Study on Flexural Behaviour and Cracking of Ferrocement Slabs by Neglecting Very Fine Sand

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Abstract

This paper presents the experimental results of eight slabs made of Ferrocement. All specimens were (700mm) long, (300mm) wide and (50mm) thick. These specimens were divided into two groups (The first group has four specimens coursed of normal sand gradient and in the other four specimens, the sand that passing from sieve No. 8 was neglected), to investigate behavior of slabs under bending effect and studying the cracks that generated after bending then, comparing the results between these two groups. A thin square welded wire mesh was used as reinforcement. The number of wire mesh layers was varied between 0 to 3 layers. Ultrasonic Pulse Velocity (UPV) Test was used to detect the cracks. The results showed that there was a slight rise in bending for first group slabs compared with second group slabs. Maximum bending strength was achieved for both slab groups with 3 layers of wire mesh. it was shown that there was a significant convergence in the load values required to cause appearing of the first crack and final failure for the two groups. The percentage of ultimate load between slab reinforced with 3 layers and without reinforcement was (25.27%) for the first group, while the increase in ultimate load for a specimen that reinforced with 3 layers was (24.16%) compared to specimen without reinforcement for the same group. On the other hand, the results showed an improvement in the performance of the second group slabs due to its resistance to appearing of cracks resulted from bending. The percentage of increasing cracks after bending for the unreinforced specimen in group 1 was (9%) compared with the unreinforced slab in group 2. Whereas the numbers of cracks number in slab reinforced with 1 and 2 layers in the second group were less than slabs with 1 and 2 layers in the first group about (8.86 %) and (7.77%), respectively. While this percentage for a specimen with 3 layers in group 2 was about (8.62%) less compared to the specimen with 3 layers in group 1.

Keywords: Ferrocement; Wire Mesh; First Crack; Fine Aggregate; Mortar, UPV.

دراسة عن سلوك الانثناء والتشقق للبلاطات الفيروسمنتية بإهمال الرمل الناعم جدا

محمد طراد نوار

الخلاصة

يقدم هذا البحث النتائج التجريبية لثمانية بلاطات مصنوعة من الفيروسيمنت. جميع العينات هي بطول (700mm)، وعرض (300mm) وسمك (50mm). تم تقسيم هذه العينات إلى مجموعتين: (المجموعة الأولى فيها أربع عينات استخدم فيها رمل ذو تدرج طبيعي والأربعة الأخرى هي المجموعة الثانية وناتجة من إهمال الرمل المار من منخل رقم (8)، لبحث سلوك هذه البلاطات تحت تأثير أحمال الانحناء ودراسة الشقوق التي تولدت بعد فحص الانحناء، ومقارنة النتائج بين هاتين المجموعتين. تم استخدام مشبكات سلكية ملحومة كطبقات تسليح، وقد تراوح عدد هذه الطبقات بين 0 إلى 3 طبقات. استخدم اختبار سرعة النبض للموجات فوق الصوتية

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(UPV) للكشف عن الشقوق. أظهرت النتائج أن هناك زيادة طفيفة في انحناء البلاطات في المجموعة الأولى مقارنة مع بلاطات المجموعة الثانية قبل حدوث الفشل النهائي. تم الحصول على أعلى قيم للانحناء عند تسليح البلاطة بثلاث طبقات من مشبك الأسلاك ولكلا المجموعتين. كما أظهرت النتائج أن هناك تقارب في قيم الأحمال اللازمة لظهور الشق الأول وأحمال الفشل النهائية لنماذج المجموعتين. فقد كانت نسبة زيادة الحمل النهائي بين العينة المسلحة بثلاث طبقات والعينة الغير مسلحة للمجموعة الأولى هي(25.27%), أما للعينة المسلحة بثلاث طبقات في المجموعة الثانية فقد كانت نسبة الزيادة في الحمل النهائي (24.16%) مقارنة مع العينة الغير مسلحة لنفس المجموعة. من ناحية أخرى، فقد أظهرت النتائج تحسنا في أداء بلاطات المجموعة الثانية في مقاومة الشقوق الناتجة من الانحناء. وكانت نسبة الزيادة بالشقوق للعينة الغير مسلحة للمجموعة الثانية هي (9%) مقارنة مع نظيرتها في المجموعة الثانية. في حين أن عدد الشقوق بلاطات المجموعة الثانية المسلحة بطبقة واحدة وطبقتين كانت أقل من بلاطات المجموعة الأولى بحوالي (8.86%) و(7.77%) على التوالي. اما نسبة التشققات للعينة المسلحة بثلاث طبقات للمجموعة الثانية اقل بحوالي (8.62%) بالمقارنة مع العينة المقابلة لها في المجموعة الأولى.

