

## Flexural behavior of one-way ferrocement slabs with fibrous cementitious matrices

Ziadoon Mohsin Ali<sup>1</sup>, Sheelan Mahmoud Hama<sup>2</sup>, Mohammed H. Mohana<sup>1</sup>

<sup>1</sup> Department of Construction and Projects, University Headquarter, University of Anbar

<sup>2</sup> College of civil engineering, University of Anbar

### ABSTRACT

Concrete compressive strength enhancement is considered as one of the popular topics in the field of civil engineering. It has received a massive attention by material and structural engineers over the past decades. The aim of this study is to investigate thin mortar matrix for the impacts of the combination of reinforcing steel meshes with discontinuous fibers, and to do this, one-way Ferrocement slabs were tested under bending with steel fibers and meshes, focusing more on the number of mesh layers (1, 2, & 3) as the studied parameter. The percentages of fiber content as volumetric ratio 0.25, 0.5 and 0.75 and type of fibers golden steel fibers and waste aluminum fibers from waste metallic cans. Results showed that at general the adding of fibers regardless of its type increased the ductility of tested slabs. In addition, results showed that steel fibers are more effective than aluminum fibers.

**Keywords:** Steel Fiber, Waste Aluminum Fiber, Ferrocement, Flexural Strength

### *Corresponding Author:*

Mohammed Hmood Mohana,  
Department of civil engineering,  
University of Anbar,  
E-mail: mhm1961mhm@uoanbar.edu.iq

### 1. Introduction

Ferrocement is a kind of thin refinement reinforced concrete which generally will be built of cement mortar without coarse aggregate reinforced with relatively small size wire mesh spaced as closely and continuously layers through the thickness [1], [2]. The reinforced mesh usually are made of metallic or may be other suitable materials [3]. There are some advantages of using ferrocement; easy to be constructed and molded in any shape, high skill are not needed during construction, with compared to conventional reinforcement concrete ferrocement has superior strength properties [4]–[6]. This is attributed to the two-way homogeneous-orthotropic attributes; the ferrocement matrix exhibited a high modulus, high tensile strength, and improved cracking behavior. Furthermore, there was a development of larger bond forces with the mortar due to the meshes' high specific surfaces [7]; this reduced the crack width and narrowed the spacing [8]–[10]. Mashrei examined the effect of silica fume, steel fibers and number of wire mesh layers on behavior of square ferrocement slabs with dimension 500\*500\*30 mm under flexural loading [11]. He found that increasing the amount of cement that replaced by silica fume from 0% to 6% results in increasing in ultimate flexural load 5%. But the 4.5% silica fume gave the higher increase about 16% compared to slab without silica fume replacement. Besides, he found that adding 1% steel fiber cased increased in ultimate flexural load with or without silica fume. Finally, the increased of no. of wire mesh layers from 6 to 8 and 10 layers increased the ultimate flexural load capacity by 25% and 76%, respectively. Al-Rifaie and Trikha inspected the impact of different arrangements of hexagonal mesh reinforcements on load capacity of two-slabs. They found that the meshes which were arranged in twin mesh layers results in isotropic performance of the slab and an increase in first crack and ultimate loads [12]. Hago et al. [13] study behavior of ferrocement roof slab panels loading under two-point load system. They examined the effects of structural shape of the panels and the number of wire mesh layers on the first crack load, ultimate flexural strength and crack spacing. They found that the utilization of monolithic shallow edge ferrocement beam with the roof slab panel improved both service and ultimate behavior of slab panels, regardless of the number of layers used. Shri and Thenmozhi [14] investigated the effect of polypropylene fibers on self – compacted ferrocement slabs behavior under flexural load. Test carried out on slab of size 700 (length)

× 300 (width) × 25 and 30 mm (thickness). The main parameters for this study were fiber content, the number of welded mesh layers and thickness of slab. Results showed that adding of polypropylene fibres increased the load capacity of slab and the number of cracks with decreasing in their width. The load capacity of slab with 3-layers welded mesh was higher than that for slab with 3 layers for the same slab's thickness. For the same fiber content and number of mesh an increase in slab thickness boosted the load carrying capacity of slab. Ashraf and Halhalli examined the effect of adding shaktiman steel fibers on behavior of self-compacting concrete (SCC) ferrocement slab panels under flexure. Eighteen slabs with dimensions 700 mm (length) × 300 mm (width) × 40 mm (thickness) have been tested. Two percentages of steel fibers were examined 0.25% and 0.50%. results showed that both load capacity and deflection at ultimate load are higher of slabs incorporating steel fibers especially for 0.50% [15].

