

# Ferrocement Blocks under Compressive Loads

Lecturer Dr. Abdulkader G. Anwar

Department of Geotechnical Engineering, Faculty of Engineering, Koya University, Erbil, Iraq

**Abstract** - Ferrocement blocks or masonry blocks are a type of thin concrete made of cement sand matrix with closely spaced relatively small diameter wire meshes, with or without steel bars of small diameters called skeletal steel. Masonry is a well proven building material possessing excellent properties in terms of appearance, durability and cost in comparison with alternatives. However, the quality of the masonry in a building depends on the materials used, and hence all masonry materials must conform to certain minimum standards. The basic components of masonry are block, and mortar, the latter being in itself a composite of cement, lime, sand and sometimes of other constituents.

Such blocks in addition to wire mesh were investigated experimentally under compressive strength. A total of nine blocks were constructed and tested under compressive load. The dimensions of hollow blocks were (400x200x200) mm. The main parameters considered in the present investigation were the number of wire mesh layers (2), and type of constituent materials (mix proportions). The behavior of block models under compressive loading was observed by reading the loads and observing the initial and crack patterns and mode of failure. It is concluded that the compressive strength of ferrocement blocks having (2 wire meshes) is considerably higher than that of mortar blocks without mesh layers only by about (73.4 %). The behavior is less significantly affected when wire mesh are added to ferrocement blocks with (2 mesh layers), the increase was about (57%) with concrete blocks, and finally the presence of wire mesh reinforcement in the blocks decreases the water absorption compared with the corresponding concrete blocks.

**Keywords** - Ferrocement block, Concrete block, Mix proportions, Compressive strength, Splitting strength, Flexural strength.

## I. INTRODUCTION

Ferrocement is a form of thin reinforced concrete structure in which a brittle cement-sand mortar matrix is reinforced with closely spaced multiple layers of thin wire mesh and/or small diameter rods, uniformly dispersed throughout the matrix of the composite. Ferrocement has taken a significant place among components used for construction, for its specification of durability and strength, and its small thickness, which makes it a component suitable for constructing many lightweight structures. From the architectural standpoint, ferrocement is very useful, since it can be molded into different shapes for

different designs. These facts ensure a significant future for the use of this component, and for these reasons, a careful study of the characteristics of this component was made, to determine its specifications from the structural engineering standpoint, to make it easier for use [1]. Ferrocement is a special form of reinforced concrete and its production, performance, strength behavior and potential utility make it imperative that it must be treated as a separate material. Ferrocement has been widely and successfully used for the construction of booths, domes, silos, tanks, folded roof structures, wall panels, barges, composite column constructions, ferrocement shell roofs or roofing elements, large span vaulted roofs, swimming pools construction and housing components [2].

The term masonry refers generally to brick, tile, stone, concrete-block etc., or combination thereof, bonded with mortar. However, many different definitions of masonry are in vogue. The International Building Code (IBC 2009) defines masonry as (a built-up construction or combination of building units or materials of clay, shale, concrete, glass, gypsum, stone or other approved units bonded together with or without mortar or grout or other accepted methods of joining) [3]. ASTM E631 defines masonry as (construction usually in mortar, of natural building stone or manufactured units such as brick, concrete block, adobe, glass, block tile, manufacture stone, or gypsum block) [4].

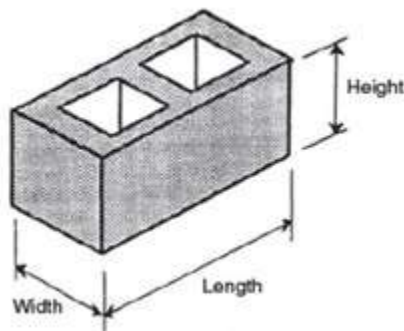
Masonry is typically laid of prefabricated units of different materials, shapes, and sizes. The common types of masonry units, typically rectangular, are clay bricks, clay tiles, concrete blocks, lightweight cellular concrete blocks, sand-lime bricks, and natural building stones. Units of shapes other than rectangular, particularly bricks, are also available. Both clay and concrete masonry units (referred to as CMU hereafter) are available in several colors, textures, and profiles to suit practically every conceivable need and convenience, visual effect, and aesthetic appeal as desired by engineers and architects. There is a world of masonry units out there. Concrete masonry units (commonly referred to as CMUs) are made from a mixture of Portland cement, aggregate (normal weight or lightweight), and water. They are available in a variety of shapes, sizes, configuration, strength, and colors. Because the properties of concrete vary with the aggregate type and mix proportion, a wide range of physical properties and weights is available in concrete masonry units.

