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Shear Behavior of Strengthened Ferrocement RC Beams by Steel Wire Mesh

Sarah H. Hameed [1], Abdulkhaliq A. Jaafer [1*]

[1] Civil Engineering Department, Collage of Engineering, University of Misan, Maysan, 62001, Iraq.

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Abstract

This paper investigates the possibility of strengthening a ferrocement RC beam with steel wire mesh under static loading. This experimental study included testing ten normal and high-strength concrete specimens made with ferrocement. The main parameters were the steel wire mesh layers 4, 8, and 10 in addition to the compressive strength and shear to span to depth ratio of 1.8 and 2.5. The cracking load, ultimate load, deflections, initial stiffness, energy absorption, diagonal and compressive strains, and crack pattern and failure modes of such beams were discussed. The outcomes exhibited that the beams behave linearly until they reach about 21.5% of the ultimate strength for the normal concrete beam and 23.2% for the high-strength concrete beam. The steel wire mesh presence affected the ultimate strength of the concrete beam, which increased the cracking load by an average of 15.5% for the high-strength RC beam and by 24.2% for normal-strength RC ones. The ultimate load was increased by an average of 40% for the high-strength strengthened beams and with less percentage for the normal ones, which was 31%. The a/d ratio affected the ultimate load-carrying capacity and maximum displacement directly, which increase a/d led to a decrease in the ultimate load-carrying capacity. The strengthening by steel wire mesh enhanced the initial stiffness, ductility, and energy absorption.

Keywords: Steel Wire Mesh; Ferrocement; Compressive Strength; Ductility; Energy Absorption.

1. Introduction

Ferrocement is a type of thin-walled reinforced concrete commonly constructed of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small-sized wire mesh. Ferrocement has found numerous applications as a thin reinforced concrete product and as a laminated cement-based composite, both in new structures and in the repair and rehabilitation of existing structures. Compared with conventional reinforced concrete, ferrocement is reinforced in two directions; therefore, it has homogenous isotopic properties in two directions. Benefiting from its usually high reinforcement ratio, ferrocement generally has a high tensile strength and a high modulus of rupture. In addition, because the specific surface of reinforcement of ferrocement is one to two orders of magnitude higher than that of reinforced concrete, larger bond forces develop with the matrix, resulting in an average crack spacing and width more than one order of magnitude smaller than in conventional reinforced concrete. Increasing the strength of the concrete members has become an urgent necessity due to the urgent need to construct structures with high strength against loads, earthquakes, and various environmental conditions. The explanation behind the formation and propagation of the cracks is their brittleness, which independently limits the use of normal concrete as a tensile stress transmitting material [1]. This means that new forms of concrete are required, the mechanical characteristics of

* Corresponding author: aljabery@uomisan.edu.iq

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which comply with current demands. One of the most effective methods for reducing crack propagation and improving the mechanical properties of concrete is to strengthen it with steel wire mesh distributed with different orientations [2-5]. Ferrocement material can be defined as a mortar integrated with steel wire mesh [6]. Ferrocement differed from traditional reinforced concrete in that the ferrocement has scaled elements.

In addition to owning the FC, the reinforcement was arranged so close and embedded in the mortar. The purpose behind the use of FC was to provide benefits such as lightness, durability, and environmental stability. Regarding the steel wire mesh, this material is considered the most effective way to shear strengthen the beams, which improves the shear and flexural capacity of the beams. It improves the cracking and ultimate load and provides good control against the crack's propagation [7]. Wire mesh is used as reinforcement in flanged ferrocement members, such as channel sections, box sections, and sandwich ribbed plates. Many studies on ferrocement as a low-cost construction material and a flexible structural system have been conducted, and many parameters have been tested to validate the new system and improve its performance.