The flexural behavior of discontinuous fibers-reinforced ferrocement slabs has been investigated by Shannag and Ziyyad, focusin more on the steel mesh layers, the inter-transverse wire spacing, and the fiber type (steel & glass). The outcome of the study showed that the addition of 2% steel fibers brought about 2.6 folds increase in the flexural strength of the slab panel, and meaningfully reduced the normal crack spacing and crack width; the energy absorption was also improved by 3.85 folds compared to the reference non-reinforced slab. It was also noted that the add-on of 2% glass fibers to steel meshes of smaller spacing significantly improved the flexural strength of the slab by about 2.6 folds and improved the energy absorption capability when compared to the non-reinforced matrix. In addition, they found that rising in the numbers of mesh layers from two to four layers results in a significantly increasing in both of flexural strength and energy absorption [16]. Based on the reported literature review studies, a few studies conducted on the flexural behavior of ferrocement one –way slabs reinforced with steel and aluminum fibers tested under bending. The contribution of the current research is the inspection of the effects of adding discrete, discontinuous short golden steel fibers and waste aluminum fibers to ferrocement one-way slabs tested under bending using four-point load system. Based on this conception, the current study is devoted to have more informative visualization on the concrete properties and behavior.

## 2. Material and method

In this research, the programming of the experiment is developed to investigate the flexural behavior of fiber reinforced ferrocement one-way slabs tested under four points load system. For this purpose a total of 9 ferrocement slabs of dimensions 600 (length) × 200 (width) × and 30 mm (thickness) reinforced with steel square wire mesh 0.9 mm diameter and with opening size 25×25 mm (see Figure 1) and were tested in four point loading bending test as shown in Figure 2. Several parameters were inspected including; number of mesh layers 1, 2 and 3, the percentages of fiber content as volumetric ratio 0.25, 0.5 and 0.75 and type of fibers golden steel fibers and waste aluminum fibers from waste metallic cans details are listed in Table 1.

Load–deflection curves, first crack load and corresponding deflection and ultimate load with corresponding deflection were recorded using microscope and dial gauge, respectively as shown in Figure 3. The crack width, crack pattern and failure mode were also investigated.



Figure 1. Reinforcing and casted fibrous ferrocement

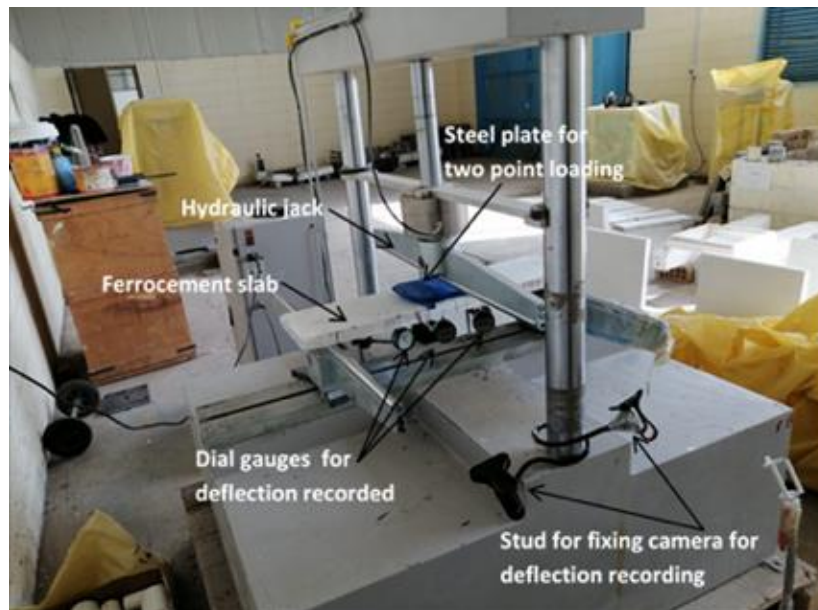


Figure 2. Four points loading bending test



Figure 3. Microscope and dial gauge that were used to recorded crack width and deflection, respectively

Table 1. The details of specimens tested

No	Group	Specimen designation*	No. of wire mesh layers	Type of fibers	Fiber %
1		SL1F0	1	None	0
2	1	SL2F0	2	None	0
3		SL3F0	3	None	0
1		SL1SF0	1	None	0
2		SL1SF0.25	1	Steel fiber	0.25
3	2	SL1SF0.50	1	Steel fiber	0.50
4		SL1SF0.75	1	Steel fiber	0.75
1		SL1AIF0	1	None	0
2		SL1AIF0.25	1	Aluminum fiber	0.25
3	3	SL1AIF0.50	1	Aluminum fiber	0.50
4		SL1AIF0.75	1	Aluminum fiber	0.75