From a structural engineering perspective, masonry is classified as plain or unreinforced masonry and

reinforced masonry. Plain masonry refers to construction from natural or manufactured building units of burned clay, concrete, stone, glass, gypsum, or other similar building units or combination thereof, made to be bonded together by a cementations agent. The strength of plain masonry depends primarily on the high compressive strength of masonry units. Plain masonry, like plain concrete, possesses little tensile strength. Therefore, it cannot be used as an efficient building material for structures or structural elements that must resist tensile forces. The poor tensile strength of plain masonry makes it unsuitable for horizontal spanning structural elements such as beams and slabs, which resist loads in flexure and, thereby, are subjected to tensile stresses. Similarly, plain masonry also cannot be used for columns subjected to eccentric loads that will produce tensile stresses in them. To overcome this drawback, plain masonry is strengthened with reinforcing materials such as steel bars, or wire mesh which greatly enhance both its tensile as well as compressive strength [5-7].

**II. EXPERIMENTAL PROGRAM**

For the experimental investigation which study the structural behavior of ferrocement blocks, can be used as precast units system. A total of (nine) ferrocement blocks were cast and tested. The ferrocement blocks have dimensions (400 x 200 x 200) mm. Full details of the blocks are given in Fig.1.



Length (mm)	400
Height (mm)	200
Width (mm)	200

Fig.1 Dimensions of ferrocement blocks

In the present investigation, three main group parameters were chosen to study the behavior and ultimate strength of blocks. Full details of these group parameters are listed in Table I. The main test variables are:

1. Type of materials.
2. Content of wire mesh.

**TABLE (I): DESCRIPTION OF THE BLOCKS**

Group No.	Mix Type	Block Mark
1	Block Concrete	BC1
		BC2
		BC3
2	Block Mortar	BM1
		BM2
		BM3
3	Block Ferrocement	BF1
		BF2
		BF3

**A. Materials Properties**

The materials used for fabricating the experimental ferrocement blocks were; cement, sand, water, and reinforcement.

**1) Cement:**

Ordinary Portland cement from (Cemsa) factory (imported Turkish cement), conforming to Iraqi standards specifications (IQS 5/1984) [8] was used throughout this investigation. The chemical compositions and physical properties are given in Tables II and III.

**TABLE (II): CHEMICAL COMPOSITION OF CEMENT**

No.	Chemical Components	Cement used %	Limitation of IQS 5/1984
1	CaO	60.5	
2	SiO <sub>2</sub>	21.4	
3	Al <sub>2</sub> O <sub>3</sub>	4.6	
4	Fe <sub>2</sub> O <sub>3</sub>	3.3	
5	SO <sub>3</sub>	2.1	2.8 *
6	MgO	2.7	5.0 *
7	Loss on ignition	1.8	4.0 *
8	Insoluble residues	1.1	1.5 *
9	L.S.F	0.94	1.02-0.66 *
		98.44%	

\*Maximum limit

**TABLE (III): PHYSICAL TEST OF CEMENT**

Properties	Test Results	Limitation of IQS 5/1984
Fineness (cm <sup>2</sup> /gm)	2960cm <sup>2</sup> /g m	Min.(2300cm <sup>2</sup> /g m)
Setting Time (hr. min.)		
A- Initial Setting	2hr 5min.	Min. (45 min.)
B- Final Setting	4hr 16min.	Max. (10 hr.)
Compressive Strength (N/mm <sup>2</sup> )		
A- at 3 days	26	Min. (15)
B- at 7 days	36	Min. (23)
Soundness(Autoclave method)	0.5	Max. (0.8%)

2) **Fine Aggregate:**

Washed natural sand obtained from (Bucket) region in Erbil Governate was used throughout this work. The results of the sieve analysis of the sand are given in Table IV, and conformed to the limits specified by B.S 882: 1992 [9].

TABLE (IV): SIEVE ANALYSIS FOR SAND

Sieve Size (mm)	Percentage by mass passing	B.S 882:1992 Limiting
10	100	100
5	100	89-100
2.36	100	60-100
1.18	88	30-100
0.60	70	15-100
0.30	32	5-70
0.15	10	0-15

3) **Coarse Aggregate:**

The coarse aggregate used in the mix was graded gravel with (9.5 mm) maximum size, obtained from (Bucket) region. The results of the sieve analysis of the coarse aggregate are given in Table V, and conforming to the limits specified by ASTM C33-86 [10].

