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Influence of Multi-Directional Expanded Metal Mesh Reinforcement on Cement Mortar Flexural Performance

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ABSTRACT: This study investigates the effect of varying the number and orientation of expanded metal mesh EMM layers as internal reinforcement on the flexural performance of mortar prisms, including flexural strength, toughness, first crack-load, and deflection at mid-span. Mixes were prepared using EMM layers embedded in prisms of dimensions 40 cm × 10 cm × 10 cm. The number of EMM layers were (one, two, and three) and their orientation: horizontal (perpendicular to applied load), vertical (parallel to applied load), and a combination of both. The results showed that the incorporation of EMM improved the overall flexural performance significantly. This improvement became more pronounced with the increase in the number of EMM layers. Mixes reinforced with vertically aligned EMM layers exhibited greater improvements than those with horizontal alignment. The percentages of increase in flexural strength, toughness, and first crack-load for the mix reinforced with three layers of horizontally aligned mesh were 80%, 595%, and 156 %, respectively. While for mixes reinforced with three layers of vertically aligned mesh, the corresponding values were 127%, 1474%, and 242%. The deflection results exhibited two different trends; under the same applied load, mixes reinforced with EMM showed lower deflection than the plain unreinforced mix, whereas at ultimate load, reinforced mixes recorded higher deflection. The mix reinforced with a combined orientation layer demonstrated the most significant improvements for all flexural performance tests, and the percentages of increase in flexural strength, toughness, and first crack load were 140%, 2063%, and 2875% relative to the reference mix, respectively.

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1- Introduction

The incorporation of reinforcement materials within cementitious composites has been widely utilized to enhance the ductility and tensile strength of mortar and concrete. In spite of the presence of various reinforcement methods, wire mesh reinforcement has been considered a promising solution due to its capability to improve flexural strength, enhance crack control, provide structural continuity, and distribute stress uniformly [1-3]. These meshes come in different forms, such as steel fabric, chicken wire mesh, and expanded metal mesh (EMM), each supplying unique mechanical advantages depending on their geometry and interaction with the matrix. Expanded metal mesh (EMM) is a type of metallic mesh with a diamond-shaped grid and is produced by slitting and stretching a metal sheet without using welding. This process generates joint less mesh and provides excellent mechanical bonding with the surrounding matrix [4]. The absence of welded joints in EMM reduces points of weakness and transfers stress uniformly across the mesh surface. In addition to strengthening bonding with the matrix due to the open and rough texture of EMM, which makes it a superior reinforcement choice in mortar applications. The utilization of EMM in mortar aims to improve tensile and flexural strengths by bridging initiated cracks, accordingly enhancing ductility and energy absorption [3]. Moreover, the openings with diamond-shaped allow for multidirectional stress transfer, which prevents crack propagation under flexural loading [5]. EMM also increases load-carrying capacity due to its ability to improve mechanical bonding with the mortar matrix [6]. Recently, several researchers have investigated the effectiveness of wire meshes in mortar and concrete composites. Alnuaimi et al. [7] investigated the effect of using hexagonal wire mesh as a multiple layers varied between two to six on roof panels flexural behaviour. The dimensions of the roof panels were 2000 mm long, 470 mm wide and 20 mm thick. The results showed that all panels obtained significant improvement in flexural behaviour. This improvement increases as the number of wire mesh layers increases. Gaidhankar and Saeed [8], Studied the effect of using expanded metal mesh with varying numbers of layers on the flexural performance of flat panels with dimensions of (200×550×25) mm. The numbers of EMM layers used were two, three, four and five. The results showed that the panels with higher numbers of EMM layers exhibited greater flexural strength and lower deflection compared to those having

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Table 1. Grading of the sand.

