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# Strength of Reactive Powder-Ferrocement Slabs under Static Load

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***Abstract:***
This research aims to investigate experimentally the structural response of ferrocement slabs made with modified reactive powder concrete subjected to concentrated loading. The experimental work consist of casting and testing twelve ferrocement slabs of dimensions (500*500*50) mm made with reactive powder concrete (contains Fly Ash as pozzolanic material) to enhance the strength of the ferrocement slabs. The parametric study adopted in this work includes using of three volumetric percentage ratio (0% , 0.5% and 1%) and the two number of wire mesh layers (2 and 4) as well as two fly ash ratios (0% and 10%). For the different RPC mixes, three cubes (70 mm) and three prisms (40*40*160)mm were cast and tested to determine the compressive strength and modulus of rupture. The comparisons between all specimens are based on first crack load, ultimate load carrying capacity, deflection, crack pattern and mode of failures.

Results showed that the steel fibers, wire meshes and fly ash have a significant effect on the strength capacity of the tested slabs. The minimum slab strength is equal to (12.2 kN) with steel fibers ratio, wire steel mesh layer and fly ash ratio equal to ( 0%, 2 and 0%) respectively , while the maximum slab strength is equal to (45.9kN) with steel fibers ratio, wire steel mesh layer and fly ash ratio equal to (1%, 4 and 10%) respectively.

Generally, the effect of steel fibers and wire meshes is increased in the presence of fly ash which enhance of the bond between the steel reinforcement (steel fibers and wire meshes) then increase its contribution of slab strength.

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## I. INTRODUCTION

Concrete is acknowledged to be a relatively brittle material when subjected to normal stresses and impact loads because of its low resistance to crack, where its tensile strength is about one tenth of its compressive strength. consequently of these characteristics, concrete element could not support such loads and stresses that usually occur, majority on concrete slabs and beams.

Many researches are required to find the most suitable material and design that can overcome these drawbacks. ***Ferrocement*** is a material that have a small thickness and at the same time strong (**PushyamitraDivekar, 2011**) which offer a possible solution to roofing concrete problems (**Abdullah and Takiguchi, 2003**). Ferrocement elements is further durable than timber elements and cheaper than imported steel (**Hago et al.**). ***Ferrocement*** is reinforced with closely layers of comparatively small wire diameter mesh and small diameter rods as skeletons reinforcement **(ACI Committee 549, 1997)** with using of rich cement mortar; that does not require gravel and used for special constructions work.

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Ferrocement has a stiffness, punching shear, and impact resistance higher than the reinforced concrete. These properties are achieved in structures with a thickness that is generally less than 50mm, a dimension that is nearly unthinkable in other forms of concrete construction. So, before fall, its subject to high deflections. It is durable, economical, lightweight, weather resistance, and versatility for comparing with the reinforced concrete **(Sakthivel, 2011)**.

An examples of structural elements that constructed using ferrocement are **(ACI Committee 549, 1997)**:flooring and roofing, silos and tanks containers, fire resistant structures, heavy floors tiles, manhole covers, pipes, sewer lines and many other structures.

(**Jaafer, 2018**) conducts a study to investigate the effect of Slurry Infiltration Fiber Concrete (SIFCON) matrix on flexural response of Ferro cement slabs. A total of fourteen Ferro cement slabs with SIFCON of size (500*120*25 mm) are cast and tested. The major variables studied in this investigation include the number of mesh layers and various volume ratio of discrete steel fiber (2.5, 5, 7.5 and 10)%. He concluded that the inclusion of SIFCON in the Ferro cement slabs can significantly improve its flexural strength and energy absorption may be concluded. Furthermore, reduction in crack width with a large number of cracks is observed in specimens contain SIFCON compared to control specimens.

**Shanna et al, (2007)** studied seventy two ferrocement slab specimens with dimensions of (350×75×12.5)mm under flexural loading. The parametric study includes number of mesh layers (2 and 4), the type of fiber (steel and glass), the geometry of mesh and the spacing of wires of the mesh (small, medium, and large). It was concluded that the addition of 2% of brass coated steel fibers to the matrix of ferrocement led to a considerable increase (2.6 times) in flexural strength compared to the matrix without fibers and the increasing the number of steel mesh layers from 2 to 4 caused an increase in the member flexural strength, for the same mesh layers number.