## 2.1 Material and testing procedures

Ordinary Portland cement (Type I) was used I.O.S No. 5 [17]. Sand was used as fine aggregate and its properties was satisfied I.O.S. No. 45 [18]. The superplasticizer used was Sika ViscoCrete-5930 a High-performance super plasticizer type G and F and met requirement of ASTM C 494 [19]. The steel square wire mesh was prepared to a wire with 0.9 mm of diameter and opening wire with 25×25 mm size and examined in the laboratory based on the protocol of the ACI Committee 549 [20]. The investigations focused on the yield strength and ultimate strength of the mesh which were determined as follows: yield strength = 220 MPa, ultimate strength = 340 MPa. The ferrocement matrix was reinforced with micro golden steel fibers and waste aluminum fibers (two types of discontinuous discrete fibers) of 0.1 mm thickness, 1.5 mm width, and 20 mm length (Figure 4a). Table 2 presents the properties of these steel fiber (as provided by the manufacturer) and the aluminum fibers (laboratory-determined). The mortar mix exhibited high workability and a compressive strength of approximately 25 MPa. The mix proportions were 1:2 cement: sand, respectively with water/cement ratio 0.45 and 0.8% superplasticizer.

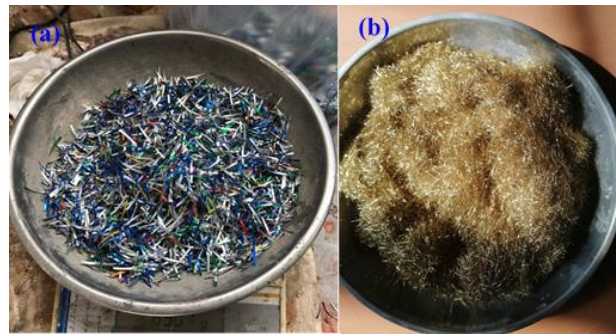


Figure 4. Fibers used in this research a) aluminum fibers; b) Steel fibers

To ensure a smooth and regular surface, the slabs were poured in molds made from smooth surface wooden mold; the positioning of the steel mesh was done in a way that will ensure a coverage of about 5 mm as shown in Figure 1. When other layers are present, they were distributed along the thickness with equal spacing. After 24 hours post-casting, the slabs were removed from the molds, cured for 28 days in portal water, and left to drain in the laboratory prior to testing [21] (Figure 5).

Slabs with four-point loading were used to conduct the bending tests as earlier mentioned under load applied from a hydraulic jack. The load signal from the load cell was recorded using a computer-based data acquisition system, while an external dial gauge was used to capture the deflection at mid span. A compression testing machine was deployed to test three cube specimens (50 mm) for compressive strength following BS EN 12390-3 specification [22].



Figure 5. Drying process of ferrocement slabs after 28 days curing



Table 2. The properties of utilized fibers

Type of fiber	Length (mm)	Diameter (mm)	Density (kg/m <sup>3</sup> )	Tensile strength (kg/ m <sup>3</sup> )	Aspect ratio	Modulus of Elasticity (GPa)
Micro steel fibers	1	0.2	7800	2600	65	210
Waste aluminum fibers	3	0.44*	7860	1250	45	180

- Equivalent diameter

### 3. Results and discussion

In the current study, the compressive strength of mortar, crack load and corresponding deflection, yield load and corresponding deflection and maximum load with corresponding deflection were recorded for all tested slabs. Also crack width and failure mode were examined.

#### 3.1 Compressive strength of mortars

Figure 6 shows the variations of compressive strength with steel fibers (SFs) percentages and with aluminum fibers (AlFs) percentages. The shape of failure is shown in Figure 7.