Sieve size (mm)	Passing by Weight (%)	passing by weight (%) according to ACI requirement [13]
2.36	95	80-100
1.18	80	50-85
0.60	40	25-60
0.30	25	10-30
0.15	8	2-10

less numbers of layers. Mebrahtom, et al. [9] investigated the effect of incorporation multiple types of wire mesh (chicken wire, welded square and expanded metal meshes) with multiple layers (one, two and three layers) on flexural strength and energy absorption of lightweight aggregate concrete, The researchers found that the flexural strength and energy absorption for mixes reinforced with the three types of meshes increase as the number of meshes layers increasing. The concrete mix containing chicken wire mesh exhibited the best improvement compared to welded square and expanded metal meshes. Hajare and Varma [10] examined the effect of using multiple types of meshes (expanded metal, galvanized woven, and welded meshes) as a reinforcement on the flexural Behaviour of Ferro-cement Panels. Panels of dimensions of (560x150x35) mm were reinforced with three layers of wire mesh. The researchers concluded that using wire meshes led to a significant improvement in the flexural behaviour of the panels. The welded mesh showed the greatest improvement when compared to expanded metal and galvanized woven meshes. Phalke and Gaidhankar [11] studied the effect of using welded square mesh with different numbers of layers (two, three, and four layers) on the flexural behaviour of flat ferrocement panels with dimensions of (550×200×25). The researchers concluded that the first crack loads and ultimate flexural loads depend on the number of welded square mesh layers, and significant Increases in ductility and toughness were recorded when the number of layers of welded square mesh increased from 2 to 4 layers. Based on a review of previous studies. This research was designed to fill the gaps by investigating the effect of using EMM with multiple layers at varying orientations horizontanl (perpendicular to the applied load), vertical (parallel to the applied load), and combined (horizontal and vertical to the applied load)

1- 1- Objectives of the Research

The objective of this study is to investigate the effect of varying the number and orientation of Expanded Metal Mesh (EMM) layers as internal reinforcement on the flexural performance of mortar prism specimens, including flexural strength, toughness, first crack load, and mid-span deflection. To achieve this, mortar prisms of dimensions 40 cm × 10 cm × 10 cm were prepared and reinforced with EMM layers placed in different orientations (horizontal, vertical, and a hybrid combination of both) and in varying numbers (one, two, and three layers). After a curing period of 28 days, a two-point loading test was carried out to evaluate the flexural performance of the mortar prism specimens.

2- Experimental Work

2- 1- Material

- Ordinary Portland cement confirmed with Iraqi standard specification [12] was used in this study.
- Natural sand was graded according to ACI requirement [13]. A maximum size of 2.36 mm was used to ensure the smooth passage of mortar through the opening of EMM without blockage. Table 1 below includes the percentages of passing by weight of sand.
- Expanded metal mesh (EMM), the specifications of expanded metal mesh used in this study were included in Table 2 below.
- Superplasticizer, Glinium 51 was used as a high-range water-reducing admixture.

Table 2. The specifications of expanded metal mesh.

Property	Value
Weight	3.5Kg/m^2
Thickness	1.5 mm
Short way diamond	20mm
Long way diamond	40mm
Yield strength	320 MPa
Effective modulus of elasticity	70 GPa

a

b

Fig. 1. Mixes reinforced with a. horizontal (EMM) layer, b. three vertical (EMM) layers placed parallel to applied load.

2- 2- Mix Proportion

Muliple trail mixes were carried out with different water-to-cement ratio (w/c) and superplasticizer dosage to obtain compressive strength of 30 MPa for 50 mm cube at 7 days, and a flow of 150 mm to ensure better passage of mortar through EMM openings. A constant cement-to-sand ratio of 1:3 by weight, water-to-cement ratio (w/c) of 0.4, and superplstisizer dosage of 1.5 % by weight of cement were used for all mixes. Expanded Metal Mesh (EMM) was cut manually to obtain a dimension of (38 cm8 × cm) to fit in the prism mould. Eight mixes were used; the mixes are described below:

a- (Ref. mix), it is a plain, unreiforced mix.

b- (Mix 2), it is a mix with one horizontal (EMM) layer placed perpendicular to the applied load, and positioned under the neutral axis, and 1cm away from the prism bottom surface as shown in Fig 1a .