Reactive powder concretes RPC is one of the new concrete type have excellent properties. RPC characterized by ultra high mechanical properties, are multi-component cementitious composites, in which the role of the binder is mainly played by cement and pozzplanic materials ( like silica fume and fly ash).

Reactive powder concrete (RPC) is the latest generation of concrete technology development. It is also classified as a form of Ultra High Performance Concrete (UHPC) **(Hiremath&Yaragal, 2017)** which is characterized by a dense mixture of high cement content, superior mechanical properties, high durability, toughness of fracture, fire resistance, and in most cases containing a steel fiber to reduce its brittleness **(Sadrekarimi, 2004)**.

The expression (RPC) is used to describe a superplasticizer, fiber-reinforced, silica fume-cement mixture with very low water-binder ratio (w/b) distinguished by the existence of ultra fine quartz sand of less than (600 μm) as an alternative of the used ordinary aggregate. The elimination of coarse aggregate has an important role in increase the microstructure bonding and then in the performance of the RPC to keep away from the weakness among the cement and the aggregate. Nevertheless, because of the make use of ultra fine sand in place of ordinary aggregate, the cement quantity of RPC is relatively high and reach to (900- 1000 $kg/m^3$).

The idea behind the RPC is to decrease the defects such as micro cracks, the interior voids which help increasing the homogeneity of the mix and decreasing the different concrete tensile strain and subsequently lead to increase load carrying capacity and great durability of RPC **(AL Saffar, 2018)**.

**Abdulrahman et al.** (2018) investigated the influence of various curing conditions on the reactive powder concrete mechanical properties (compressive strength, splitting tensile strength and modulus of rupture). Three curing methods are used; exposure to hot steam for 5 hours daily until 28 days

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according to **ASTM C684-99,** immersion in water with temperature of 90 $^{O}$C for 5 hours daily and immersion in water with temperature degree of 35 $^{O}$C (which considered as the reference curing method). Also. the research includes study of the influence of addition silica fume as ratio of cement weight on the reactive powder concrete mechanical properties with different ratios (5,10 and 15)%. The results demonstrated that the curing method of immersion in hot water at temperature 90 $^{O}$C indicated best enhancing of the RPC mechanical properties for the all silica fume percentages. As well, the best used percentage of silica fume was 10% for the all curing methods used in the study.

## II. Problem Statements

The traditional reinforced concrete slabs used in building have a heavy weight and relatively high cost, thus, the use of ferrocement slabs are represent one of the solution for some construction cases. However, ferrocement slabs have relatively lower strength compared with the traditional reinforced concrete slab. Thus, this research aims to increasing the strength of ferrocement slab by using a modified reactive powder concrete RPC (contains Fly Ash as pozzolanic material) instead of traditional cement mortar.

**Study Aim**

The aim of this research is to investigate the strength and behavior of ferrocement slabs cast from Reactive Powder Concrete RPC (contains Fly Ash as pozzolanic material) under effect of static loads. The parametric study which have been adopted in this study including the effects of the following parameters: number of layers of steel mesh, volume fraction of steel fibers and the adding "Fly Ash" as a pozzolanic material to the mix.

## III. Experimental work

### 3.1 The Used Materials

### 3.1.1 Cement

Ordinary Portland cement (Type I) is used in the experimental work. The results of cement test showed that the used cement is confirmed to the Iraqi specification No.5/1984.

### 3.1.2 Fine aggregate (Silisious sand)

The natural siliceous sand used is sieved on 600 μm sieve which is suitable to be used in casting of RPC. The grading is satisfied according to the B.S. specification No. 882/1992.

### 3.1.3 Fly Ash

The used fly ash produced by the Turkish Company (ISKENment-TR), which is a by-product of the ignition of powdered coal in the plants of power as it is extracted from coal-burning gases during production Electricity. In this work, the fly ash is added to the mix as a replacement ratio of cementious materials weight.