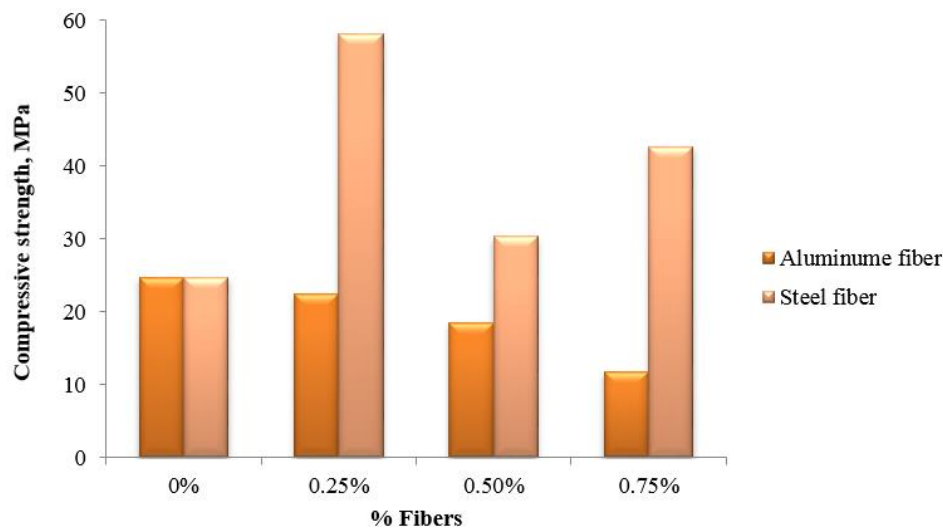


Figure 6. Compressive strength variation with fiber type and content



Figure 7. Mode of failure under compression force

From the test results revealed in Table 2 and Figure 6 aluminum fibre shown a negative influence on ferrocement strength and they had the lowest compressive strength among other specimens especially with increasing of fiber amount. The negative response may due to loss of bond inside the specimens due to excess amount of fiber

and a kind of reaction was happened between this type of fibers and surrounding mortars results in appearance of a porous on the specimens surfaces as shown in Figure 8. It can be concluded that using aluminum fibers in ferrocement composite led to decrease compressive strength. While addition of micro steel fibers had shown different effect on the specimens compared to the reference one. ferrocement with 0.25% steel fiber shown the highest increased in strength compared to reference one and among all the specimens.



Figure 8. Identified porous on slab surfaces for specimens incorporating aluminum fibers

### 3.2 Behavior of ferrocement slabs

The main goal of present investigation was to inspect the influence of fibers types on the structural behavior of ferrocement slabs incorporating fibers imperiled to two-point load. In current experimental program, the one-way slabs were categorized into three separate groups; Group 1 showed the effect of number of wire mesh layer, Group 2 showed the effect of different content of SFs, and finally Group 3 showed the effect of different content of AIFs, Table 1.

#### 3.2.1 Load-deflection relationships

##### 3.2.1.1 Effect of number of wire mesh

Figure 9 shows the effect of number of mesh layers on load-deflection behavior of ferrocement slabs. With increasing in the number of wire mesh layers the ultimate load and ductility of the ferrocement slabs increases due to the specific surface of wire mesh reinforcement.

##### 3.2.1.2 Effect of fiber content

The flexural strength test results of ferrocement and aluminum fiberous reinforced ferrocement, as shown in Figure 10 shows an increasing in the value of ultimate load and corresponding deflection with adding of 0.25% aluminum fibers. Adding 0.5% aluminum fibers results in similar ultimate load 920 MPa but the corresponding deflection increased at failure which means a more ductile behavior. While adding 0.75% aluminum fibers results in lower ultimate load 800 MPa compared reference slab but highest corresponding deflection was recorded at failure compared with other reference slab and other two percentages of fibers.

The flexural strength test results of ferrocement and fiberous reinforced ferrocement, as shown in Figure 11 presents an increasing in the value of ultimate load and corresponding deflection with the increasing amount of steel fibers. 0.5% gave the highest ultimate load while 0.75% gave the highest deflection at failure.