c- (Mix 3), it is a mix with two horizontal (EMM) layers placed perpendicular to the applied load, and positioned under the neutral axis, and the bottom layer is located 1 cm above the prism's bottom surface. A mortar layer with a thickness of 1 cm was used to separate EMM layers,

d- (Mix 4), it is a mix with three horizontal (EMM) layers placed perpendicular to the applied load, and positioned under the neutral axis, and the bottom layer located 1 cm above the prism's bottom surface. A mortar layer with a thickness of 1 cm was used to separate EMM layers,

e- (Mix 5), it is a mix with one vertical (EMM) layer placed parallel to the applied load, positioned in the middle of the prism, and located 1 cm above the prism's bottom surface.

f- (Mix 6), it is a mix with two vertical (EMM) layers placed parallel to the applied load, and positioned in the middle third of the prism, and located 1 cm above the prism's bottom surface.

g- (Mix 7), it is a mix with three vertical (EMM) layers placed parallel to the applied load, and positioned with a spacing of 2.5 cm between each layer, and about 2.5 cm away from the prism wall, as shown in Fig 1b. The space between the prism's bottom surface and the EMM layers was 1cm.

h- (Mix 8), it is a mix with three vertical (EMM) layers placed parallel to the applied load, and positioned with a spacing of 2.5 cm between each layer, and about 2.5 cm away from the prism wall. In addition to one horizontal (EMM) layer placed under vertical (EMM) layers at a spacing of 1cm away from the prism bottom surface.

Firstly, mortar was poured to obtain a mortar layer of 1 cm at the prism bottom to cover the EMM. Then (EMM) layers were placed in the allocated position as mentioned above, and the mortar poured in the prism mould and compacted by using a vibrating table. After a curing period of 28 days, the flexural performance tests including flexural strength, toughness, first crack load, and mid-span deflection. were carried out for each prism. Tow point load flexural strength was calculated according to [14]. Prisms with dimensions of 40 cm × 10 cm × 10 cm were used to measure the flexural strength of cement mortar, to incorporate multiple EMM layers and to better simulate the practical conditions of cement mortar prisms under flexural load. Clear span to depth ratio of prisms was 1:3 according to the requirement of [14]. To determine deflection at any flexural load, a dial gauge was mounted at mid span of the prism. The first crack load was determined visually during the flexural test. Toughness was determined

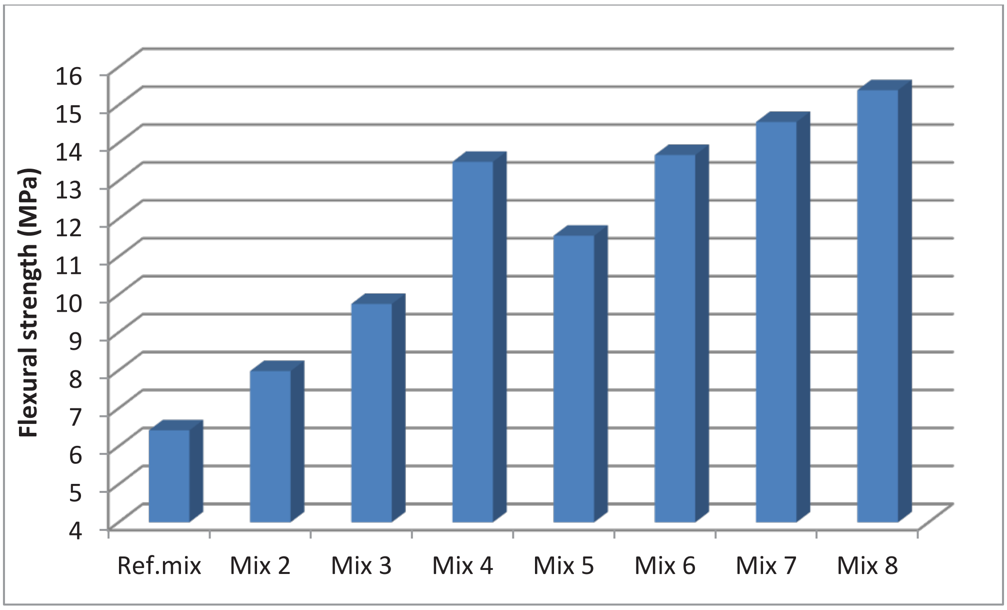


Fig. 2. The results of flexural strength for all mixes.