### 3.1.3Superplasticizer

The admixtureSika®Viscocrete 5930-L supplied by Sika company is used to produce high performance concrete and mortar. It meets the requirements for super plasticizer according to ASTM-C 494 Types G and F.

### 3.1.4 Steel fibers

The steel fibers used in this study are straight steel fibers. A type with ultimate tensile strength reached to 2600 MPa with length of approximately 15mm and a diameter of 0.2mm (Aspect ratio of 75) that are generally used in producing the RPC is used. The fibers are gold-colored because a brass layer coating is applied to the fibers during the manufacturing producing.

### 3.1.5 Steel wire mesh

The locally available welded wire mesh was used as a reinforcement locally known as a chicken wire mesh. The average diameter of grids is 0.68 mm and opening size is 13mm distributed equally in two orthogonal directions with yielding stress ($f_y$) equal to 389 MPa.

### 3.2 Concrete Mix

To produce the RPC, the material mix proportions stated in table (1) is used in this work. This proportion is based on previous research **(Al Bayati, 2017**).

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**Table (1) Proportions of Mix**

| ingredients | Fine sand (600 µm) | Cementiuos materials | | Water** | SP*** |
|---|---|---|---|---|---|
| | | Cement | Fly Ash* | | |
| Amount (kg/m³) | 1060 | 954 | 106 | 215 | 24, 28 and 32 |

* 10% partial replacement by weight cementious materials.
** Water/binder (w/b) ratio = 0.2
***2.25%,2.26% and 3% of Cementiuos materials (cement+fly ash) weight for $V_f$= 0% , 0.5% and 1% respectively

Steel molds are used for casting slabs with inner dimensions of (500 *500*50)mm.

Mixing process is significant to get the necessary workability and homogeneity of concrete. Mixing was conducted using a drum mixer of capacity(0.05)m$^3$.

**3.3 Tests**

**3.3.1 Flow Table Test for Fresh Concrete**

The flow table have been used to determine the workability for all RPC mixes accordance with **ASTM C1437-01**. for all mixes, the flow table values are 110 ±5%. This test is carried out immediately after mixing process operation by drop the table which contains the RPC specimen twenty five times in fifteen second, Fig. (1).

**3.3.2 Compressive Strength Test**

A cubes of dimensions (70 mm) were used to determine the compressive strength and tested in accordance with BS (116_1881)The compression tests are conducted using a compression machine of (2000) kN capacity. Average of three specimens was adopted for each mix.

Fig. (1) Flow Table Test

Fig.(2) Slabs flexural test

**3.5.2.2 Modulus of Rupture ($f_r$ )**

Flexural strength (modulus of rupture) $f_r$ tests were carried in accordance with ASTM C78 on three standard mortar prisms with dimensions of (40×40×160) mm were tested at ages 28 days.

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**3.5.2.3 Flexural Strength Test**

All slabs specimens of dimensions (500 × 500 × 50)mm were tested by using the two columns Universal Testing Machine (SANS) with maximum range capacity of (2000) kN, see figure (2) .

All slab specimens have been tested as a simply supported beams under static loading with one concentrated loads center of slab. The deflection is recorded with the corresponding load and the loading continued until the final failure of the slabs.

Crack patterns has been monitored and the failure mode was observed. Also, the locations of the first and the other following cracks were marked on the slab. The failure load has been recorded.

**4.2 The Parametric Study**

The main goal of this research is to study the behavior of ferrocement slabs made with RPC. Thus; tests were conducted on (12) RPC-ferrocement slabs with different mixtures.The parametric study which have been adopted in this study including the effects of the number of layers of steel mesh, volume fraction of steel fibers and the and the adding of "Fly Ash" as a pozzolanic material to the mix on the behaviour of the tested slabs as well as on the mechanical properties of the produced RPC. Table (2) presents the variables take on for RPC mixes while table (3) presents the parametric study of the tested slabs throughout the current study.