1. Introduction

Ferrocement can be considered as a type of thin reinforced concrete where cement mortar is used instead of concrete, in addition to using small diameters of wire meshes that are distributed throughout the cross-section uniformly instead of reinforcing bars. [1]

The ACI Committee 549 has given the following definition for Ferrocement in their report in 1988: (Ferrocement is a form of reinforced concrete using closely spaced multiple layers of mesh and/or small diameter rods completely infiltrated with, or encapsulated in a mortar). [2]

Applications of Ferrocement in construction is vast due to its unique characteristics, such as the lack of need to skilled workers and it can be constructed with using available materials with a minimum of skilled labour, low self-weight and it does not need a framework. Proven suitable for tanks, decorations, it has many other tested or potential applications in agriculture and industry. [3]

Ferrocement has a very high tensile strength/weight ratio and superior cracking behaviour in comparison to reinforced concrete. Therefore, the applications involving it have been increased. Over the years, the Ferrocement has been respected in terms of excellent performance by the ease of construction and resistance to tensile strength. [4,6]

A small boat was the first known example for Ferrocement. Joseph-Louis Lambot's original French patents on reinforced boats by chicken wires were issued in 1847 not long after the development of Portland cement and the name of this material in that time period was (Ferci-ment).[7]

A Frenchman, Joseph Monier (1823 - 1906), produced flower pots made of cement mortar reinforced with wire mesh and showed his invention at the world exhibition held in Paris in 1867. In the early 1940s, Pier Luigi Nervi resurrected the original Ferrocement concept when he observed that reinforcing concrete with layers of chicken wire produced a material possessing the mechanical characteristics of an approximately homogenous material and capable of resisting high impact. [8,9]

Nervi first used Ferrocement in a public structure in 1948 that was an exposition hall at Turin with 100 m span roof. In 1972 the U. S. National Academy of Sciences, through its Board of Science and Technology for International Development, established an (Ad Hoc Panel) on the Utilization of Ferrocement in Developing Countries. In 1975, the American Concrete Institute formed Committee 549 to develop a body of knowledge on Ferrocement. [8] Then, in 1976, the International Ferrocemet Information Center was founded at the Asian Institute of Technology in Bangkok. International Ferrocement Society formed a committee IFS-10/01 which developed Ferrocement Model Code (FMC) in 2001. [9]

In successive years, researches are evolving and going on to develop it as a substitute material for various conventional construction materials such as bricks, stones, timber, steel and concrete.

This study explores the effect of neglect the fine sand passing from sieve No.8 on the Flexural strength of slabs and its cracking behaviour.

Few of literatures are available on Ferrocement subjected to a flexural load. The deflection with cracking of nine roof panels made of Ferrocement reported by Alnuaimi, Hago & Al-Jabri (2006).[10]

Thin hexagonal wire mesh was used as reinforcement. The number of wire mesh layers was varied between two to six. The wires were impregnated midway through the thickness of the panels which tested for bending moment with supports. Feasibility of using Ferrocement was assessed for the strengthening of a deteriorated Reinforced Concrete Slab and study cracking behaviour by Khan, Raffeqi and Ayub (2013) [11]. Rebound hammer and ultrasonic pulse velocity (UPV) tests were conducted to assess the degree of deterioration. Results were presented in the form of load-deflection response of the slabs along with the crack pattern of the slab at various stage of loading. Results were found that the slab reinforced with three layers of Ferro-mesh performed better in terms of load carrying capacity and stiffness compared with reference specimens. Work on Metakaolin Ferrocement under flexural loading has been reported by the author Amarnath Yerramala (2013) [12]. A series of Ferrocement specimens were cast with a varying number of mesh layers and replaced varying percentages of cement by using Metakaolin. The results show that 10% Metakaolin was the optimum content to obtain maximum impact strength. Up to 15% Metakaolin replacement the strengths were higher than control Ferrocement at all curing ages and for all the mesh layers. Gaidhankar and Kulkarni (2014) [13], investigated Ferrocement panels under flexural by using expanded metal mesh. They studied the behaviour of flat Ferrocement panels by using thickness variation and different numbers of wire mesh layers on the flexural strength. The experimental test results of the Ferrocement panels showed that the flexural loads at first crack and ultimate loads depend on a number of reinforcing mesh layers and increasing the number of layers of wire mesh from 2 to 4 layers significantly increased the ductility and capability to absorb the energy of the panels. In addition to, increased the number of mesh layers improved the ductile behaviour of Ferrocement slabs.