In 1948, the first use of ferrocement was by *Joseph Louis Lambot*, who stated that ferrocement could be used in a variety of practical applications, such as the repair and strengthening of damaged RC members. According to the previous research, it has been discovered that the use of ferrocement offers an acceptable strength, higher cracking load, and better crack propagation, stiffness, energy absorption, and ductility, besides the flexural strength. Using ferrocement as the main material in the structural members exposed good strength against the shear forces [8-10]. Several types of research were conducted regarding the possibility of using ferrocement as a low-cost construction material and several parameters were used. Most of this research concluded that ferrocement can be used as a structural material in RC buildings due to the offered properties and features [11, 12]. Prathima and Jaishankar [13] presented experimental research which investigated the use of steel wire mesh as steel reinforcement and found that the use of wire mesh layers as an extra reinforcement greatly improves flexural strength by distributing force along the section and improves the cracking load and ultimate load carrying capacity. In addition, the conclusion was that the possibility of use of FC with steel wire mesh did not exceed the optimum percentage, which will provide additional advantages to concrete beams in addition to its environmental and economic benefits, which were the main purposes of its use. Al-Sulaimani et al. [14] carried out an experimental study concerning the shear behaviour of flanged beams made with ferrocement and strengthened with steel wire mesh. The outcomes explored that cracking load and maximum strength capacity against shear stresses were enhanced when the reinforcement by steel wire mesh was arranged in webs. In addition to the effect of the shear span to beam depth ratio (a/h), when a/d is increased, the ultimate load is decreased. In addition, the conclusion was that the possibility to use FC with steel wire mesh does not exceed the optimum percentage, which will provide additional advantages to the concrete beam in addition to its environmental and economic benefits, which were the main purposes of its use.

Mansur et al. [15] investigated the shear behavior of FC beams. The studied variables were the a/d, and volume fraction of the wire mesh, in addition to the compressive strength. According to the obtained outcomes, when a/d was reduced and FC volume fraction and compressive strength were both raised, the ultimate shear strength increased. Walker et al. [16] investigated the possibility of using the ferrocement as an external strengthening layer to enhance the shear strength with many values of a/d. The presence of ferrocement enhanced the shear strength of the member. The beam behaves as a tied arch at low (a/d) ratios. In 1991, the structural performance of ferrocement sandwich load-bearing wall panels was investigated by Basunbul et al. [17]. Due to the delaminating and buckling effects of skeletal steel, ferrocement wall panels reinforced with wire mesh only revealed an improved axial and lateral ductility than panels reinforced with wire mesh plus skeleton steel. Meng et al. [18] studied the behavior of reinforced concrete beams with different transverse reinforcements. The transverse reinforcement method was used, which included using stirrups as the main reinforcement only, the use of wire mesh, and a combination of wire mesh and stirrups. The outcomes referred to the use of wire mesh as shear reinforcement in the beam improved the shear strength capacity. Jafer [19] investigated the strengthening of RC columns by ferrocement reinforced by steel wire mesh under the influence of many parameters, such as the volume fraction and the mortar compressive strength. The results referred to the effectiveness of the ferrocement in enhancing the mechanical properties of the reinforced concrete members, which enhanced the load-carrying capacity besides improving the other properties such as ductility, which improved significantly. In 2019, El-Sayed and Erfan [20] presented an experimental and numerical investigation regarding improving the shear strength of beams by the use of ferrocement. The used parameters were the type of wire mesh (expanded and welded wire mesh) and the layer number. The results revealed that testing of seven (7) beams showed that welded and expanded wire meshes show multiple features over steel reinforcement, especially for structures with complex shapes and curvatures, because they are lighter, easier to handle, easier to cut, and easier to bend than steel reinforcement. Increasing the number of layers of expanded and welded wire mesh led to improved ultimate load, load deflection, stiffness, toughness, and shear stress of ferrocement beams. Accepted agreement between experimental results and analytical ones was obtained.

Based on the previous studies, it’s found that the previous studies didn’t focus on the relationship between the normal and high strength ferrocement RC beams with steel wire mesh with many variables such as the wire mesh layers and a/d ratio, which have not been studied and discussed previously. The variables used in the previous study were limited.

Therefore, the focus will be on variables that provide a full understanding of the behavior of this type of beam. The main objective of this work is to assess the possibility of upgrading the capacity of the load-carrying capacity of beams. The variables include strengthening the beams with many layers of steel wire mesh, taking into consideration the effect of the a/d ratio besides the compressive strength, which will explain the relationship between the use of steel wire mesh in both normal and high-strength concrete beams. In addition to the failure mode and crack pattern, the results were given in terms of load-displacement curves, ductility, energy absorption, stiffness, diagonal strain, and compressive strain.