**Table (2) variables of the used mixes**

| Mix No. | Steel Fibers % | Fly Ash % |
|---|---|---|
| M1 | 0 | 10 |
| M2 | 0.5 | 10 |
| M3 | 1 | 10 |
| M4 | 0 | 0 |
| M5 | 0.5 | 0 |
| M6 | 1 | 0 |

**Table (3) Parametric study of the RP-Ferrocement slabs**

| Specimen symbol | No. of steel mesh layers | Steel Fibers % | Fly Ash % |
|---|---|---|---|
| S1 | 2 | 0 | 10 |
| S2 | 4 | 0 | 10 |
| S3 | 2 | 0.5 | 10 |
| S4 | 4 | 0.5 | 10 |
| S5 | 2 | 1 | 10 |
| S6 | 4 | 1 | 10 |
| S7 | 2 | 0 | 0 |
| S8 | 4 | 0 | 0 |
| S9 | 2 | 0.5 | 0 |
| S10 | 4 | 0.5 | 0 |
| S11 | 2 | 1 | 0 |
| S12 | 4 | 1 | 0 |

**4.3 Results and Discussion**

**1- Mechanical Properties of RPC**

Figure (3) Shows the compressive strength values of cube specimens of RPC. It can be shown the maximum compressive strength is for mix have steel fiber $V_f$=1% while the mix have no steel fiber content ($V_f$ =0%) have the less value. Generally the presence of steel fibers in the concrete will prevent the total splitting of the specimens under compressive failure. Also, the presence of fly ash have been increased the concrete compressive strength for all different steel fibers ratios.

The test results of the modulus of rupture M.O.R of RPC mixes are presented in figure (4). It can be observed that the increasing of the steel fiber volumetric ratio ($V_f$) have a great influence in increasing of the value of modulus of rupture of the mix. The highest value of M.O.R is for fiber ratio ($V_f$=1%), while the lowest value is for the mix have no steel fiber ($V_f$ =0%). This is due to that the steel fiber have high tension strength compared with the concrete and can carry the tensile strength after concrete failure due to tension stresses as well as arresting and bridging the cracks which occur in the concrete, which main increasing to resisting tensile stress. As well, the presence of fly ash with percent 10% will increase the M.O.R for the all steel fiber ratios.

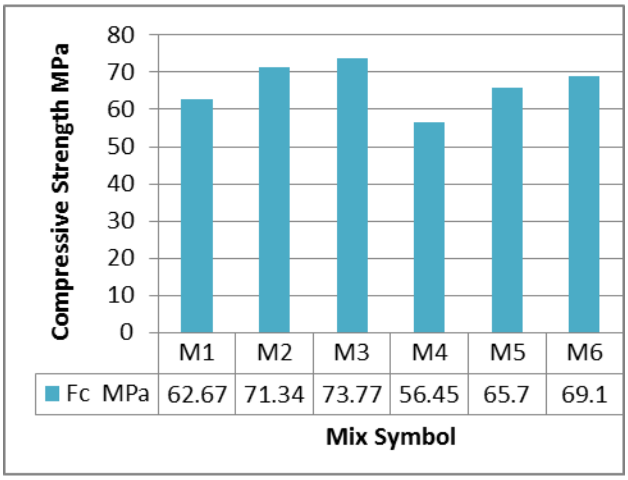


**Fig.(3)Compressive Strength for RPC mixes**

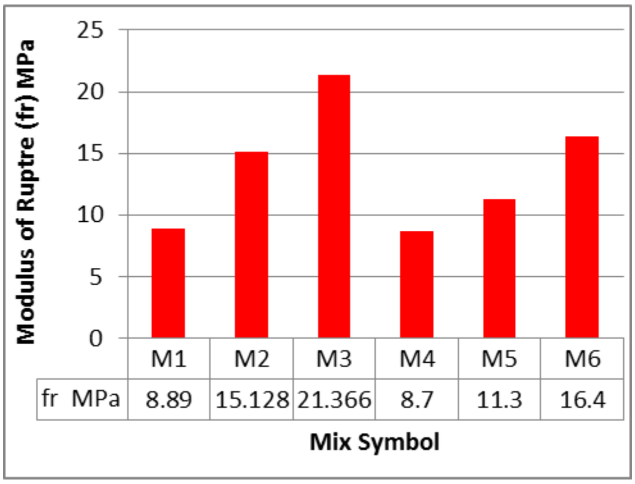


**Fig.(4) M.O.R for the RPC mixes**

### 4.3.2 Flexure Strength of Slab

Table (4) presents the first crack, ultimate load as well as the deflection values at failure of the tested slabs for the adopted variables.