2- EXPERIMENTAL INVESTIGATION

2.1 Specimen details:

A total of eight slabs (700mm×300mm×50mm) were fabricated and tested in this experimental program of this study. The proposed program consisted of 2 groups, where their details are shown in Table 1 .This program aims to study the effect of neglecting very fine sand (which passing from sieve No. 8) with different layers of wires mesh in group 2 under flexural load and comparing it with reference specimens in group 1.

Table 1. Details of Specimens

Group 1		Group 2	
S_0	Slab without reinforcement	**S^n_0**	Slab without reinforcement and no very fine aggregates
S_1	Slab reinforced with 1 layer of wires mesh	**S^n_1**	Slab reinforced with 1 layer of wires mesh and no very fine aggregate
S_2	Slab reinforced with 2 layers of wires mesh	**S^n_2**	Slab reinforced with 2 layers of wires mesh and no very fine aggregate
S_3	Slab reinforced with 3 layers of wires mesh	**S^n_3**	Slab reinforced with 3 layers of wires mesh and no very fine aggregate

In addition to using steel rods with a diameter of 4 mm for all specimens to stabilize the reinforcing layers and ensures stability when placing the mortar in the wooden mould and prevents it from moving when using the vibrator as shown in figure 1.

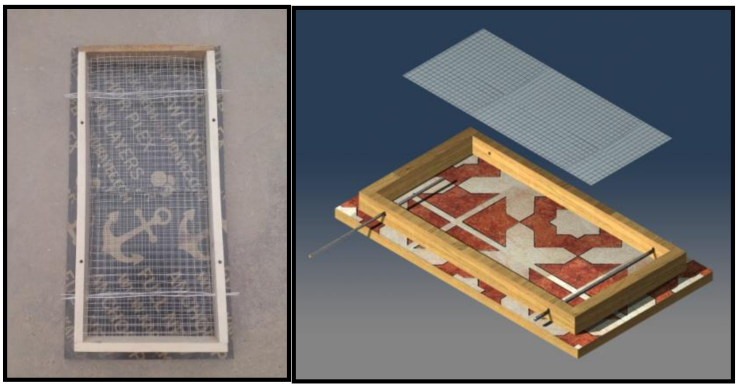

Figure 1. The Mould That Used in This Test

2.2 Materials

2.2.1 Cement

Ordinary Portland Cement of grade CEM I 42.5R is used in this work, which was stored in a cool and dry place before using it. Physical and chemical properties of cement found are given in Table 2 and 3, respectively.

Table 2. Physical Properties of Cement According to Iraqi Specification No.5, 1984[20]

Physical properties	Test Result	Limits of Iraqi Specification No.5/1984
Setting time(minutes)		
• Initial setting	120	**≥ 45 minutes**
• Final setting	360	**≤ 600 minutes**
Fineness by Blaine method (m^2/Kg)	300	**≥ 230**
% Auto Clave	0.31	**≤ 0.8**

Table 3. Chemical Properties of Cement according to Iraqi Specification No.5, 1984[20]

Oxide	Weight (%)	Limits of Iraqi Specification No.5/1984
CaO	62.3	-
SiO_2	20.28	-
Al_2O_3	5.55	-
Fe_2O_3	4.20	-
MgO	2.60	< 5.0
K_2O	0.75	-
Na_2O	0.4	-
SO3	2.4	< 2.5
Loss on Ignition	1.65	< 4.0
Lime saturation factor	0.81	0.66 – 1.02
Insoluble Remains	0.5	< 1.5 %
F.L	0.65	-
Total	99.63	-
Compound	**Weight (%)**	**Limits of Iraqi Specification No.5/1984**
C3S	50.05	-
C2S	20.45	-
C3A	4.05	-
C4AF	13.20	-

2.2.2 Sand

Fine aggregate in this work was taken from Al-Bokhirbeet Quarry. This sand is totally free from all impurity and organic matters. Experiment physical properties obtained are shown in Table 4.

Table 4. Physical Properties of Sand according to Iraqi Specification No.45, 1984[21]

Sieve No. (mm)	Accumulated Percentage Passing (Reference Samples) % -Type II	Limits of Iraqi Specification No.45/1984	Specimens of Group 2 caused by :
4.75	100	90-100	Passing } Used
2.36	74.57	100-70	Retaining } Used
1.18	62.77	90-55	Neglected
0.6	36.20	59-35	Neglected
0.3	9.15	30-8	Neglected
0.15	2.36	10-0	Neglected

2.2.3 Water

Tap water was used in mortar mixing and curing.