TABLE (V):SIEVE ANALYSIS FOR GRAVEL

Sieve Size (mm)	Percentage by mass passing	ASTM C33-86
12.5	100	100
9.5	86	85-100
4.75	25	10-30
2.36	5.3	0-10
1.18	1.3	0-5

4) **Water:**

Tap water was used for mixing and curing the blocks for all experimental programs.

5) **Reinforcement:**

Locally available woven hexagonal chicken wire mesh with an average diameter of (0.40 mm) has been used. Fig.2 shows the geometry of the mesh used. Fig.3 shows the stress strain curve for the tested wire mesh.



Fig.2Dimensions of ferrocement blocks

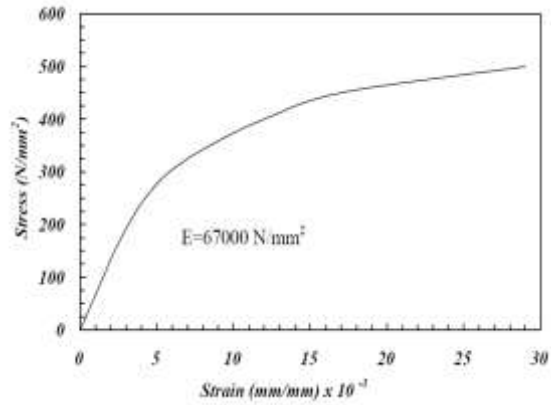


Fig.3Stress-strain curve of the wire mesh

**B. Mix Design**

The design of concrete mix cannot be based on the same parameters that are used for ferrocement mix. The mix proportions used are based on experiments carried out on the ferrocement and work of others in the field [11]. After many trials, the mix proportion by weight (350 kg/m<sup>3</sup>) was achieved and used in this investigation it is 1:2:4:0.45(cement: sand: gravel :water) for concrete mix while 1:2:0.40 (cement: sand: water) for ferrocement mix. The workability was measured by slump test according to ASTM C143-86 [12]. The results of the slump tests are given in Table VI.

TABLE (VI): PROPERTIES OF FERROCEMENT MIXES

Mix	Slump (mm)	Remarks
Concrete	37	Stiff
Mortar	130	wet

**C. Mixing, Casting and Curing**

All the mixes were batched in a tilting pan type mixer of (0.04 m<sup>3</sup>) capacity as shown in Fig.4. Half of sand and gravel were first mixed dry(30 second), then half quantity of cement was added to the mix and mixed for(30 second), then after half quantity of water was dispersed gradually for(30 second), and the residual sand and gravel were added to the mixer and mixed for (30 second), and the residual cement was added to the mixer and mixed for(30 second) and final the remaining water were added to the mix and mixed for (30 second). The mixer was stopped when a good homogeneous mix was produced. The mix was poured in two layers into the molds which had the required reinforcement.

Each layer was compacted by using a large table vibrator. The specimens were left under polythene sheets in the laboratory for one day after casting, then they were remolded and the specimens were marked and stored in a water pool(tank) until time of testing (28 days), and finally taken out from the pool and kept in the open at room temperature before testing. All specimens were painted white before testing so that

cracks would be easily noticed and clearly photographed.



Fig.4 Tilting pan type mixer

#### D. Molds

A mold was made for casting the blocks. The formwork consists of two main parts, (i.e.) edge wood of (400 x 200 x 200) mm and core wood strips. Three molds were made and used. Full details of the mold used in casting of blocks are given in Figs. 5 & 6. The wood core strips were fixed and connected to the wood edges together by two pieces of wood and preventing the sides' way of edge strips from the base when the mold is vibrated.