**Table (4) First crack load, ultimate failure load and deflection at ultimate load values**

| Specimen symbol | No. of layers | Steel Fiber ($V_f$ %) | Fly Ash % | Crack Load $P_{cr}$ (kN) | Ultimate Load $P_u$ (kN) | $P_{cr}/P_u$ | Deflection $\Delta u$(mm) |
|---|---|---|---|---|---|---|---|
| S1 | 2 | 0% | 10% | 4.9 | 14.8 | 0.33 | 0.6 |
| S2 | 4 | 0% | 10% | 6.2 | 25 | 0.25 | 1.3 |
| S3 | 2 | 0.5% | 10% | 7.4 | 24 | 0.31 | 2.04 |
| S4 | 4 | 0.5% | 10% | 8.9 | 33 | 0.27 | 5.04 |
| S5 | 2 | 1% | 10% | 10.2 | 31 | 0.33 | 3.42 |
| S6 | 4 | 1% | 10% | 10.2 | 46.3 | 0.22 | 7.66 |
| S7 | 2 | 0% | 0% | 4.3 | 12.2 | 0.35 | 2.3 |
| S8 | 4 | 0% | 0% | 4.9 | 16.5 | 0.3 | 2.29 |
| S9 | 2 | 0.5% | 0% | 5 | 21 | 0.24 | 7.05 |
| S10 | 4 | 0.5% | 0% | 7.1 | 31 | 0.23 | 7.96 |
| S11 | 2 | 1% | 0% | 8.2 | 26.5 | 0.31 | 5.1 |
| S12 | 4 | 1% | 0% | 8.8 | 39 | 0.23 | 5.5 |

### 4.3.2 First Cracking and Ultimate Loads Values

The values of first crack load for the tested specimens are presented in table (4). It can be shown the that the first crack loads $P_{cr}$ are varied (as percentage from ultimate failure load $P_u$) from about (22%) for Slab S6 (with 1% steel fibers and four wire mesh layers) to about (35%) for Slab S7 (with 0% steel fibers and two wire mesh layers). This means that the increases the steel ratio (as a fiber percentage or wire mesh layers) increase the range between the first crack load level and final failure which means increasing the safety related to the failure prediction. Regarding to the ultimate failure load values, It can be seen that there is a large variation of the $P_u$ values for the different tested slabs. The $P_u$ values ranged from 12.2 kN for slab S1 (with $V_f$=0%, layer No.=2 and F.A=0%) to 46.3 kN for slab S6 (with $V_f$=1%, layer No.=4 and F.A=10%). It can be concluded that the increases of steel fiber volumetric percentage $V_f$ from 0% to 1% and increasing number of wire mesh layer from (2)

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to (4) is largely increase the ultimate failure load of RP-Ferrocement slab specimens. As well, it can be shown that the using of fly ash with percentage of 10% will increase the ultimate load capacity for all steel fibers ratios and for all wire mesh numbers. The maximum increased in ultimate load due to addition of fly ash to the mix is reached to 51% (for the slabs with steel fibers ratio 0% and four wire mesh layers). The deflection at ultimate load is increased with increasing the ultimate load value, where it begin from 0.6 mm for slab S1 to 7.66 for slab S6.

### 4.3.3 Load –Deflection Relationship

The load versus mid-span deflection relationships of the tested specimens at all stages of loading up to failure have been constructed and drawn in figure (5). Generally, the load-deflection relationships for the tested slabs can be divided into three stages. In the first phase before initiation of racks, the load-deflection relationship is linear until the initiation of the first cracks. In the second phase, the propagation of the cracks makes additional loss of initial stiffness and nonlinear behavior is observed up to steel mesh yielding . Then the third phase starting with yielding of steel mesh and finish with slab failure. The stiffness of the slab is further weakened.