2.2.4 Wire mesh:

Square welded layers of wires mesh having 2 mm diameter and 25 mm spacing of wires mesh was used. Plate 2 and Fig. 1 show the details of wires mesh and its distribution in the specimens.

Plate 2. View of wire mesh

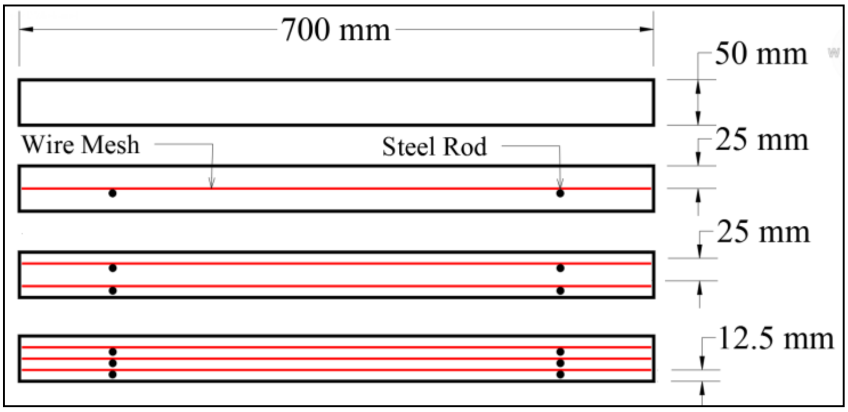

Figure 1. Details of Reinforcement in Specimens

2.3 Mix Proportions

The proportion of cement to sand used in this study was (1:2), while the water/cement ratio was (0.4).

2.3.1 Preparation of Mortar

After preparing the mortar by calculating the exact amount of cement, sand and water. The cement and sand were mixed dry by using a mechanical mixer with the capacity (0.1 m3) operated by electrical power and mixing were continued until the dry mix became homogenous. Then, water was added and mixing continued until the uniform mix obtained.

2.3.2 Casting

All wooden moulds are prepared in terms of reinforcing layers (0, 1, 2 and 3 layers of wire mesh). According to the size of the slab, the mesh pieces were cut down and leaving a cover of 3 mm on both sides of the mesh. Then, drilling two holes for each layer on the long side of the mould to pass the steel rod from on to the other side. The utility of this rod is to prevent the movement of wire mish during the placement of mortar and vibrator operation by installing the mesh on this rod. Next, cast all samples.

2.3.3 Curing

After 24 hours of casting the slabs, they were removed from moulds. Then, the steel bars were cut off from the ends of the samples. The slabs were cured in a water tank for a period of 28 days to be ready for the test.

2.3.4 Tests Performed

The slabs were removed from the curing tank after completion 28 days. Then, the specimen's surface was cleaned to facilitate the visibility of cracks clearly with the naked eye. The specimens were tested under two-point loading through a pre-calibrated 5 tones proving ring as shown in Plate 3. A dial gauge (0.01mm accuracy measurement) was used to measure deflections at mid-span.

Plate 3. Photo of Concrete Flexural Machine used in this test

After completion of the flexural test and obtaining the results, it was necessary to know the deep of cracks generated by bending the slab. C372N (High performance) Ultrasonic Pulse Velocity Tester is used for this purpose. UPV methods involve propagating ultrasonic waves in the concrete section and measuring the time of the pulse.[14]

Two transducers, one as a transmitter and the other one as a receiver, are used to send and receive 55 kHz frequency as shown in Plate 4. The velocity of the wave was measured by placing two transducers, one on each side of Ferrocement slab. A thin grease layer applied to the surface of the transducer in order to ensure effective transfer of the wave between element and transducer. [15]

The Pulse velocity (V) can be found from the sample's distance (L) (the distance between the transducers) divided on the electronically measured transit time (T) of this pulse:

$$V = L\ (Km) / T\ (sec) \qquad (1)$$

The standard transducers were calibrated for the display unit. The calibration value was (42.5 μ_s) which marked on the calibration rod. [16]