Table 3. The percentages of increase in Flexural strength, Toughness and First crack load

	% Increasing in		
Mix designation	Flexural strength	Toughness	First crack load
Ref.mix			
Mix 2	24	79	22
Mix 3	52	223	78
Mix 4	110	1160	189
Mix 5	80	595	156
Mix 6	113	1298	211
Mix 7	127	1474	244
Mix 8	140	2063	278

by calculating the area under the flexural load – deflection curve.

3- Results and Discussion

3- 1- Flexural Strength

The results of the flexural strength of all mixes are included in Fig 2. below. As a general trend, the results show that using EMM led to an increase in flexural strength for all mixes. The percentages of increasing in flexural strength are included in Table 3.

The inclusion of (EMM) within cement mortar has led to a noticeable improvement in flexural strength results for all tested specimens. This improvement can be attributed to multiple synergistic mechanisms. Firstly, the internal crack-arresting structure of the EMM prevents the initiation and propagation of micro-cracks under flexural loading. The mesh intersects crack paths and transfers stresses across the initiated cracks, thus enhancing post-cracking performance and delaying failure resulting from the brittle nature of cement mortar [15]. Secondly, a strong mechanical interlock between the mortar matrix and the mesh, due to the diamond-shaped openings of EMM, which provides efficient load transfer and strong interface bond [16]. Moreover, the utilization of EMM leads to a more uniform distribution of internal stresses and prevents stresses concentrating within the mortar matrix [17]. Finally, the increase in the ductile behaviour for mortar containing EMM allows it to sustain higher deformations before failure [7]. For mixes containing horizontal EMM, the results show an increase in flexural strength, and this increment is proportional directly to the number of EMM layers. The increment percentages were (24%, 52%, and 110%) for (mix2, mix3, and mix4) relative to Ref.mix, respectively. These improvements in flexural strength can be attributed to greater increases in the reinforcement within the tensile zone under neutral axis, and improved stress distribution within the mortar, which caused minimum stress concentrations and increased structural efficiency [17]. As the mixes reinforced with horizontal EMM layers, mixes reinforced with vertical EMM layers exhibited significant improvements in flexural strength, but the percentages of increment in flexural strength were higher than those for horizontally reinforced mixes. This superiority for vertically reinforced mixes may be aatributed to the alignment of EMM layers with the direction of applied load, which makes the reinforcement more effiecint, because the vertical alignment which extended across the full depth of the prism, causes a redistribution of stresses and a better mechanical interaction between the EMM layers and the mortar along the full depth of mortar prism tensile zone. The results also that the mix 8, which was reinforced with three vertical EMM layers and one bottom horizontal layer, showed the greatest improvement in flexural strength among all mortar mixes. This improvement can be attributed to the synergistic effect between the vertical layers, which Resists the tensile stresses along the full depth of the mortar prism, and the horizontal layer, which resists the tensile stresses within the tensile zone under the neutral axis near the bottom o of the mortar prism .

3- 2- Toughness

The results of toughness are included in Fig 3, while table 3 contains the percentages of increment in toughness relative to Ref mix.

For horizontally reinforced mixes, the results exhibited a significant improvement in the toughness when compared to the Ref. mix. The improvement was more pronounced with the increase in the number of EMM layers. Mixes reinforced vertically exhibited the same progressive trend, but with higher percentages of increasing compared to their horizontal counterpart. The enhancement in the toughness with increasing of the number of EMM layers can be attributed to the higher reinforcement density, which resists crack propagation and redistributes stress under flexural loads effectively [18]. Toughness is the capability of the specimen to absorb energy before failure and calculated as the area under the load-deflection curve [19]. Fig 4 below shows the load-deflection curve for all mixes.

The Ref.mix showed the lowest toughness due to the brittle nature of unreinforced cement mortar. While mixes reinforced with EMM layers showed significant increases. The enhancement in toughness for the mortar reinforced with (EMM) can be attributed to increasing absorbed energy during and after crack initiation, due to the ability of EMM layers to bridge initiated cracks. [20-22]. In addition to improving the ductility under flexural loading resulting from the diamond-shaped openings of EMM, which enhances mechanical interlocking with the matrix. This mechanical interlocking resists crack propagation and redistributes loads [20]. The highest toughness among all mixes was recorded with Mix 8, which was reinforced with three vertically aligned layers with one horizontally aligned layer. The superior performance of Mix 8 may be attributed to the synergistic effect of vertical and horizontal reinforcement, which enhances multi-directional resistance and improves the ability of mortar to absorb energy.