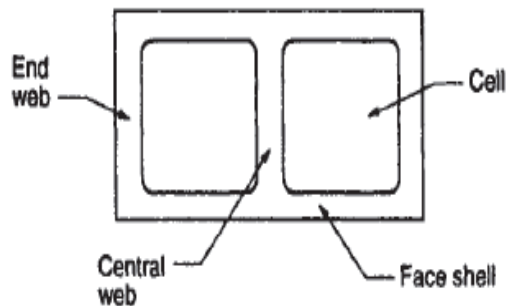


Fig.5 Description of mold used



Fig.6 Details of mold of the ferrocement block

#### E. Fabrication of the Blocks

The metallic mesh reinforcement was cut to an appropriate size. The layers of wire mesh were placed in two phases. The blocks were reinforced with layer of wire mesh in longitudinal direction in top and bottom layer direction in order to gain the best strength from the mesh reinforcement. After cleaning and oiling the mold, the reinforcement layers were connected to each side of the wooden form by means of a connecting wire, which went through the opening of the edge strips in front of the hole whose height was equal to the height of the layers. Then they were connected from the outside, thus, maintaining the required distance between the layers. After completing the reinforcement framework, placing was accomplished by placing the ferrocement or concrete blocks in the framework, and then it was vibrated by using a vibrator machine, so that the mix penetrates into the framework. Fig.7 shows the plastering (casting) process during placing.



Fig.7 Distribution of hole on side of wooden frame

#### F. Control Specimens

Since it was necessary to carry out test on each model, it was important to make cylinders from the mortar and concrete to determine the compressive strength  $f_m$  and  $f_c$ . The specimens have been air dried for 24 hours, then kept in a water tank for 28 days at room temperature of about (20° C) and finally taken out from the water tank and kept in the open at room temperature before testing them. For each group blocks in compression loading three specimens were made. The compression test was carried out on (100mm x 200mm) cylinders according to ASTM C39 [13]. The compression testing machine is shown in Fig.8. All blocks were tested in 3000 kN (300 tons) capacity hydraulic jacks operated by a digital machine.

#### G. Compression Test

The compression tests were carried out by using a digital machine to press the loading pad (square area) (400 x 200) mm as shown in Fig.8. The load continued until failure, and then the failure mode and the crack patterns were noticed and recorded by photographs.



Fig.8 Testing machine for control specimens (compression test)

### III. TEST RESULTS AND DISCUSSION

The test results and discussion for control specimens and blocks are presented herein.

#### A. Compressive Strength for Control Specimens:

From Table VII it can be seen that the inclusion of gravel has little effect on the compressive strength. Since compressive strength is very sensitive to density, gravel mixes may have more voids than mortar mixes, if they are not properly compacted, and this may be a factor influencing the experimental results of compressive strength. However, the change in the compressive strength seems to be affected by the gravel, water content and the method of compaction. Plain mortar and concrete mixes cylinders disintegrated immediately after the maximum load was reached.

#### B. Static Modulus of Elasticity for Control Specimens:

The values of the static modulus of elasticity of mortar and concrete mixes are given in Table VII. It can be seen that the properties of materials like mortar increases the value of modulus of elasticity. The value of the modulus of elasticity of masonry,  $E_m$ , has been found to be dependent on the 28-day compressive strength of masonry ( $f_m$ ). This relationship is analogous to the modulus of elasticity of concrete which depends on the 28-day compressive strength of concrete. Accordingly, the values of modulus of elasticity of masonry are expressed as a function of the 28-day compressive strength of masonry prism as follows (MSJC-08 Code Section 1.8.2.2) [14]:

$$E_m = 900 f_m \quad \text{For Concrete masonry Equation (1)}$$

The above values of the modulus of elasticity are carryover from 1999 and 2002 MSJC Codes. In earlier masonry codes, the value of modulus of elasticity was specified as  $1000 f_m$ . Research has indicated a large variation in the relationship between the compressive strength of masonry and the modulus of elasticity, and values of modulus of elasticity lower than  $1000 f_m$  may be more typical. Values of  $E_m$  given by Equation (1) are higher than indicated by the best fit of data

relating the modulus of elasticity of masonry to the compressive strength of masonry. This is justified in view of the fact that actual compressive strength of masonry significantly exceeds the specified compressive strength.