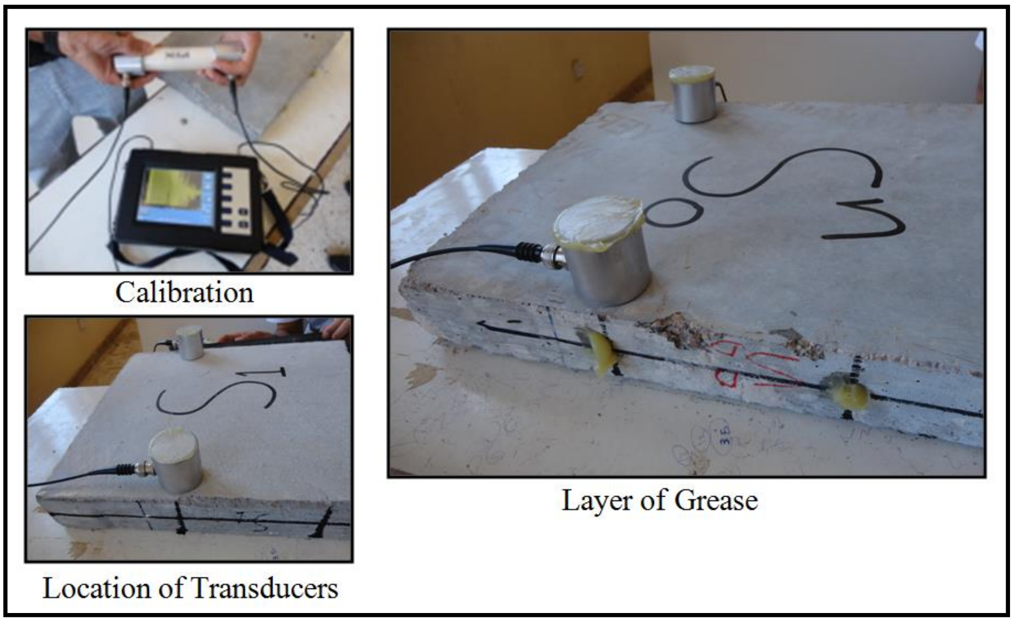

Plate 4. Details of UPV Test

3- RESULTS AND DISCUSSION

3.1 Flexural Slabs

Figure 2 and Table 5 show the vertical deflection values at mid-span. Initially, the experimental results illustrated that there were not much different of deflection between two groups when the volume of aggregate is constant. Although, there was a slight rise in bending for slabs that contain normal sand (group 1), because the mortar's workability for the group 1 is better than the group 2 and the very fine sand absorbs part of the mixing water and thus reduces the water content in the mixture, which increased the strength of specimens for loads. According to ASTM C33 suggestion that the very fine sand will increase the water demand of the mix, while very coarse sand could compromise its workability. (17) (18)

On the other hand, for Groups 1 and 2, it is clear that in the case of using three layers of wires mesh, we got maximum bending values at every stage of loading. Followed by, 2-layers and 1-layer reinforced slabs. As for the non-wired slabs, they gave fewer deflection values and failed load levels less than in the other specimens.