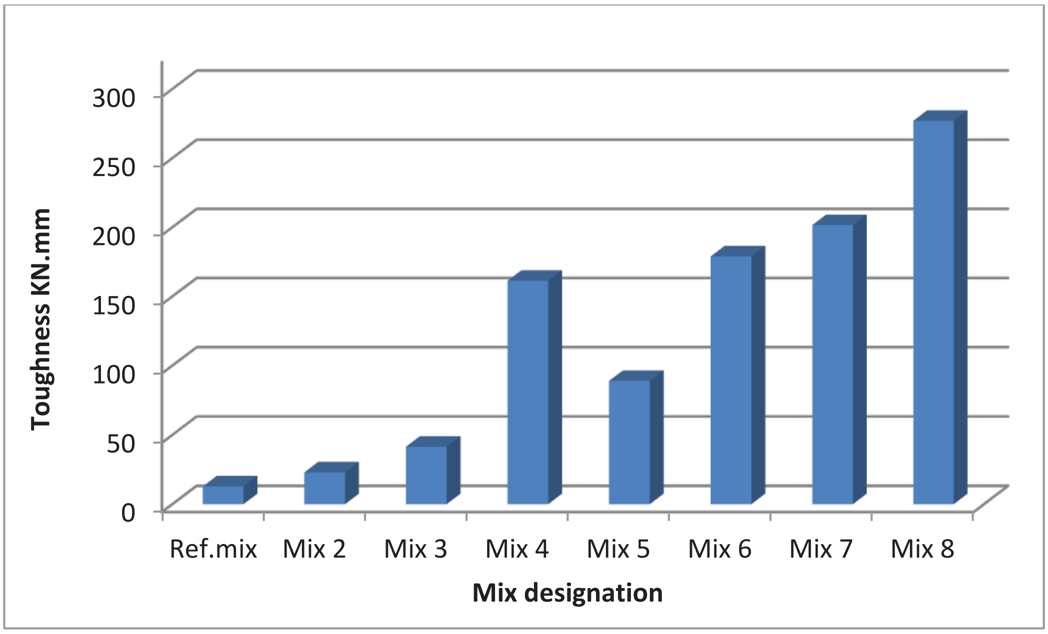


Fig. 3. The results of toughness for all mixes.

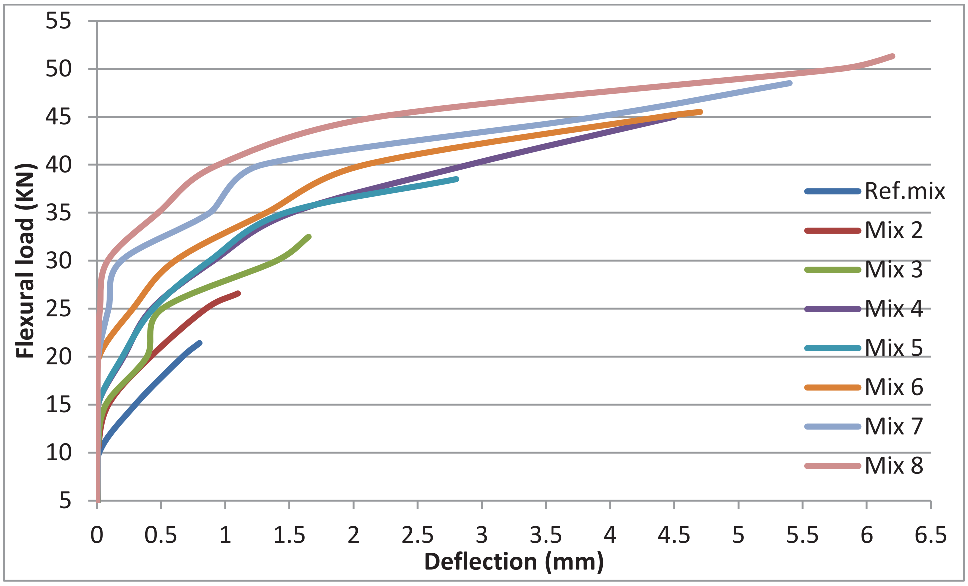


Fig. 4. Load-deflection curves for all mixes.