2. Materials Properties and Concrete Mixes

Proportions of the mix for the production of normal and high strength ferrocement are presented in Table 1. The mix included the use of cement, sand, water, silica fume, superplasticizer, and steel wire mesh. Before the concrete components mix, the material must be checked physically and chemically. The inspection of materials included testing of cement according to the Iraqi standards while the other testing such as the sieve analysis, and compressive strength were tested according to the ASTM C109 [21], ASTM C-136 [22], ASTM C191 [23], and Iraqi standards No. 45/1984 [24] respectively. The high strength concrete included the addition of silica fume to the concrete mix and an increase in the ratio of the cement with an optimized procedure to produce a high strength concrete as revealed in Table 1. A grey condenser grade 920 D silica fume was used. Regarding the additives, the superplasticizer that is used is confirmed and checked according to ASTM C494-99 [25]. Steel wire mesh with diameters of 1 mm and grid size of 10 × 10 mm was used as presented in Table 2.

Table 1. Concrete Mix details

Material /(kg/m^3)	Mix 1 (NSC)	Mix 2 (HSC)
Cement.	695.8	950
Sand.	1391.6	1050
Super PS.	3.4	26.6
Silica fume.	-	142.5
water	278.32	190
Density kg/m^3.	2240	2470
fcu (7 days)	14.1	15.3
fcu (28 days)	35	65
f_t.	5.1	8.1
f_r.	5.5	9.1
Cement.	695.8	950

Table 2. Characteristics of used Steel fibers

Type	Opening (mm)	Diameter (mm)	Density	Tensile strength
Wire mesh	10×10	1	200 GPa	550 MPa

3. Experimental Program

3.1. Concrete and Steel Bars

Reinforced concrete with compressive strength of (35-65) MPa was used to manufacture normal and high strength ferrocement RC beams. Regarding the steel reinforcement, rebar with a diameter of Ø10 and Ø16 mm was used to reinforce the ferrocement beams (FCRBs). These rebars have yield stress equal to (549 and 569) MPa respectively as revealed in Table 3 and Figure 1. Rebar's test was carried out according to the American standard specification ASTM A615, 2020 [26].

Figure 1. Constructing of the ferrocement beams

Table 3. Beams Components details

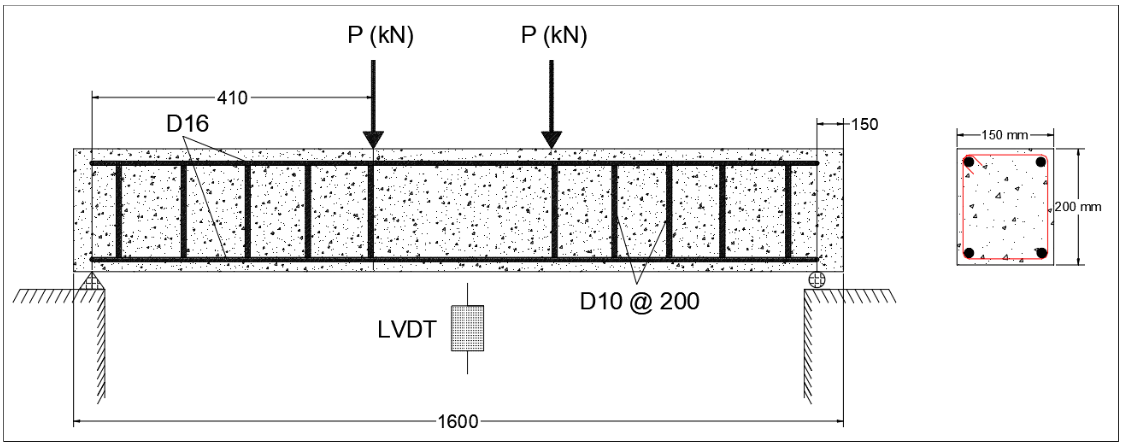
Material Type	Compressive Strength [MPa]	Grade [MPa]
Ferrocement RC	35 & 65	-
Rebar Ø10	-	549
Rebar Ø16	-	569
Wire mesh	-	550

3.2. Beams Details and Testing Procedure

In this work, the reduced scale model is considered which included testing the concrete beams with reduced dimensions of 150 × 200 × 1600 mm for the concrete beams that were designed to fail in shear. The small scale of models is selected according to many considerations which must be enough to obtain a result that a near to the true behavior of the full model with real dimensions. The optimum scale factor was chosen according to the feasibility study which was carried out to satisfy the constraints such as the weight and dimensions which should be compatible with laboratory equipment. The second constraint is the ultimate capacity of the testing machine. Regarding the steel reinforcement, main and transverse reinforcement with Ǿ10 and Ǿ16 mm were placed in the molds. Steel wire mesh was arranged isotopically in three directions of the transverse reinforcement. The dimensions in mm and details of the beam specimens are presented in Table 4 and Figure 2. All specimens were tested under a two-point load using a universal testing machine of 600 kN. The (LVDT) is placed in the mid-span of the beam and was used to monitor the deflection of the beam. Two strain gauges with a length of 300 mm were used to measure strains, one of them on the upper surface at midspan was used to measure concrete compressive strain. Another one was placed in the mid shear span to measure diagonal shear strain.