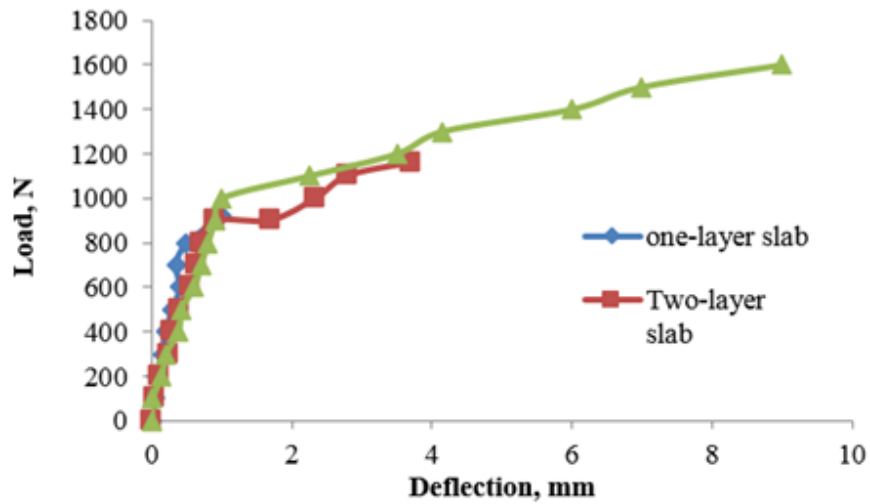


Figure 9. Effect of number of wire mesh layer on load-deflection behavior

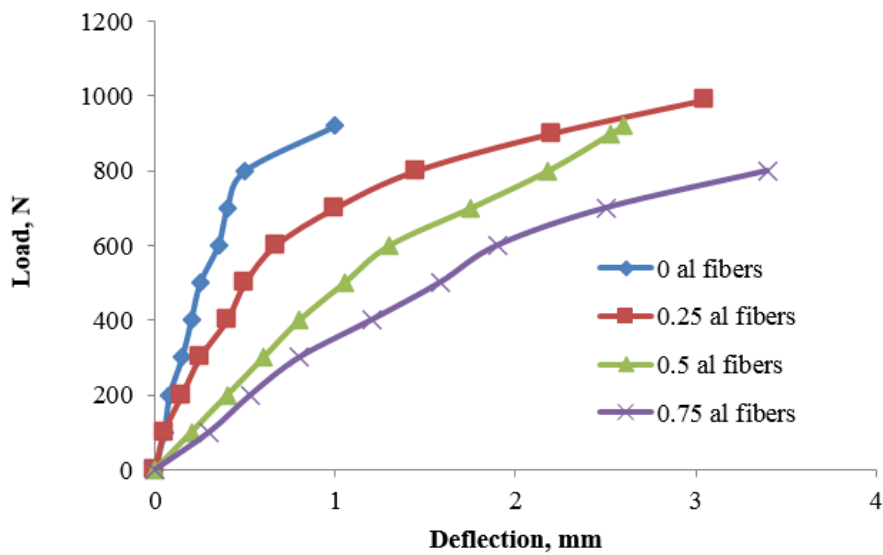


Figure 10. Effect of aluminum fibers content on load-deflection behavior

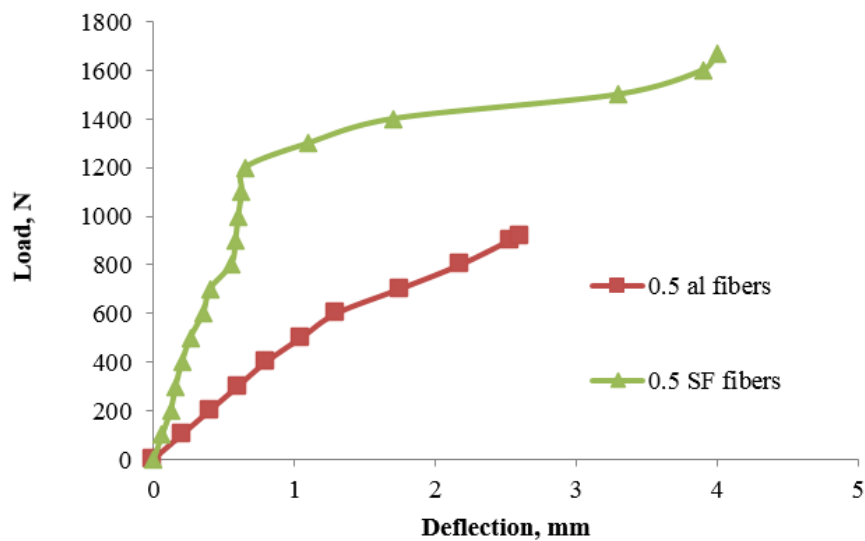


Figure 11. Effect of steel fibers content on load-deflection behavior

### 3.2.1.2 Effect of type of fiber

Figures 12, 13 and 14 showed a comparison between the results of tested slabs incorporating aluminum fibers with those incorporating steel fibers. The results showed that for all percentages of fibers the steel fibers are more effective than aluminum fibers. This is because the steel has a higher strength, higher modulus of elasticity and more stiffness than aluminum fibers.