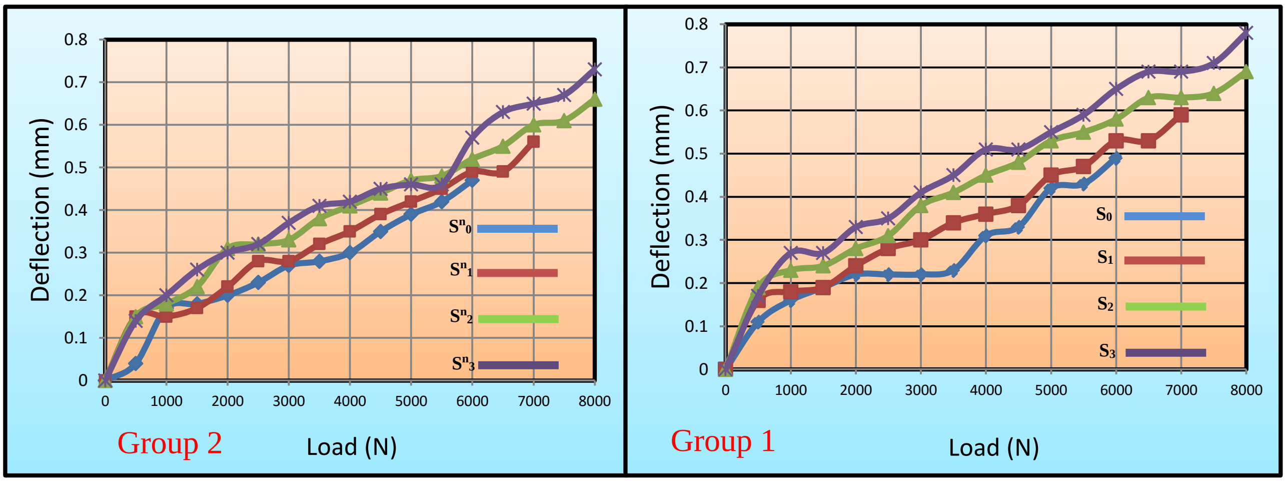

Figure 2. Deflection - Load Relationship of Ferrocement Slabs

Table 5. Results of Deflection Obtained from Flexural Test

Load (N)	S_0 (mm)	S_1 (mm)	S_2 (mm)	S_3 (mm)	$S^n{}_0$ (mm)	$S^n{}_1$ (mm)	$S^n{}_2$ (mm)	$S^n{}_3$ (mm)
0	0	0	0	0	0	0	0	**0**
500	0.11	0.16	0.19	0.17	0.04	0.15	0.15	**0.14**
1000	0.16	0.18	0.23	0.27	0.17	0.15	0.18	**0.2**
1500	0.19	0.19	0.24	0.27	0.18	0.17	0.22	**0.26**
2000	0.22	0.24	0.28	0.33	0.2	0.22	0.31	**0.3**
2500	0.22	0.28	0.31	0.35	0.23	0.28	0.32	**0.32**
3000	0.22	0.3	0.38	0.41	0.27	0.28	0.33	**0.37**
3500	0.23	0.34	0.41	0.45	0.28	0.32	0.38	**0.41**
4000	0.31	0.36	0.45	0.51	0.3	0.35	0.41	**0.42**
4500	0.33	0.38	0.48	0.51	0.35	0.39	0.44	**0.45**
5000	0.42	0.45	0.53	0.55	0.39	0.42	0.47	**0.46**
5500	0.43	0.47	0.55	0.59	0.42	0.45	0.48	**0.46**
6000	0.49	0.53	0.58	0.65	0.47	0.49	0.52	**0.57**
6500	-	0.53	0.63	0.69	-	0.49	0.55	**0.63**
7000	-	0.59	0.63	0.69	-	0.56	0.6	**0.65**
7500	-	-	0.64	0.71	-	-	0.61	**0.67**
8000	-	-	0.69	0.78	-	-	0.66	**0.73**
1st Crack (N)	5872	5890	6112	6128	5825	5840	5900	**6020**
Max. Load (N)	6730	7440	8330	8431	6612	7230	8050	**8210**

According to the graphs in Fig. 2, there was a steady rise in the deflection of the group 1 for reinforced specimens, but these levels fluctuated in unreinforced specimens, especially at loads (2000, 2500, 3000 and 3500N), there was no change in deflection and it was constant at value 0.22 mm. This shows the role of wire meshes in redistribution of loads, regularly. Then, the values rose gradually until it reached a higher value of 0.49 mm.

In contrast, there is also a gradual increase in deflection values for group 2, but with more fluctuation compared to the group 1, where it can be noted that there is an overlap deflection among the samples at some points, especially at loads around 1000 N. After that, the deflection growth continuously with steady rate and reached the final values.

3.2 First Crack and Failure Load

The first crack was visibly seen to naked eyes, and the corresponding load at the time of formation of initial crack is what is described as the (first crack load). With further increase in load, final major crack at failure load was noticed at the middle surface of the specimen as shown in Plate 5, and the ultimate states of the specimens are defined as (ultimate failure load) that shown in Plate 6. A coloured line was drawn on the crack path to show it.

The results illustrated that there was a significant convergence in the load required to initiate the first crack and final failure for the two groups. The ultimate loads of S3 and S2 were 25.27% and 23.77% more than S0 specimen, while this percentage decreased to reach about 10.55% for S1 specimen. In contrast, Sn3 showed an increase in ultimate load to 24.16% compared to Sn0, but there was significantly decreased for Sn2 and Sn1 to 21.75% and 9.34%, respectively. Figure 3 shows that the loading period between the appearance of the first crack and failure increased by increasing the reinforcing layers.

On the other hand, the first crack load for S^n_3 was 6020N. It is almost identical to specimens S^n_2 and S^n_1 (5900N and 5840N), while the value of first crack load was 5825N for S^n_0. we note that it was less than their counterparts in group 1 (S_2 and S_1) because. The load continued to increase and some other cracks were detected at higher load levels. The specimens S^n_2 and S^n_1 failed at a load of 8050N and 7230N, which was lower than the failure load of the S_2 an S_1 specimen, respectively.

