips of Polypropylene Spacing S (mm)	Polypropylene Width of Strips T (mm)	Strips in the Short Direction No. of Strips (N)	Strips of Short Direction Spacing (S) (mm)	Polypropylene Short Direction Width of Strips T (mm)	Failure Load (KN)	Failure Displacement (mm)	Deflection Load Rate (mm/KN)	Failure Mode	Notes
1	A	-	-	-	-	-	-	-	-	1.20	1.20	1.00	Flexural Failure	Control Specimen
2	B	10Φ2	-	-	-	-	-	-	-	5.86	8.20	0.71	Flexural Failure	Control Specimen
3	C	-	0.9	-	-	-	-	-	-	1.58	1.50	0.95	Flexural Failure	
4	D	-	1.8	-	-	-	-	-	-	1.78	1.20	0.67	Flexural Failure	
5	E	10Φ2	0.9	-	-	-	-	-	-	6.52	6.50	0.99	Flexural Failure	
6	F	10Φ2	1.8	-	-	-	-	-	-	7.33	5.90	0.80	Flexural Failure	
7	G	10Φ2	0.9	5	20	20	5	40	40	15.66	8.70	0.56	Flexural - Crushing Failure	Single Spacing
8	H	10Φ2	0.9	5	27	13	5	53	27	13.84	7.70	0.56	Flexural - Rupture Failure of Poly. Strips	Double Spacing
9	I	-	0.9	1	-	400	1	-	200	13.36	8.00	0.60	Flexural - Crushing Failure	One Sheet 400x200
10	J	-	0.9	3	33	33	3	67	67	9.20	5.90	0.64	Flexural - Rupture Failure of Poly. Strips	Single Spacing
11	K	-	0.9	5	20	20	5	40	40	10.30	7.10	0.69	Flexural - Rupture Failure of Poly. Strips	Single Spacing
12	L	-	0.9	7	14	14	7	29	29	12.50	8.70	0.70	Flexural - Rupture Failure of Poly. Strips	Single Spacing
13	M	-	0.9	3	44	22	3	89	45	5.56	4.40	0.79	Flexural - Rupture Failure of Poly. Strips	Double Spacing
14	N	-	0.9	5	27	13	5	53	27	7.78	5.90	0.76	Flexural - Rupture Failure of Poly. Strips	Double Spacing
15	O	-	0.9	7	19	9	7	38	19	10.38	8.40	0.81	Flexural - Rupture Failure of Poly. Strips	Double Spacing
16	P	-	0.9	3	50	17	3	100	33	4.94	3.90	0.79	Flexural - Rupture Failure of Poly. Strips	Triple Spacing
17	Q	-	0.9	5	30	10	5	60	20	7.04	5.40	0.77	Flexural - Rupture Failure of Poly. Strips	Triple Spacing
18	R	-	0.9	7	21	7	7	43	14	9.60	8.00	0.83	Flexural - Rupture Failure of Poly. Strips	Triple Spacing

Properties of Concrete : fcu = 21.1 MPa

Properties of Steel :

ϕ = 2 mm; As = 3.14 mm2

fy = 1.27 GPa; Yield Strain = 0.016

fu = 1.28 GPa; Ultimate Strain = 0.039; Es = 80 GPa

Properties of the Polypropylene Sheets Coted By Epoxy :

Type	Intensity (Kg / m2)	Strength (GPa)
I	0.3	1

Properties of Fibers Thread :

f = 0.76 GPa; Ultimate Strain = 0.049

In the Long Direction: N * T + N * S = 400 mm; Then T + S = 400 / N

In the Short Direction: L * T + L * S = 200 mm; Then T + S = 200 / L

Where

N, L are the number of strips in the long and the short directions.

S is the spacing between strips (mm) & T is the strip width (mm).