3- 3- First Crack Load

The first crack load results and the percentage increases in first crack load relative to Ref.mix are included in Fig 5 and Table 3, respectively. The results demonstrated significant improvements in all mortar prisms reinforced with EMM when compared to the Ref. mix. The results also show that the first crack load increased progressively with increasing the EMM layers, reaching a peak value of 34 kN in Mix 8, compared to 9 kN in the Ref.mix specimen. This enhancement can be attributed to the EMM's ability to bridge the initiated crack and delay its propagation through the cementitious matrix [23, 24]. Additionally, the denser reinforcement of EMM layers distributed internal stresses equally, and reduced stress concentration [25]. Mixes reinforced with vertically aligned EMM showed higher first cracking loads than those with horizontally reinforced counterparts. This superior performance of vertically aligned EMM layers may be explained by the ability of vertical alignment to intercept cracks along the height of the tensile zone and resist micro-crack propagation at early stages of loading. Mix 8, with combined reinforcement of vertical and horizontal alignments, exhibited the highest first crack load among all mixes. This may be due to the synergistic ability of EMM to scatter stress in multiple directions and delay crack initiation. Fig.6 shows the crack formation and propagation behavior of the mixes. For Ref. mix, the first crack initiated suddenly at the bottom of prism near the mid-span and propagated vertically upward, fracturing the prism into two halves and did not show any residual deformation, due to its brittle behaviour of unreinforced morar as shown in Fig. 6a. The mix reinforced with horizontal EMM layer exhibited a delayed crack initiation, and the crack propagation was restrained near the mesh layer. When the crack reached the mesh layer, its progress became slow, due to the bridging action of the mesh., The failure pattern is mainly single and vertical as shown in Fig. 6b. For the mix reinforced with a vertically aligned EMM layer, Fig. 6c shows that the first crack initiated near the mid-depth of the prism and extended along the mesh wires. The failure pattern is mainly small multiple cracks around the mesh instead of a single and vertical crack, due to a more effective stress distribution through the depth of the specimen. For the combined mesh corientation, Fig. 6d shows that the cracks were initiated in the tensile zone but were arrested and redirected by the intersecting meshes. The failure pattern is a complex crack network, demonstrating strong mesh–matrix interaction and enhanced energy absorption.

3- 4- Deflections

The results of deflection and ultimate deflection are included in Table 4. The results show that the mortar prisms reinforced with EMM demonstrated two different trends. At the same applied load, specimens reinforced with EMM showed a noticeable reduction in deflection values compared to the unreinforced Ref. mix. This reduction became more pronounced as the number of EMM layers increased. This decrease in mid-span deflection when EMM layers were used can be attributed to improved structural stiffness, restrained crack propagation, and enhanced the ability of crack-bridging[15, 26, 27]. The results also show that mixes reinforced with vertically aligned EMM layers exhibited greater reduction in deflection than those with horizontally aligned layers under the same applied load. Mix 8 exhibited the lowest deflection at the same applied load among all mixes, indicating the superior dimensional stability. For ultimate deflection at failure, an opposite trend was noticed; all mixes reinforced with EMM exhibited higher deflection at peak load compared to the Ref. mix. Whereas the inclusion