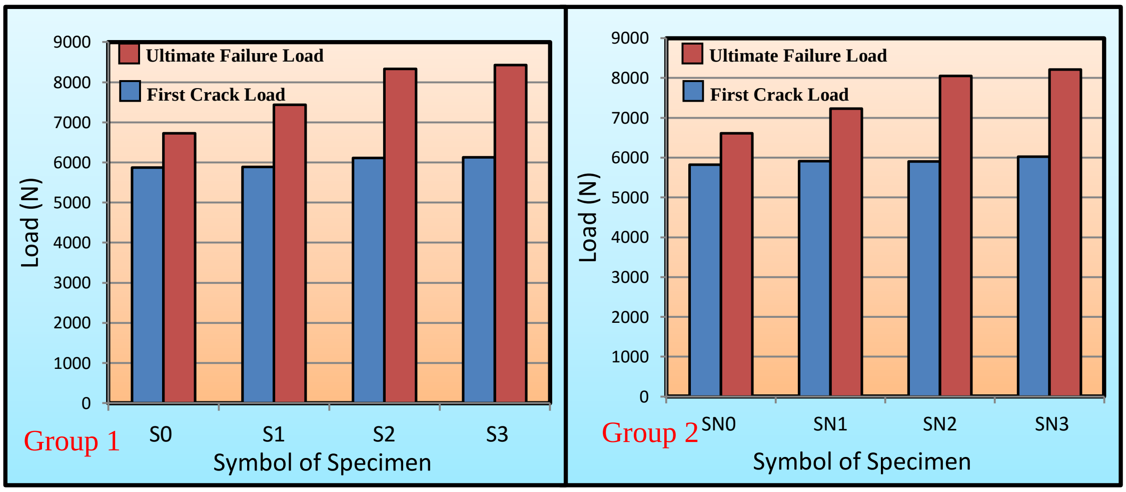

Figure 3. First Crack and Ultimate Failure for All Slabs

Plate 5. First Crack for All Specimens

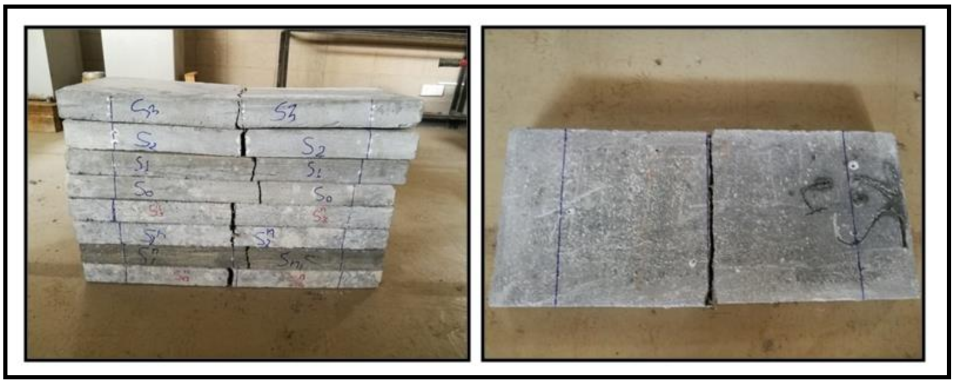

Plate 6. Final Failure for All Specimens

3.3 UPV Results

The average of every two readings was taken for each specimen. [19] It is clear from the results in Table 6 that the average passage time of the ultrasonic (microsecond) in the group1 was significantly compared with group 2. This implies that there was increased the gaps and cracks in the group 1 more than group 2. The porosities in the specimen in group 2 have only been filled with cement paste; they have formed a solid block with few cracks compared to the group1. The bar chart in Fig. 4 showed that the pulse velocities in the mortar specimens which neglected the very fine sand were faster than those of their normal sand specimens.

Table 6. Results of Velocities that Obtained from UPV Test

The distance between the transducers (L) = 30 cm (width of slab)									
No.	Transit Time (T) (μsec)			V	No.	Transit Time (T) (μsec)			V
	Reading 1	Reading 2	Average	Km/sec		Reading 1	Reading 2	Average	Km/sec
S_0	73.10	72.90	73.00	4.11	S^n_0	66.30	66.40	66.35	4.52
S_1	72.80	73.00	72.90	4.11	S^n_1	66.30	66.50	66.40	4.51
S_2	72.20	72.40	72.30	4.15	S^n_2	66.30	67.00	66.65	4.50
S_3	72.30	73.00	72.65	4.13	S^n_3	65.50	67.10	66.30	4.52