S = T in case of single spacing

S = 2T in case of double spacing

S = 3T in case of triple spacing

Polypropylene strips were made from Polypropylene sheets of intensity 0.3 Kg/m2

Table (2) Analysis of the Test Results

(1) The Effect of Fibermesh Doze on the Strength of Plain Concrete

Specimen	A	C	D
Load (KN)	1.2	1.58	1.78
Ratio Related to A	1.000	1.317	1.483
Ratio Related to C	-	1.000	1.127

(2) The Effect of Fibermesh Doze on the Strength of Reinforced Concrete

Specimen	B	E	F
Load (KN)	5.86	6.52	7.33
Ratio Related to B	1.000	1.11	1.25
Ratio Related to E	-	1.000	1.124

(3) The Effect of Polypropylene Strips on the Strength of Reinforced Concrete

Specimen	E	H	G
Load (KN)	6.52	13.84	15.66
Ratio Related to E	1.000	2.123	2.402
Ratio Related to H	-	1.000	1.132

(4) The Effect of Polypropylene Strips (Number, Width and Spacing) on the Strength

(a) Effect of Width

Three Strips

Specimen	J	M	P
Load (KN)	9.2	5.56	4.94
Ratio Related to J	1.000	0.604	0.537
Ratio Related to M	-	1.000	0.888

Five Strips

Specimen	K	N	Q
Load (KN)	10.3	7.78	7.04
Ratio Related to K	1.000	0.756	0.683
Ratio Related to N	-	1.000	0.905

Seven Strips

Specimen	L	O	R
Load (KN)	12.5	10.38	9.6
Ratio Related to L	1.000	0.83	0.768
Ratio Related to O	-	1.000	0.925

Table (2) Analysis of the Test Results (Cont.)

(b) Effect of Spacing (Number of Strips)

For specimen (I) (one strip 400 x 200 mm) the strength was 13.36 KN which is 11.13 and 2.28 times of the specimens (A) and (B) respectively. $\lambda = 100$ %

S = T (Single Spacing , Spacing = Width) $\lambda = 50$ %

Specimen	J	K	L
Load (KN)	9.2	10.3	12.5
Ratio Related to J	1.000	1.12	1.359
Ratio Related to K	-	1.000	1.213

S = 2 T (Double Spacing , Spacing = Double The Thickness)

Specimen	M	N	O
Load (KN)	5.56	7.78	10.38
Ratio Related to M	1.000	1.4	1.867
Ratio Related to N	-	1.000	1.334

S = 3 T (Triple Spacing , Spacing = Triple the Width) $\lambda = 25$ %

Specimen	P	Q	R
Load (KN)	4.94	7.04	9.6
Ratio Related to P	1.000	1.425	1.943
Ratio Related to Q	-	1.000	1.364

(5) Comparison of Strength (Specimens Having Reinforcing Steel and/or Polypropylene Strips)

Specimen	A	B	I	J & K & L	M & N & O	P & Q & R
Load (KN)	1.2	5.86	13.36	9.2 to 12.50	5.56 to 10.38	4.94 to 9.6
Ratio Related to B	0.200	1	2.28	1.57 to 2.13	0.95 to 1.75	0.84 to 1.64

(6) Comparison of Steel Rebar and Polypropylene Costs (Specimens Having Reinforcing Steel and/or Polypropylene Strips)

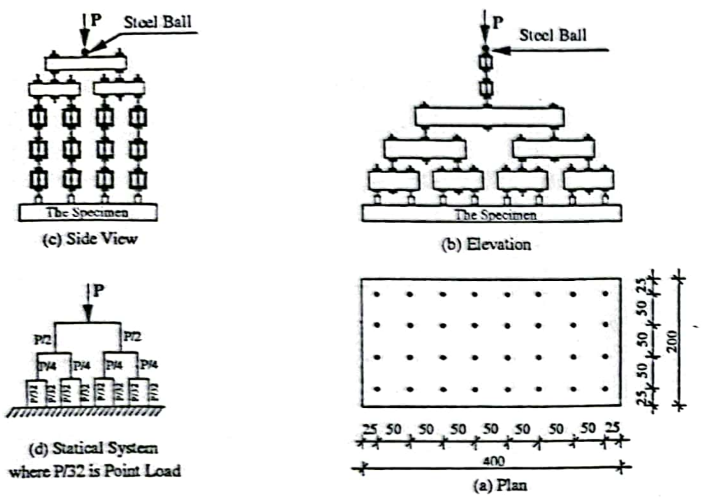
Specimen	A	B	I	J, K & L	M, N & O	P, Q & R
Ratio Related to B	-	1	3	1.5	1	0.75