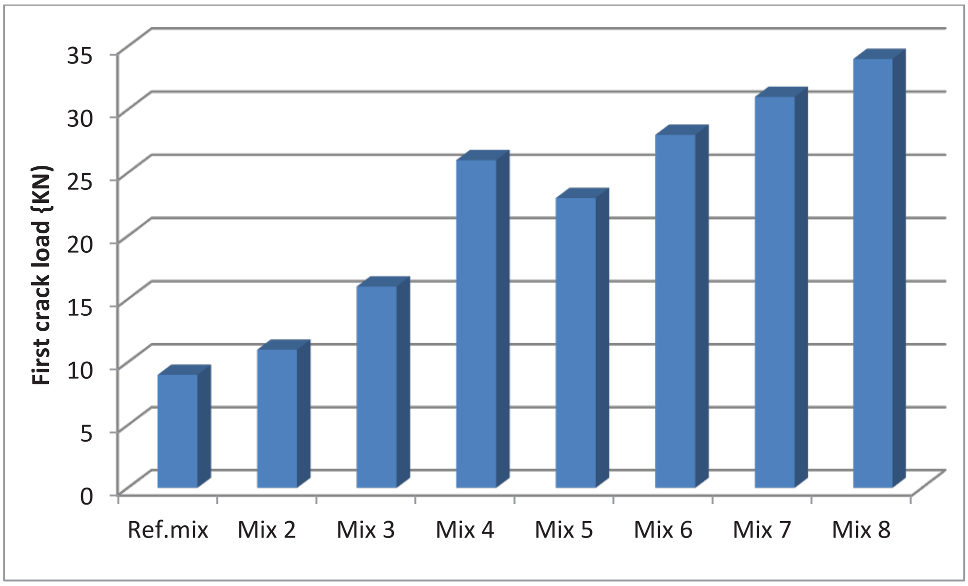
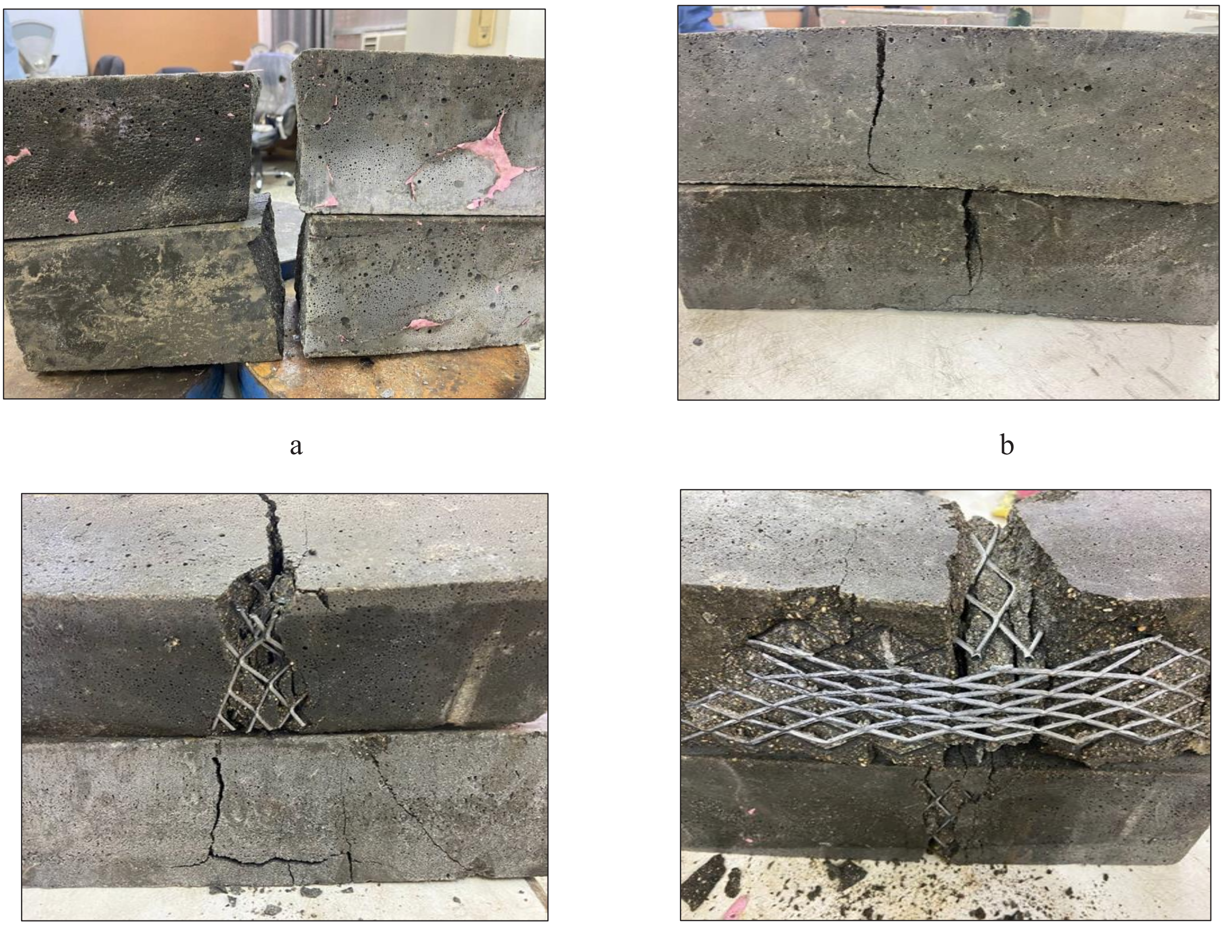