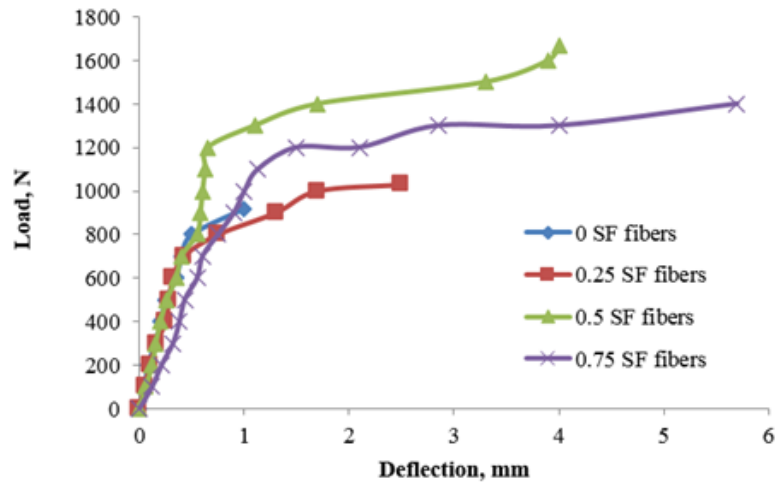


Figure 12. Effect of 0.25% fibers content on load-deflection behavior

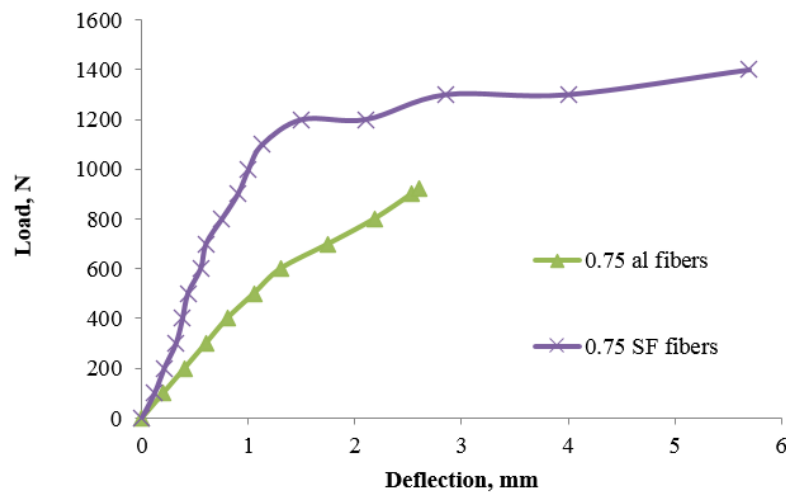


Figure 13. Effect of 0.5% fibers content on load-deflection behavior

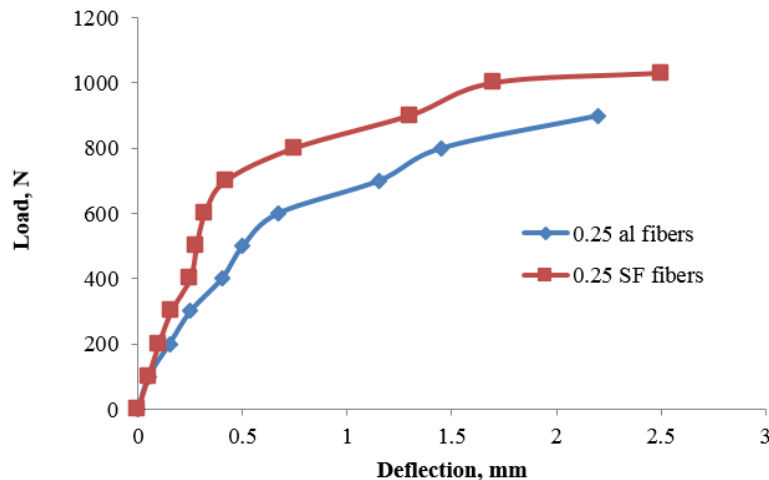
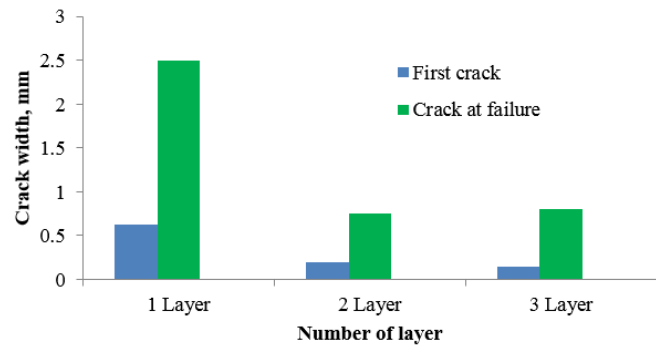