Table 4. Beam's details

Series	ID	No. of Wire Mesh Layers	Tension Steel bar	Compression Steel bars	Stirrups	Volume Fraction	a/d	Compressive Strength of Mortar (MPa)
Group1	2HS	Control beam	2 Ø 16	2 Ø 10	@200	---	2.5	65
	2HS4	4	2 Ø 16	2 Ø 10	@200	0.00314	2.5	65
	2HS8	8	2 Ø 16	2 Ø 10	@200	0.00628	2.5	65
Group 2	1HS	Control beam	2 Ø 16	2 Ø 10	@200	---	1.8	65
	1HS4	4	2 Ø 16	2 Ø 10	@200	0.00314	1.8	65
	1HS8	8	2 Ø 16	2 Ø 10	@200	0.00628	1.8	65
	1HS10	10	2 Ø 16	2 Ø 10	@200	0.0078	1.8	65
Group 3	2NS	Control beam	2 Ø 16	2 Ø 10	@200	---	2.5	35
	2NS4	4	2 Ø 16	2 Ø 10	@200	0.00314	2.5	35
	2NS8	8	2 Ø 16	2 Ø 10	@200	0.00628	2.5	35



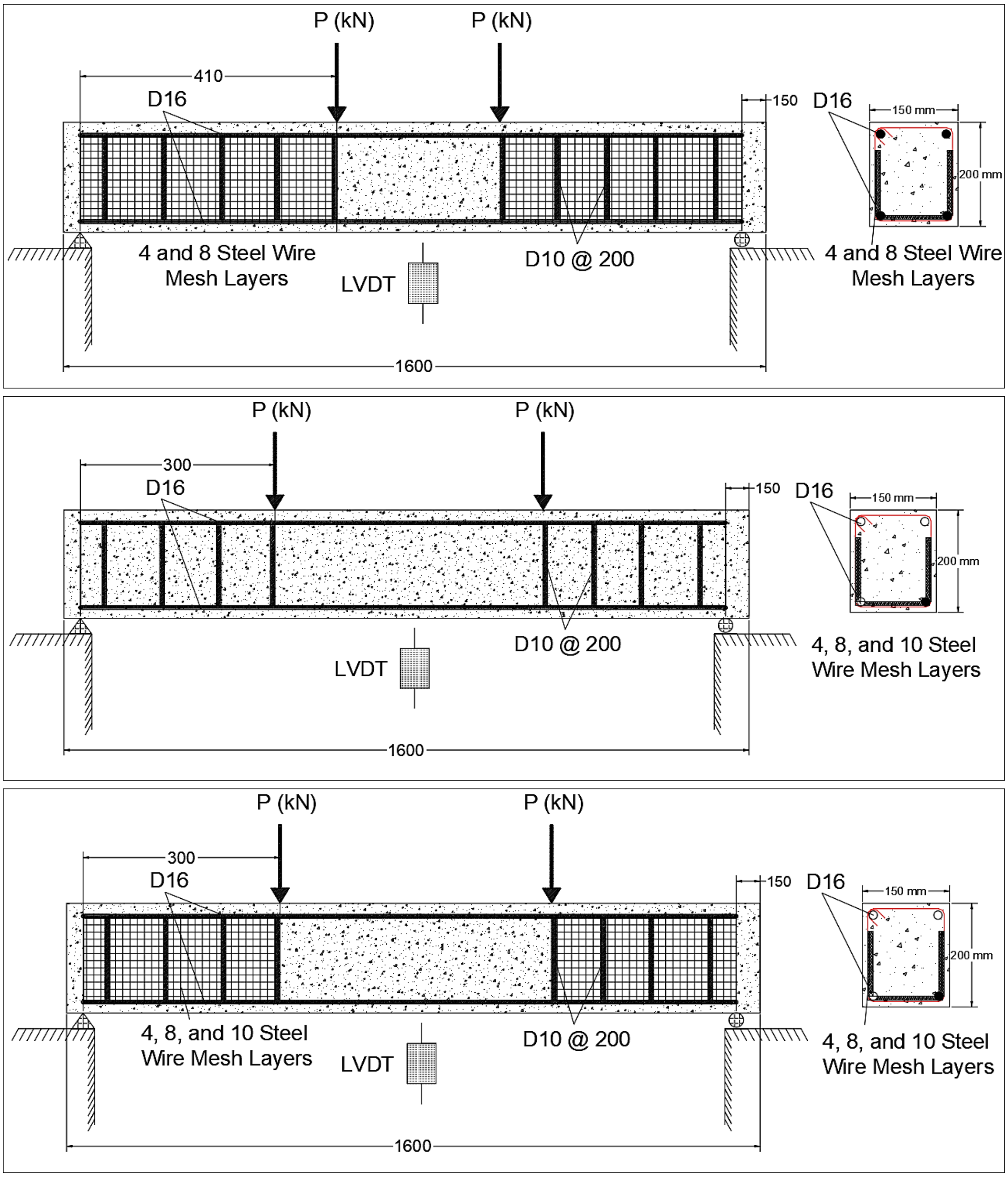


Figure 2. RC beams details

4. Obtained Results with Discussion

4.1. Failure Mode and Crack Patterns

Figure 3 illustrated the failure details such as the crack pattern at ultimate load, and deformed area. It should be noted that the reference beam specimens face a failure in shear while when strengthened with wire mesh the failure turned to the flexural one. The shear failure occurred for the beams when the strength of the concrete beam against shear was less than flexural strength which the shear forces beat the shear strength of the beam. A shear load is a force that causes a material to slide along a plane parallel to the force's direction of application. The beams with shear failure showed the development of cracks from the support and extended to the load region. A large crack developed and extended which made the failure in this region with the existence of small flexural cracks in the concrete. The control beams fabricated with ferrocement and without steel wire mesh showed an average cracking load 47.5 kN for the beams with high strength concrete which is equal to 26.4% of the ultimate load-carrying capacity. While the normal strength of concrete, the cracking load was 31 kN which is equal to 22.6% of the ultimate load-carrying capacity. In the case of flexural beams, the strengthening shifted the failure from shear to flexure due to the high resistance of the shear zone due to the presence of the wire mesh. At the average cracking load of 20.9% of the ultimate load-carrying capacity, cracks began to develop. Following this load, cracks expanded into the cross-compression section's zone, followed by further tiny flexural cracks emerging in the same location.