TABLE (VII): PROPERTIES OF TEST RESULTS FOR CONTROL SPECIMENS

Group No.	Block Mark	Load (kN)	$f_c$ or $f_m$ (N/mm <sup>2</sup> )	$E_m^*$ (N/mm <sup>2</sup> )	$E_m^{**}$ (N/mm <sup>2</sup> )	$E_m^{***}$ (N/mm <sup>2</sup> )
1	BC1	168.3	21.4	21881	19260	21400
	BC2	130.7	16.6	19271	14940	16600
	BC3	148.2	18.9	20563	17010	18900
2	BM1	178.1	22.7	22536	20430	22700
	BM2	174.8	22.3	22336	20070	22300
	BM3	188	24.0	23172	21600	24000
3	BF1	214.2	27.3	24714	24570	27300
	BF2	202.2	25.7	23979	23310	25700
	BF3	230.1	29.3	25603	26370	29300

\* $E_m = 4730 \sqrt{f_c}$  (N/mm<sup>2</sup>) (ACI Code-2008)[15]

\*\* $E_m = 900 f_m$  (N/mm<sup>2</sup>) (MSJC Code-2008)

\*\*\* $E_m = 1000 f_m$  (N/mm<sup>2</sup>) (MSJC Code-2008)

#### C. Compression Test Results for Blocks:

As was stated in paragraph (G and F), the distributed load was applied at the top surface of blocks. The loading was continued until ultimate load was reached and failure of the block occurred. Table VIII gives the experimental test results for ultimate load for the blocks under a distributed load at the top surface of the block.

TABLE (VIII): EXPERIMENTALS RESULTS OF TESTS FOR BLOCKS

Group No.	Block Mark	Load (kN)	Compression Strength (N/mm <sup>2</sup> )
1	BC1	271.7	4.53
	BC2	178.3	2.97
	BC3	141.2	2.35
2	BM1	106.3	1.77
	BM2	283	4.72
	BM3	145.2	2.42
3	BF1	310.3	5.17
	BF2	312.8	5.21
	BF3	304.2	5.07

The mechanical characteristics are covered by Load-bearing concrete masonry units (hollow load-bearing units conforming to ASTM (C90-06) [16]. All units have to meet a minimum compressive strength calculated on average net area Table IX.

This method requires masonry units to be tested prior to and during construction to ensure their adequate strength. The value of  $f_m$  (specified compressive strength of masonry) is based on the compressive

strength of the masonry units and the type of mortar. Concrete masonry units should conform to their respective ASTM Specifications.

ASTM (C270-05a) [17] defines, for all cementitious systems, different mortar types. In general, these are distinguished by the proportion of cement in the mortar. Types of masonry mortar are designated by ASTM C270 using the letters M, S, N, O, and K, representing every second letter of the phrase, “mason work” (Ma S o N w O r K) [18].

TABLE (IX): MINIMUM COMPRESSIVE STRENGTH FOR CONCRETE MASONRY

Masonry Type	Grade	Minimum total area compressive strength (N/mm <sup>2</sup> )		Absorption upper limit (%)
		Average of 3 units	Individual unit	
Solid	N	13	11	10
	S	9	7	15
Hollow	N	7	6	15
	S	5	4.5	20

- Type S: Moderate compressive and tensile bond strength.
- Type N: Low compressive and tensile bond strength.

The first cracking strength of ferrocement blocks is assumed that many micro cracks can form randomly in the cement matrix under load. When a group of such micro cracks link together to form a three-dimensional surface separating the specimen into two totally unconnected parts, a true structural crack is formed. The first cracking strength of ferrocement blocks in tension increases with an increase in the specific surface of reinforcement.

The failure mode of each tested ferrocement blocks is described in Table VIII. Although the modes of failure can become indistinct in some cases and it is sometimes difficult to distinguish between two modes (brittle or flexural), especially when mesh reinforcement is existing, however, the principal modes of failure appeared and occurred.

As the applied load was increased, these cracks extended and new cracks with different orientations were developed. No cracks were noticed on the compression face (top surface) of the block at any stage of loading before failure. The crack pattern on the tension side (bottom surface) of the block was observed to be about the same in the ferrocement blocks except that in the later the cracks were much finer and more in number than in the ferrocement blocks as shown in FIG.9.

In ferrocement, as in reinforced concrete, the most efficient layer of mesh is that closest to the extreme fiber or face of the element. When several layers of mesh are used, it seems that overall behavior is better

when these layers are about equally spaced or distributed within the depth. It is indeed believed that concentrating several layers of mesh very near the surfaces with no reinforcement in between may lead to delamination due to horizontal shear cracking.

From the structural point of view, the compressive strength of the unit is the controlling factor. Blocks of various strengths are available to suit a wide range of architectural and engineering requirements. Table X gives a classification of blocks according to the compressive strength.