Figure 14. Effect of 0.75% fibers content on load-deflection behavior

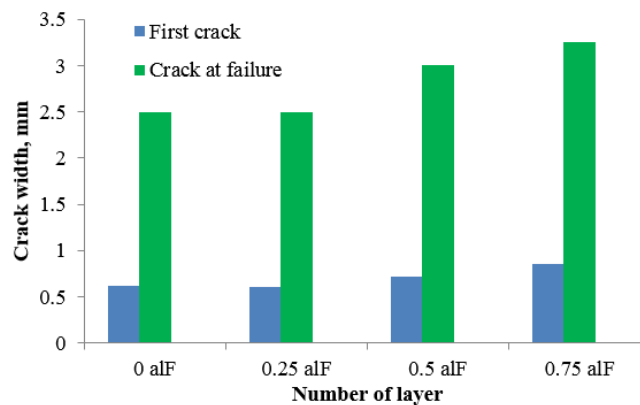


### 3.2.2 Failure modes and crack pattern

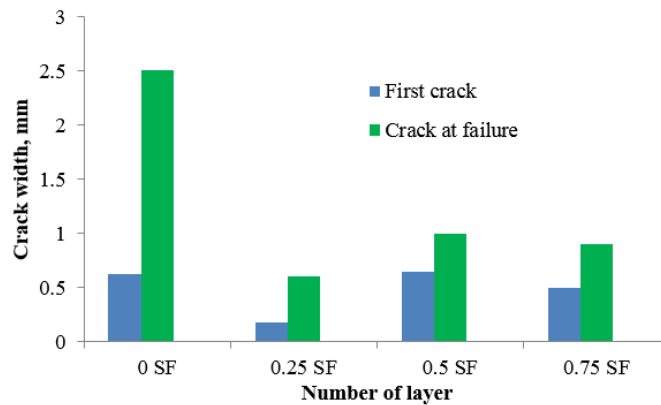
The cracks in all the tested slabs initiated at the bottom side of the reinforced ferrocement slabs as evidenced in the failure modes and crack patterns. There was also a clear effect of fibers volume on the crack patterns. The presence of the fibers in the slabs led to the exhibition of preferable behaviors as characterized by a small crack width and a larger extent of cracks. The reinforced fiber slabs exhibited gradual & ductile patterns when compared to the non-reinforced slabs. Also increasing the number of wire mesh layer transferred the behavior of tested slabs to more ductile behavior. Figures 15 (a, b and c) show the crack width for first invisible crack and at failure. It seems that adding fibers increased the number of cracks until failure. The increasing of reinforced layer decreased the crack width and increased the numbers of cracks. The steel fibers as mentioned before more effective in control of crack width and the behavior of tested slabs. Adding steel fibers are more effective to control crack widen compared to aluminum fibers and its more effective even than increased the layer number.



(a)



(b)



(c)

Figure 15. a) Crack width variation with a) number of wire steel mesh layer, b) aluminum fibers content, c) steel fibers content

#### 4. Conclusions

The main focus of the current study is to investigate thin mortar matrix for the impacts of the combination of reinforcing steel meshes with discontinuous fibers, and to do this, one-way Ferrocement slabs were tested under bending with steel fibers and meshes, focusing more on the number of mesh layers (1, 2 and 3) as the studied parameter. The conclusions of the current research were summarized as follows:

- i. The increment of wire number mesh layers and distributed along the thickness of slab results in a higher strength capacity and more ductile behavior.
- ii. Adding of steel fibers led to increase in compressive strength especially for 0.25% fibers.
- iii. Adding of aluminum fibers led to decrease in compressive strength.
- iv. Adding of fibers regardless of its type led to a more ductile behavior for tested slab under flexural loads.
- v. Steel fibers are more effective compared to aluminum fibers and clearly increased the load capacity of tested slabs.

As future research commitment, the compressive strength of the concrete can be simulated using the computer aid models for better simulation strategy [23-26].

#### Conflict of interest

The author declares no Conflict of interest.

#### Acknowledgements

The author is acknowledged his appreciation to the support by the University of Anbar laboratory support for conducting the experiments.

structural behavior of reinforced concrete beams having construction joint at different elevation

#### References

- [1] U. A. Mughal, M. A. Saleem, and S. Abbas, "Comparative study of ferrocement panels reinforced with galvanized iron and polypropylene meshes," *Construction and Building Materials*, vol. 210, pp. 40–47, 2019.
- [2] S. Z. Abeer, Z. A. Hasan, and S. Q. Abdulridha, "Investigation some properties of recycled lightweight concrete blocks as a fine aggregate in mortar under elevated temperature," *Periodicals of Engineering and Natural Sciences*, vol. 8, no. 1, pp. 400–412, 2020.
- [3] M. H. Mussa, A. M. Abdulhadi, I. S. Abbood, A. A. Mutalib, and Z. M. Yaseen, "Late Age Dynamic Strength of High-Volume Fly Ash Concrete with Nano-Silica and Polypropylene Fibres," *Crystals*, vol. 10, no. 4, p. 243, 2020.
- [4] A. D'Alessandro, D. J. Corr, and S. P. Shah, "Use of Tetraethyl Orthosilicate to Improve Durability of Ferrocement.," *ACI Materials Journal*, vol. 116, no. 6, 2019.
- [5] Z. M. R. A. Rasoul, "Accuracy of concrete strength prediction behavior in simulating punching shear behavior of flat slab using finite element approach in Abaqus," *Periodicals of Engineering and Natural Sciences*, vol. 7, no. 4, pp. 1933–1949, 2019.
- [6] Z. M. Yaseen, M. T. Tran, S. Kim, T. Bakhshpoori, and R. C. Deo, "Shear strength prediction of steel fiber reinforced concrete beam using hybrid intelligence models: A new approach," *Engineering Structures*, vol. 177, no. April, pp. 244–255, 2018.
- [7] A. N. Abbas, H. K. Al-Naely, H. H. Abdulzahra, and Z. S. Al-Khafaji, "Structural behavior of reinforced concrete beams having construction joint at different elevation."
- [8] G. Batson, "Ferrocement and laminated cementitious composites," *Materials and Structures*, 2000.
- [9] H. S. Muhammed, N. M. Al Abdaly, H. A. Zeini, and A. H. Saeed, "Use of polypropylene ropes in concrete to minimize steel reinforcement," *Periodicals of Engineering and Natural Sciences*, vol. 7, no. 4, pp. 1904–1914, 2019.
- [10] B. T. Yerimbetov, B. M. Chalabayev, Y. B. Kunanbayeva, Z. A. Ussenkulov, Z. I. Orazbayev, and Z. A. Aldiyarov, "Seismic resistance of multi-storey reinforced concrete wall-frame structures at destructive earthquakes," *Periodicals of Engineering and Natural Sciences*, vol. 7, no. 4, pp. 1582–1598,