Where :

S is the spacing between Polypropylene strips

T is the width of the Polypropylene strips

$$\lambda = \frac{\text{Surface area of Polypropylene strips}}{\text{Surface area of the specimen}}$$



All Dimensions Are in mm

Fig. (1) Schematic View of the Loading System

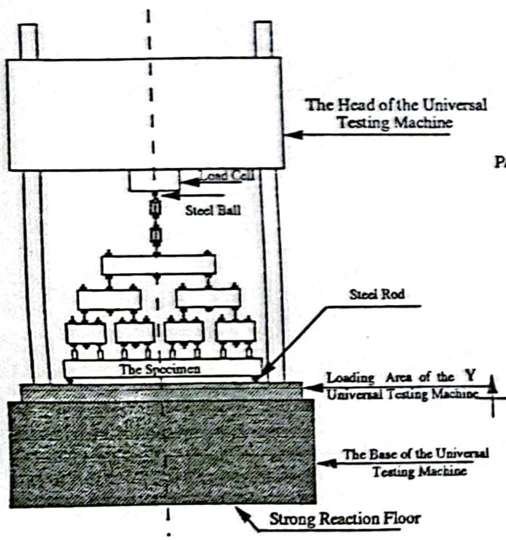
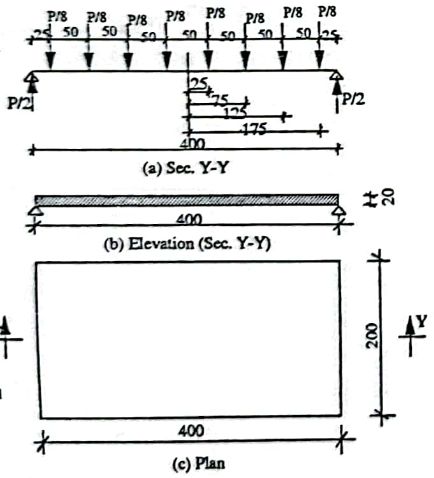