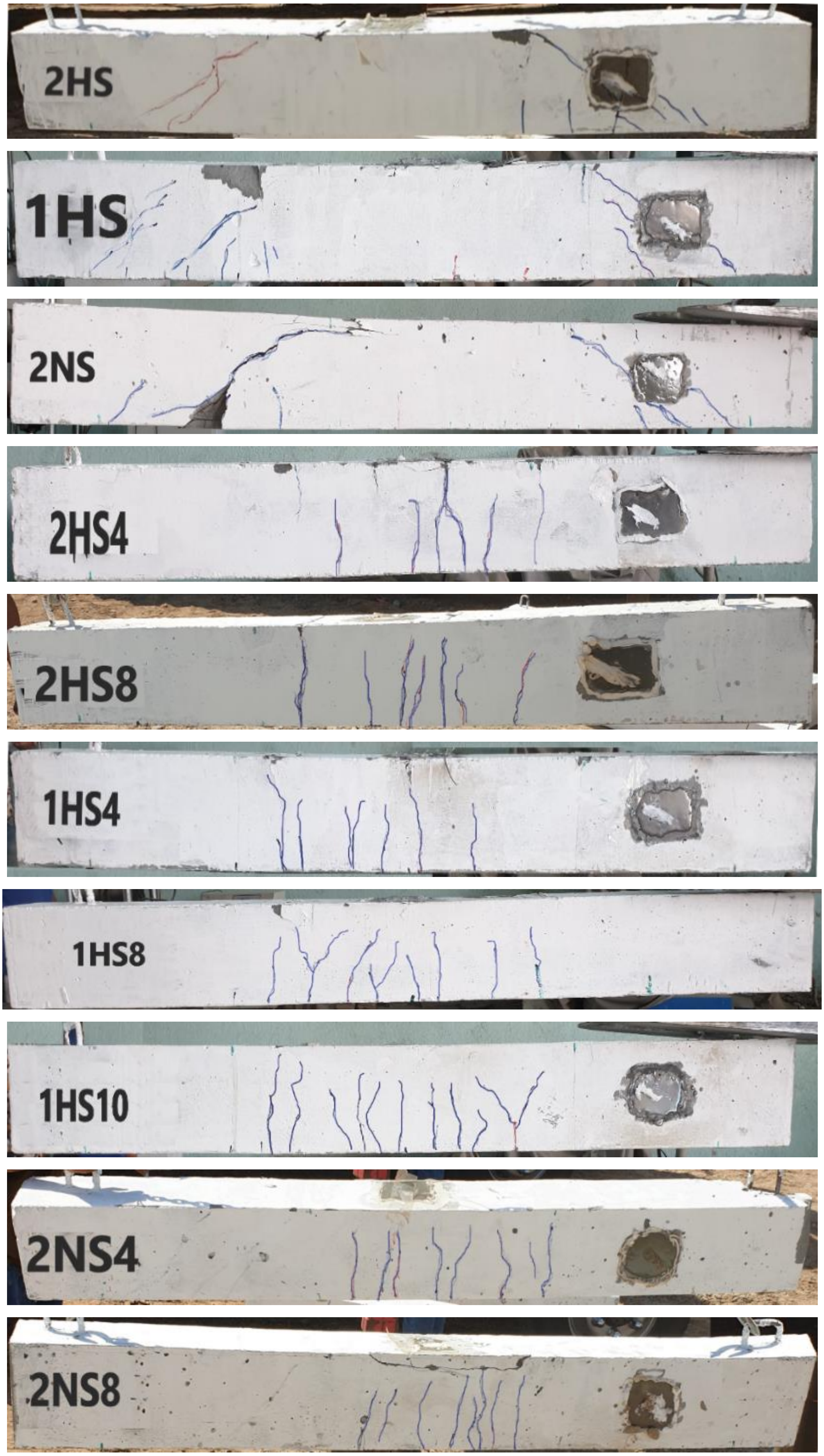


Figure 3. Failure mode and cracks propagation

4.2. Load-Displacement Relationship

The obtained results of the beams are presented in Table 5 which included testing of ten beam specimens strengthened with steel wire mesh under static loads which showed an average ultimate load-carrying capacity of 137 and 181 kN for the normal and high strength reference beams while the parametric beams exposed an ultimate load ranged between 137-299 kN with occurred displacement ranged between 8.2-16.1 mm as demonstrated in Table 5. The ultimate load carrying was affected due to several parameters such as the changes in the steel wire mesh layers, a/d, in addition to the compressive strength. Expressing the obtained results and discussion is in terms of stiffness, energy absorptions, strains (diagonal and compressive strains), and ductility. These calculations provide a full understanding of the behavior of such beams. According to the obtained results and as exposed in Figure 4, it is found that the beams behave linearly until it reaches