- 2019.
- [11] M. Mashrei, "Effects of steel fibres and silica fume on the behaviours of square ferrocement slabs under flexural loading," in *IOP Conference Series: Materials Science and Engineering*, 2018.
- [12] W. N. Al-Rifaie and D. N. Trikha, "Effect of arrangement and orientation of hexagonal mesh on the behavior of two-way ferrocement slabs," *Journal of ferrocement*, vol. 20, no. 3, pp. 219–230, 1990.
- [13] A. W. Hago, K. S. Al-Jabri, A. S. Alnuaimi, H. Al-Moqbali, and M. A. Al-Kubaisy, "Ultimate and service behavior of ferrocement roof slab panels," *Construction and Building Materials*, vol. 19, no. 1, pp. 31–37, 2005.
- [14] S. D. S. R. Thenmozhi and S. D. Shri, "An Experimental investigation on the flexural behavior of scc ferrocement slabs incorporating fibers," *International Journal Of Engineering Science and Technology (IJEST)*, 2012.
- [15] M. Ashraf and V. Halhalli, "Flexural Behaviour of SCC Ferrocement Slabs Incorporating Steel Fibers," *International Journal of Engineering Research & Technology (IJERT)*, vol. 2, no. 10, pp. 557–561, 2013.
- [16] M. J. Shannag and T. Bin Ziyad, "Flexural response of ferrocement with fibrous cementitious matrices," *Construction and Building Materials*, vol. 21, no. 6, pp. 1198–1205, 2007.
- [17] T. Matschei, B. Lothenbach, and F. P. Glasser, "The AFm phase in Portland cement," *Cement and Concrete Research*, vol. 37, no. 2, pp. 118–130, 2007.
- [18] T. Y. Hsiao, Y. T. Huang, Y. H. Yu, and I. K. Wernick, "Modeling materials flow of waste concrete from construction and demolition wastes in Taiwan," *Resources Policy*, vol. 28, no. 1–2, pp. 39–47, 2002.
- [19] A. (American S. for T. and Materials), "C494: Standard specification for chemical admixtures for concrete." ASTM International West Conshohocken, PA, USA, 2005.
- [20] P. N. Balaguru and G. B. Batson, "State-of-the-art Report on Ferrocement," *ACI Committee*, vol. 549, 1997.
- [21] A. A. Shubbar *et al.*, "Properties of cement mortar incorporated high volume fraction of GGBFS and CKD from 1 day to 550 days," *Journal of Building Engineering*, vol. 30, 2020.
- [22] B. S. EN, "Testing hardened concrete–Part 3: compressive strength of test specimens," *British Standard Institution, London, UK*, 2009.
- [23] A. A. H. Alwanas, A. A. Al-Musawi, S. Q. Salih, H. Tao, M. Ali, and Z. M. Yaseen, "Load-carrying capacity and mode failure simulation of beam-column joint connection: Application of self-tuning machine learning model," *Engineering Structures*, vol. 194, no. November 2018, pp. 220–229, 2019.
- [24] Z. M. Yaseen, H. A. Afan, and M.-T. Tran, "Beam-column joint shear prediction using hybridized deep learning neural network with genetic algorithm," *IOP Conference Series: Earth and Environmental Science*, vol. 143, p. 012025, Apr. 2018.
- [25] A. A. Al-Musawi, A. A. H. Alwanas, S. Q. Salih, Z. H. Ali, M. T. Tran, and Z. M. Yaseen, "Shear strength of SFRCB without stirrups simulation: implementation of hybrid artificial intelligence model," *Engineering with Computers*, vol. 36, no. 1, pp. 1–11, Jan. 2020.
- [26] Z. M. Yaseen *et al.*, "Predicting compressive strength of lightweight foamed concrete using extreme learning machine model," *Advances in Engineering Software*, vol. 115, pp. 112–125, Jan. 2018.