### 4.3.4 Effects on of Number Wire Mesh Layers, Steel Fibers and Fly Ash

- Related to the wire mesh effect, it can be concluded that the increase of the wire mesh number from (2) to (4) will generally increase the slab strength for the all steel fiber percentage ratios and for fly ash ratios as well as the deflection at first crack and the ultimate load failure. This increase is reached to 80% for the slabs group of steel fiber $V_f$=1% and fly ash 10%.
- Related to the steel fiber percentage effect**,** it can be concluded that the increase of the steel fiber volume ratio $V_f$ from will generally increase the slab strength for the both wire mesh numbers and for fly ash ratios with increasing the deflection at first crack and the ultimate load. This effect is clearer for the slabs of lower layers number (i.e. for 2 layers) with maximum increasing in ultimate load reached to about 74% when increasing $V_f$=0% to 1% .

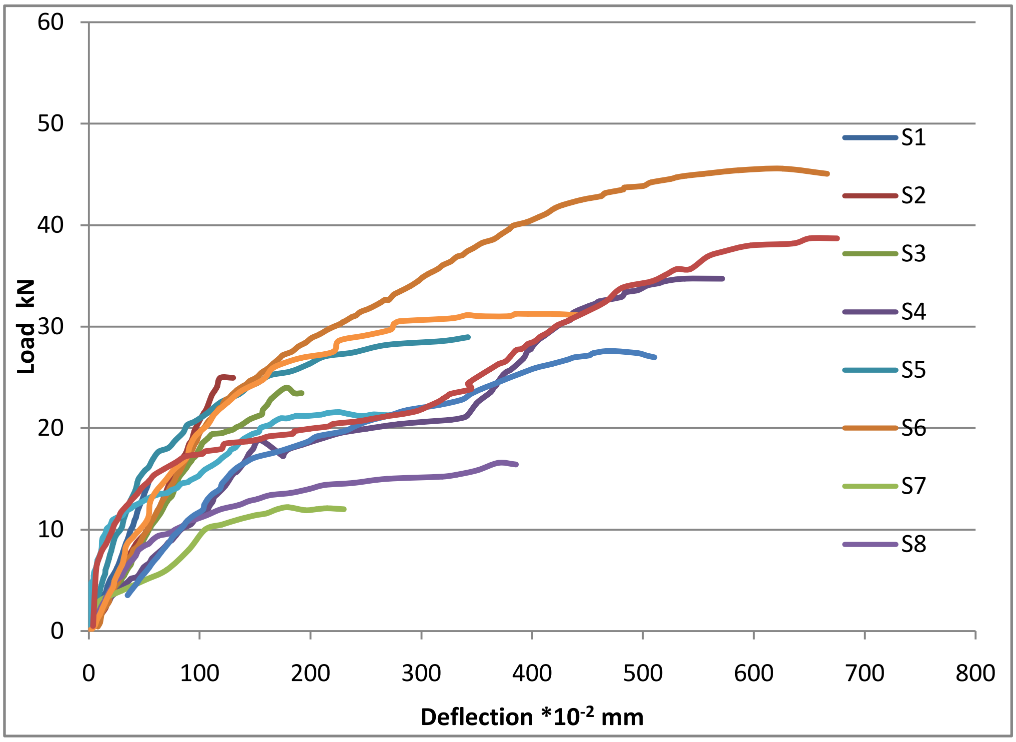


**Fig.(5) Load - Deflection relationship for the all tested slabs**

- Related to the Fly Ash effect**,** It can be concluded that adding the fly ash with replacement ratio 10% will generally increase the slab strength (first crack load and ultimate load) for the both wire mesh numbers and steel fiber ratios. The maximum increasing in ultimate load reached to 51%.

#### 4.3.7 Failure Modes

The slabs modes of failure due to flexural tests are presented in figure (6). The failure modes are vary from one major crack (as shown clearly in slab S3) to minor multiple cracks failure for higher steel fiber ratio or higher wire mesh layer (as observed in slabs S7 and S8). Generally, when the amount of the reinforcement steel (steel fiber ratio or number of wire mesh layers) is increased, then the number of slab cracks at failure is also increased.