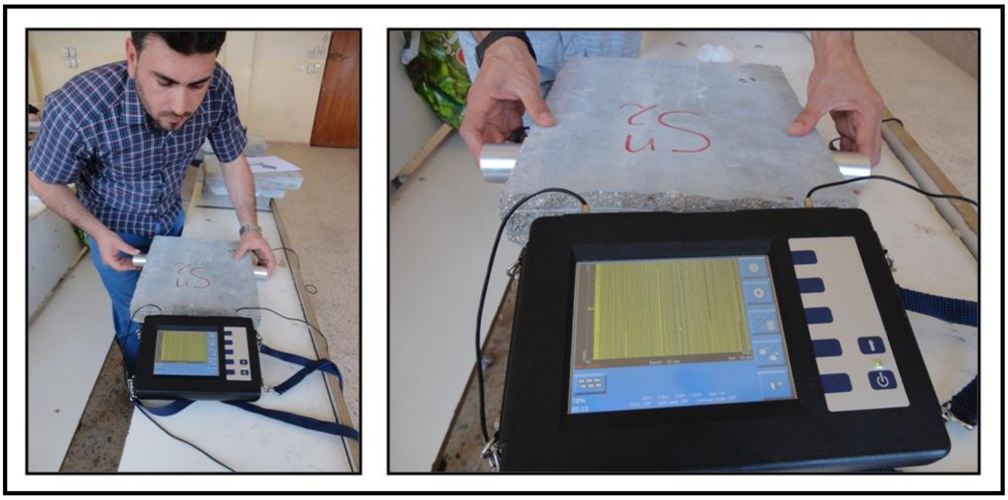

Plate 7. Ultrasonic Pulse Velocity (UPV) Test

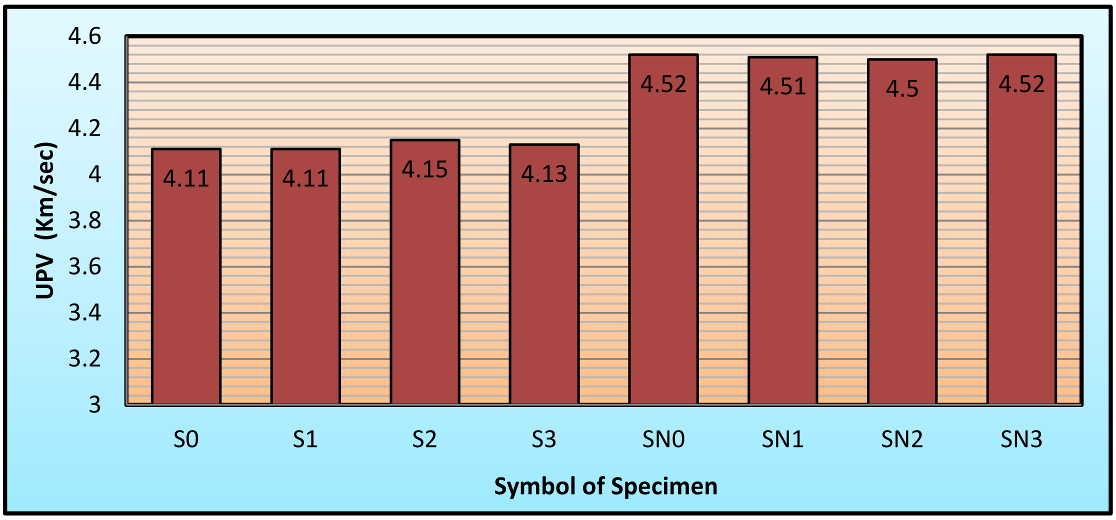

Figure 4. UPV Levels According to No. of Slab

For group 1, the results ranging from 4.11 to 4.15 Km/sec, while group 2 ranging from 4.5 to 4.52 Km/sec. The percentage of increasing cracks for S_0 specimen was 9 % compared with S^n_0. Whereas the numbers of cracks in S^n_1 and S^n_2 slabs were less than S_1 and S_2 with about 8.86 % and 7.77 %, respectively. While this percentage was 8.62% for sample S^n_3 compared to S_3 specimen.

4. CONCLUSION

The following conclusions can be made from based on experimental test results:

1. There was the difference in deflection between the ordinary sand and coarse sand specimens when the volume of aggregate is constant.
2. The bending strength of slabs increases with increasing the number of reinforcing layers.
3. The experimental test results for unreinforced slabs gave deflection values and failed loads less than the other specimens; this shows the role of wires mesh in the distribution of loads, regularly.
4. There was a significant convergence in the load required to initiate the first crack and final failure for the two groups of specimens.
5. The number of cracks in the first group slabs with normal grade sand was more than specimens in the second group.

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