Concrete block (1)



Concrete block (2)



Concrete block (3)

Fig.9 Cracks pattern for concrete blocks

As seen from Table XI the average mortar blocks compressive strength (BM1, BM2, and BM3) are less than from the others blocks because the concrete blocks contain gravel which that the main property to resist the failure (BC1, BC2, and BC3) while the average compressive strength for ferrocement blocks (BF1, BF2, and BF3) are larger values because the presence of wire mesh (2 layer) (the volume fraction of reinforcement  $V_r = 5.2\%$ ), and (the specific surface

of reinforcement  $S_r = 5.2 \text{ cm}^2/\text{cm}^3$ ) in blocks, and these values are acceptable with standards specification ASTM C90 which permit the minimum value are  $(5 \text{ N/mm}^2)$  for hollow block grade S.

**TABLE (X): COMPRESSIVE STRENGTH OF CONCRETE MASONRY UNITS AND TYPE OF MORTAR USED IN CONSTRUCTION TO (MSJC-08)**

Net compressive strength of concrete masonry units ( $\text{N/mm}^2$ )		Net area compressive strength of masonry ( $\text{N/mm}^2$ )
Type M or S mortar	Type N mortar	
	13	9
13	15	10
19	21	13
25	28	17
33	36	21

**TABLE (XI): EXPERIMENTAL RESULTS OF TESTS FOR BLOCKS**

Group No.	Block Mark	Compression Strength ( $\text{N/mm}^2$ )	Average ( $\text{N/mm}^2$ )	Standard Deviation
1	BC1	4.53	3.28	1.123
	BC2	2.97		
	BC3	2.35		
2	BM1	1.77	2.97	1.55
	BM2	4.72		
	BM3	2.42		
3	BF1	5.17	5.15	0.072
	BF2	5.21		
	BF3	5.07		

**D. Water Absorption Results for Blocks**

Absorption (used to measure void volume) is evaluated in the following manner. The unit is weighted in the air temperature as dry weight ( $w_1$ ) and then immersed in cold water for (24 hours) and weighted as wet weight ( $w_2$ ) and the calculate the absorption ratio for this unit.

Table XII gives the experimental test for water absorption results for concrete and ferrocement masonry units and may be classified by their unit weights or applications as follows in Table XIII.

As seen from Tables XII & XIII the mortar blocks absorption (BM1, BM2, and BM3) are less than from the others blocks because the concrete blocks contain pores (BC1, BC2, and BC3) and the ferrocement blocks (BF1, BF2, and BF3) are lesser values because the presence of wire mesh the volume fraction of

reinforcement ( $V_r = 5.2\%$ ), the specific surface of reinforcement ( $S_r = 5.2 \text{ cm}^2/\text{cm}^3$ ) in blocks, and these values are acceptable with standards specification ASTM C90 which permit the maximum value are (15%, & 20%) for hollow blocks [19-20].

One of the best ways to insure good durability is to have a fully compacted matrix with low permeability and low porosity. Limiting the water to cement ratio in the range of 0.35 to 0.45 seems to provide good protection.

**TABLE (XII): EXPERIMENTAL RESULTS OF WATER ABSORPTION FOR BLOCKS**

Group No.	Block Mark	Wet Weight (gm)	Dry Weight (gm)	Absorption %
1	BC1	21050	20704	1.7
	BC2	19260	18724	2.9
	BC3	20810	20471	1.7
2	BM1	20275	20001	1.4
	BM2	20433	20101	1.7
	BM3	19564	19236	1.7
3	BF1	21726	21134	2.8
	BF2	21256	21030	1.1
	BF3	21150	20932	1.1

**TABLE (XIII): EXPERIMENTAL RESULTS OF WATER ABSORPTION FOR BLOCKS**

Group No.	Block Mark	Absorption %	Average (%)	Standard Deviation
1	BC1	1.7	2.1	0.693
	BC2	2.9		
	BC3	1.7		
2	BM1	1.4	1.6	0.173
	BM2	1.7		
	BM3	1.7		
3	BF1	2.8	1.7	0.982
	BF2	1.1		
	BF3	1.1		

**E. Volume of Fraction of Reinforcement:**

The volume fraction of reinforcement is the ratio of volume of reinforcement to the volume of composite:

$$V_r = \frac{V_{\text{reinforcement}}}{V_{\text{composite}}} \text{Equation (2)}$$

In the above definition, the volume of reinforcement includes the skeletal steel. However, if the skeletal steel is placed in the center of the ferrocement member and if bending is considered, its influence may be ignored. The volume fraction of reinforcement for hexagonal or chicken wire mesh can be calculated from the following formula:

$$V_r = \frac{N}{h} \frac{W_r}{\gamma_r} \text{Equation (3)}$$

where:

$N$  = number of layers of mesh.