Fig. 5. First crack load for all mixes.



a b c d

Fig. 6. Failure pattern of a. Ref.mix b. mix reinforced with horizontal EMM layers c. mix reinforced with vertical EMM layers d. mix reinforced with horizontal and vertical EMM layers

Table 4. The results of deflection for all mixes.

Ref.mix		Mix 2		Mix 3		Mix 4		Mix 5		Mix 6		Mix 7		Mix 8	
load	Def.	load	Def.	load	Def.	load	Def.	load	Def.	Load	Def.	load	Def.	load	Def.
KN	mm	KN	mm	KN	mm	KN	mm	KN	mm	KN	mm	KN	mm	KN	mm
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0.005	5	0.0048	5	0.0045	5	0.0035	5	0.0042	5	0.0036	5	0.003	5	0.0021
10	0.018	10	0.009	10	0.0078	10	0.0069	10	0.0064	10	0.005	10	0.0046	10	0.004
15	0.3	15	0.09	15	0.07	15	0.009	15	0.009	15	0.0068	15	0.005	15	0.0045
20	0.67	20	0.42	20	0.39	20	0.21	20	0.2	20	0.017	20	0.01	20	0.009
21.4	0.8	25	0.85	25	0.51	25	0.43	25	0.44	25	0.28	25	0.09	25	0.025
		26.6	1.1	30	1.4	30	0.91	30	0.88	30	0.61	30	0.19	30	0.085
				32.5	1.65	35	1.52	35	1.47	35	1.32	35	0.88	35	0.48
						40	2.9	38.5	2.8	40	2.09	40	1.29	40	0.95
						45	4.5			45	4.4	45	3.9	45	2.2
										45.5	4.7	48.5	5.4	50	5.8
														51.3	6.2

of EMM in mortar specimens led to enhancing ductile behaviour, increasing post-cracking energy absorption, and allowing the mortar specimens to endure higher deformation before the final failure occurrence [18, 25]

4- Conclusions

1-The mortar specimens reinforced with Expanded Metal Mesh (EMM) layers exhibited significant improvements in flexural strength, toughness, and first crack load.

2-The improvement in flexural performance was more significant with the increase in the number of EMM layers, and mixes reinforced with vertically aligned EMM exhibited greater improvements than those with horizontal alignment. The percentages of increase in flexural strength, toughness, and first crack load increased from (24 %, 79 %, and 22%) to (110%, 1160%, and 189 %) for mixes reinforced with horizontally aligned mesh of one and three layers, respectively. In contrast, vertically reinforced mixes with one layer and three layers showed increases from (80%, 595%, and 156%) to (127%, 1474%, and 242%), respectively.

3- The deflection results exhibited two different trends: mixes reinforced with EMM layers showed lower deflection than the unreinforced mix under the same applied load, due to improved stiffness. Whereas at ultimate load, reinforced mixes with EMM layers showed higher deflection, reflecting enhanced ductility and increased energy absorption.

4- Among all mixes, the mix reinforced with a combination of three vertical layers and one horizontal layer demonstrated the most significant improvements for all flexural performance tests, due to the synergistic effect of multi-directional reinforcement on flexural performance. The percentages of increase in flexural strength, toughness, and first crack load were (140%, 2063%, and 2875%) relative to the reference mix, respectively.

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