about the average value 23.5% of their ultimate strength. Table 5 also lists the calculated initial stiffness, ductility, and index energy absorption. It should be noted that the obtained results are compared with the previous study presented by Mansur et al. [15].

Table 5. Test results of punching shear series

Series	ID	Pcr (kN)	P_u (kN)	Deflection (mm)	Ductility index	Initial stiffness (kN/mm)	Energy absorption (Tn) (kN.mm)	Diagonal Strain	Compressive Strain
Group 1	2HS	42	155	13.98	3	32	1703	1.34×10^{-3}	2.24×10^{-3}
	2HS4	46	186	16.09	3.5	35.2	1995.87	1.7×10^{-3}	2.8×10^{-3}
	2HS8	51	248	12.44	2.8	40.4	2380.56	1.2×10^{-3}	2×10^{-3}
Group 2	1HS	53	207	11.98	2.18	39	1849.38	1.01×10^{-3}	1.42×10^{-3}
	1HS4	59	245	14.09	2.5	43.2	2189.58	1.41×10^{-3}	1.8×10^{-3}
	1HS8	65	271	10.64	1.9	46.5	2518.64	8.91×10^{-4}	1.2×10^{-3}
	1HS10	68	299	9.544	1.6	49	2648.74	8.14×10^{-4}	1.08×10^{-3}
Group 3	2NS	31	137	8.7	1.88	23.4	720.84	9.82×10^{-4}	1.04×10^{-3}
	2NS4	36	159	9.87	2.1	25.8	990.6	1.09×10^{-3}	1.38×10^{-3}
	2NS8	41	200	8.2	1.7	31	1022.71	8.7×10^{-4}	9.5×10^{-4}