$W_r$  = unit weight of reinforcing mesh (weight per unit area such as  $\text{kg/m}^2$ ); this could be determined for any mesh.

$\gamma_r$  = density of reinforcement material such as ( $\text{kg/m}^3$ ).

$h$  = thickness of ferrocement element.

These equations is used for galvanized meshes, care should be taken to minimize the error due to galvanizing. Typically the weight of the zinc coating varies between (10 and 30 %) of the weight of the mesh. It is higher for meshes with smaller diameter wires and smaller mesh opening. The volume fraction of reinforcement is reduced in direct proportion to the percentage of zinc coating by weight.

To find the volume fraction of reinforcement for a ferrocement element (30 mm) thick reinforced with (2 layers) of hexagonal or chicken wire mesh, of unit weight ( $1.85 \text{ kg/m}^2$ ). The density of steel which the mesh is made is ( $7850 \text{ kg/m}^3$ ) [1].

$$V_r = \frac{N W_r}{h \gamma_r} = \frac{2 \times 1.85}{0.030 \times 7850} = 0.0157 \text{ or } 1.57\%$$

Assume that the hexagonal or chicken wire mesh is zinc coated and that the weight of zinc coating is estimated to be (17%) of total weight. In that case the volume fraction of reinforcement is:

$$V_r = \frac{N W_r (1 - 0.17)}{h \gamma_r} = \frac{2 \times 1.85 \times 0.83}{0.030 \times 7850} = 0.013 \text{ or } 1.3\%$$

Then the total volume fraction of reinforcement for ferrocement blocks is equal to  $1.3\% \times 4 = 5.2\%$  .Then  $V_r = 5.2\%$

#### F. Specific Surface of Reinforcement

The specific surface of reinforcement is the total lateral surface area of reinforcement (assumed bounded) divided by the volume of composite; that is, the surface area of bounded reinforcement per unit volume of composite [1]:

$$S_r = \frac{\text{Total surface area of bounded reinforcement}}{\text{Volume of composite}} \text{Equation (4)}$$

For mesh of wire diameter (or equivalent wire diameter) ( $d_w$ ) the following relation can be easily derived:

$$S_r = \frac{4 V_r}{d_w} \text{Equation (5)}$$

$$S_r = \frac{4 V_r}{d_w} = \frac{4 \times 0.052}{0.04} = 5.2 \text{ cm}^2/\text{cm}^3$$

#### IV. CONCLUSIONS

Based on the analysis performed on the experimental data of ferrocement blocks by focusing on compression, tension, and flexural tests to obtain the acceptable results of ferrocement used in this study the following conclusions can be shown:

- 1- All mortar control specimens cylinders failed in a sudden catastrophic manner. However, the change in the compressive strength seems to be affected by the gravel, water content and the method of compaction. Plain mortar and concrete mixes cylinders disintegrated immediately after the maximum load was reached.
- 2- The failure mode of the ferrocement blocks was sudden. The addition of wire mesh reinforcement changed the failure from brittle and sudden to flexural failure.
- 3- The presence of wire mesh reinforcement in the blocks tends to delay the formation of first crack, and controls the development of the cracks at the tension side. The cracks were much finer and more in number compared with the ferrocement blocks.
- 4- Ferrocement blocks differ from reinforced concrete in the manner of formation, growth and propagation of cracks. Ferrocement blocks have higher strength and greater extensibility than reinforced concrete. The fine and narrowly spaced cracks show the tendency to close when loads are withdrawn even after collapse.
- 5- Increasing the number of wire mesh layers tends to increase the initial cracking and ultimate load.
- 6- The ultimate load of ferrocement blocks is reached by breaking of the wires in most cases.
- 7- The increase of number of layers beyond (2) contributes significantly to the increase in flexural strength of blocks masonry when adding wire mesh reinforcement to ferrocement blocks.
- 8- The presence of wire mesh reinforcement in the blocks increases the compressive strength compared with the corresponding mortar blocks. This increase is (73.4%).
- 9- The presence of wire mesh reinforcement in the blocks increases the compressive strength compared with the corresponding concrete blocks. This increase is (57%).
- 10- The presence of wire mesh reinforcement in the blocks decreases the water absorption compared with the corresponding concrete blocks. This decrease is (23.5%).