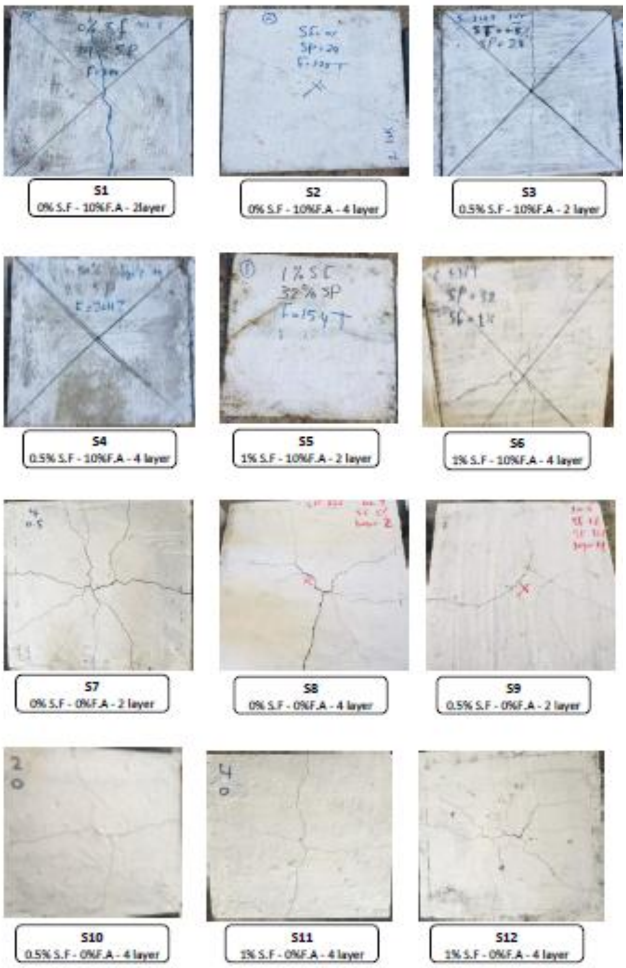


Figure (6) Failure modes of the tested slabs

## IV. CONCLUSION

The following points can be concluded from the current experimental work:

5.1 Mechanical Properties

1. Concrete made from RPC showed a high compressive strength compared with the ordinary concrete. The maximum compressive strength at 28 day age is (73.7 MPa) for steel fiber ratio (Vf=1%) and fly ash ratio (10%) while the minimum compressive strength is (56.4 MPa) for steel fiber ratio (Vf=0%) and fly ash ratio (0%).
2. Concrete made from RPC showed a high flexural strength compared with the ordinary concrete. The modulus of rupture of mixes increased largely when increasing of steel fiber ratio. The M.O.R reached to (16.47 MPa) for mix with steel fiber ratio (Vf=1%) with no Fly Ash. When adding the Fly Ash with percentage of (10%) the M.O.R is increased to (21.366 MPa) with the same steel fiber ratio.

5.2 Flexure Strength of Slab

1. The flexural strength of the ferrocement-RPC slab is increased when increasing of steel fiber ratio for the first crack load Pcr and for the ultimate crack load Pu for the all wire mesh layer number and fly ash ratios. The minimum first crack strength and ultimate crack strength was (4.3 kN) and (12.2 kN) for slab S7 (of two wire mesh layers, 0% steel fiber and 0% fly ash), while the maximum first crack strength and ultimate crack strength was (10.2 kN) nd (46.3 kN). This means that the increases the steel ratio (as a fiber percentage or wire mesh layers) increase the range between the first crack load level and final failure..
2. The adding of steel fiber to the ferrocement-RPC slab will increase the range between the first crack and the final ultimate crack. This range is also increased when increasing of wire mesh numbers, which mean increasing of the safety for the final failure predict. The maximum ratio between first crack and ultimate load is (35%) for slab S7, while the maximum ratio between first crack and ultimate load is (22%) for slab S6.

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3. The flexural strength of the ferrocement-RPC slab is increased when increasing of number of layers from (2) to (4) layers. for the first crack load Pcr and for the ultimate crack load Pu for the all steel fiber percentage and fly ash ratios.

4. The addition of fly ash with percentage (10%) (as replacement with cement weight) will increase the crack load as well as the ultimate load for the all steel fibers ratios and for the all wire mesh layer number.

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