Fig. (2) Schematic View of the Test Set Up



All Dimensions are in mm

Fig. (3) Loading System, Dimensions of the Tested Slab

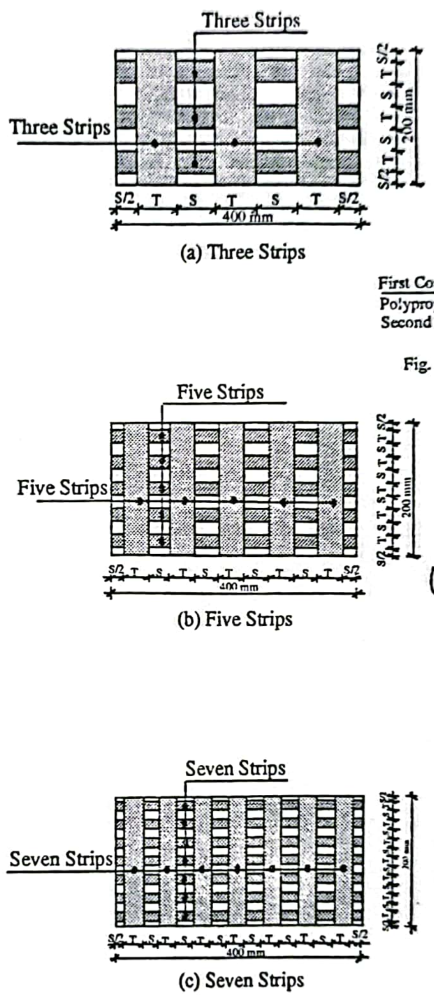


Fig. (4) Strips Arrangements

Fig. (5) Application of Polypropylene Strips on the Specimen

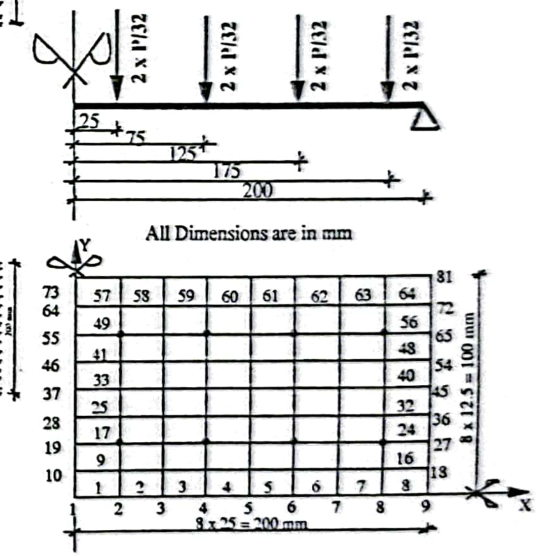


Fig. (6) Loading and Finite Element Mesh of the Quarter the Tested Slab

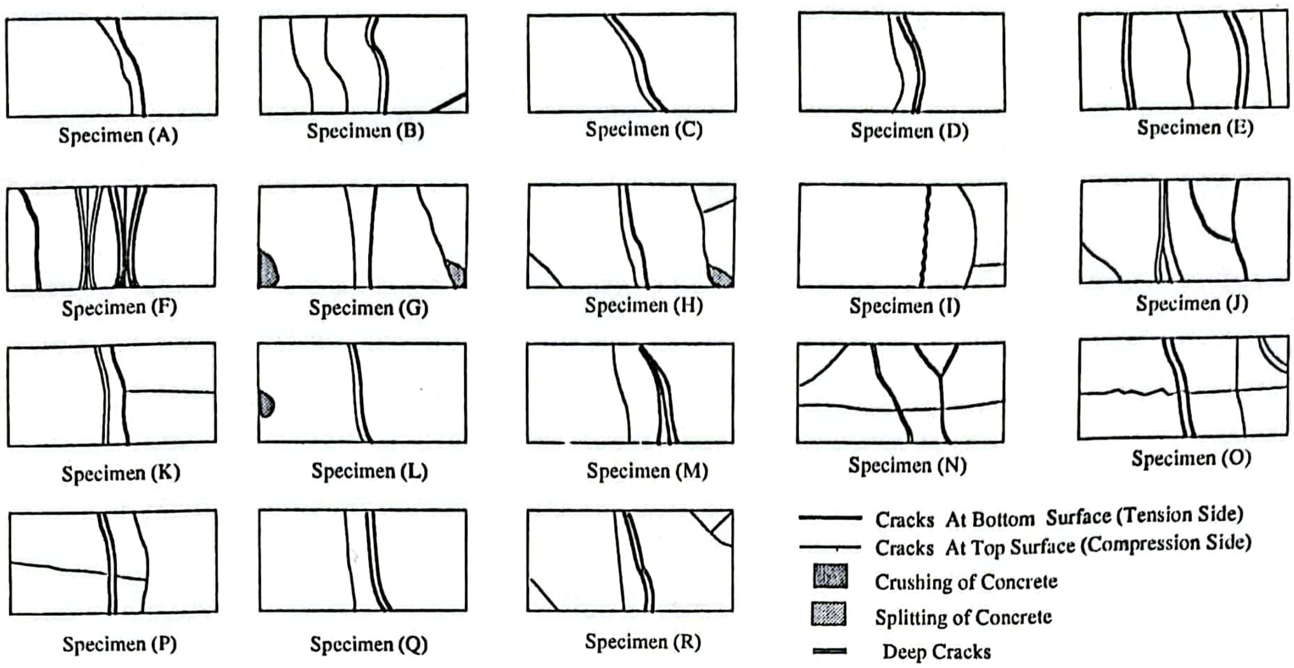


Fig. (7) Schematic View of the Crack Pattern of the Failure Modes