#### V. RECOMMENDATIONS

- 1- The effect of the wire meshes type and orientation.
- 2- The effect and additions of steel and metallic fiber in masonry units.
- 3- Studying the arrangement of mesh layers on blocks.



- 4- Studying the effect of dynamic loading on ferrocement blocks.
  - 5- The effect of fatigue loading on the behavior of ferrocement blocks.
  - 6- Analytical and experimental approaches are required to study the flexural behavior of ferrocement blocks under the effect of compression loads by using finite element method.
- [19] IQS 1077/1987"Load- Bearing Concrete Masonry Units", NCCLR, Ministry of Housing & Construction, Baghdad, 2004, pp.164.
  - [20] IQS 1129/1988"Non-Load Bearing Concrete Masonry Units", NCCLR, Ministry of Housing & Construction, Baghdad, 2004, pp.164.
  - [21] Hiren A. Rathod , Prof. Jayeshkumar Pitroda"From Bricks To Blocks: A Masonry Unit From Western Gujarat Region of India ", International Journal of Engineering Trends and Technology (IJETT), V4(6),2338-2343 ISSN:2231-5381,June 2013.

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#### REFERENCES

- [1] Naaman, Antoine E., "FERROCEMENT AND LAMINATED CEMENTITIOUS COMPOSITES" , Techno Press 3000, 2000, pp. 372.
- [2] ACI 544.1 R-96"State-of-the-Art Report on Fiber Reinforced Concrete", American Concrete Institute, Detroit, Michigan, 1996, pp.1-24.
- [3]IBC(2009), *International Building Code*, International Code Council, Washington DC, PP.676.
- [4] ASTM: *Standard Terminology of Building Construction* (E631-15), ASTM International, West Conshohocken, PA.
- [5] Taly, N., "*Design of Reinforced Masonry Structures*"; McGraw-Hill, 2010, PP.753.
- [6] Hendry, A.W., Sinha, B.P., and Davies, S.R. "*Design of Masonry Structures*", E & FN SPON, 3th ed.,2004,pp.279.
- [7] Lane, J.W."Concrete Masonry Manual", Concrete Manufacturers Association, 8th ed., 2007,pp.110.
- [8] IQS 5/1984 " *Portland Cement*", NCCLR, Ministry of Housing & Construction, Baghdad,2004, pp.164.
- [9] B.S.882: 1992"Aggregate from Natural Sources used in Concrete"British Standard Institute BSI.
- [10] ASTM Designation C 33-86 "*Standard Specification for Concrete Aggregates*", 1989 Annual Book of ASTM Standard, American Society for Testing and Materials , Philadelphia , Pennsylvania , Section 4 , Vol.04 - 02 , pp. 9 - 15.
- [11] ACI 211.1-91 "*Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete*", American Concrete Institute, Detroit, Michigan, 1996, pp.1-38.
- [12] ASTM Designation C 143-86 "*Standard Test Method for Slump of Hydraulic Cement Concrete*", 1989 Annual Book of ASTM Standard, American Society for Testing and Materials, Philadelphia, Pennsylvania, Section 4, Vol. 04 - 02.
- [13] ASTM Designation C 39-86 "*Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*", 1989 Annual Book of ASTM Standard, American Society for Testing and Materials, Philadelphia, Pennsylvania, Section 4, Vol. 04 - 02, pp. 20 - 23.
- [14] MSJC (2008). *Commentary to Specification for Masonry Structures* (TMS 602-08/ACI 530.1-08/ ASCE 6-08), American Concrete Institute, Farmington Hills, MI; Structural Engineering Institute of the ASCE, Reston, VA; and the Masonry Society, Boulder, CO.
- [15] ACI Committee 318, " *Building Code Requirements for Structural Concrete* (ACI 318M-08) and *Commentary ACI 318RM-08*", American Concrete Institute, Detroit, Michigan, 2008, pp.371.
- [16] ASTM: *Specification for Load-Bearing Concrete Masonry Units* (C90-06), ASTM International, West Conshohocken, PA.
- [17] ASTM: *Specification for Mortar for Unit Masonry* (C270-05a), ASTM International, West Conshohocken, PA, 2002.
- [18]Klingner, R.E.,"*Masonry Structural Design*", McGraw Hill, 2010, pp.560.