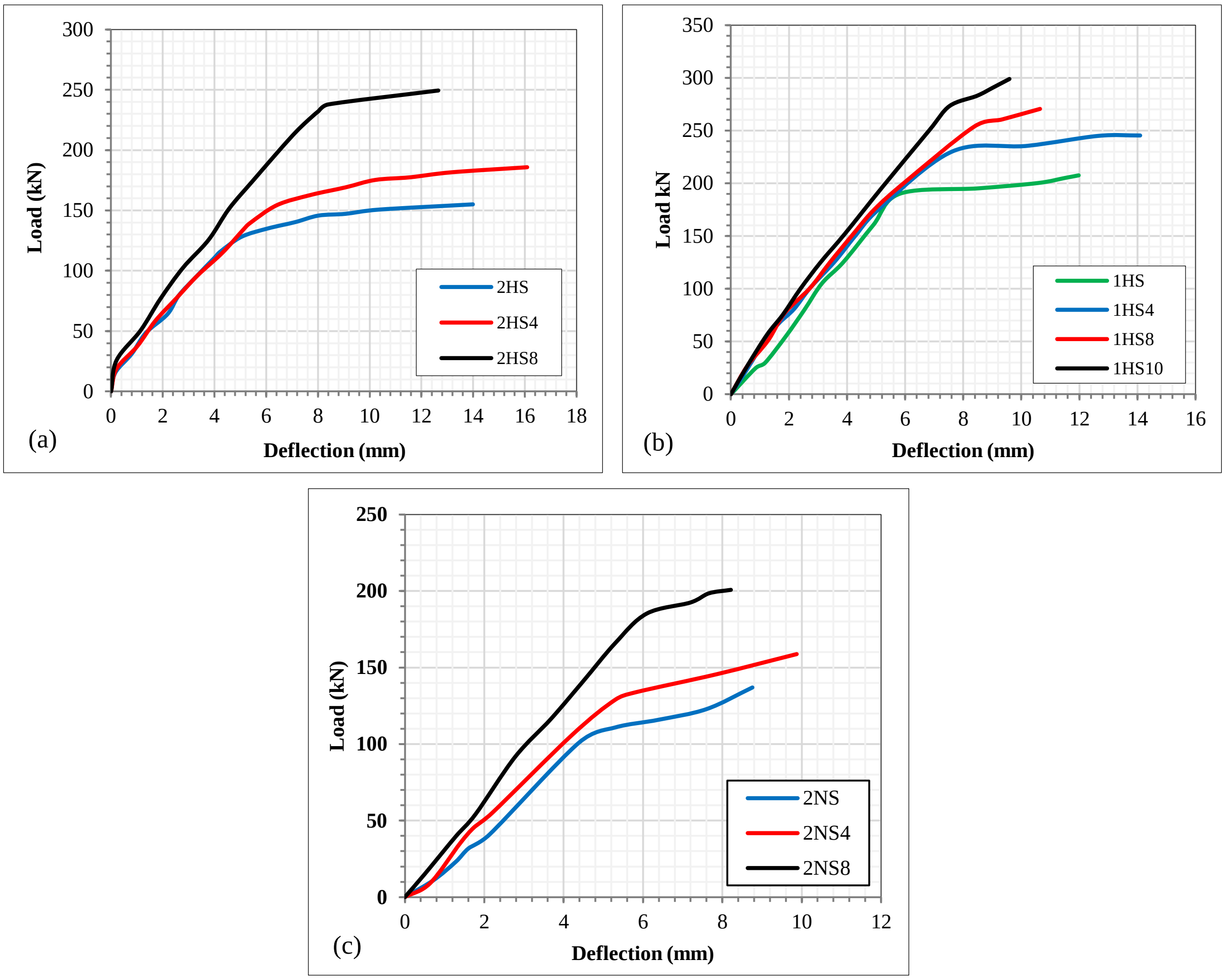


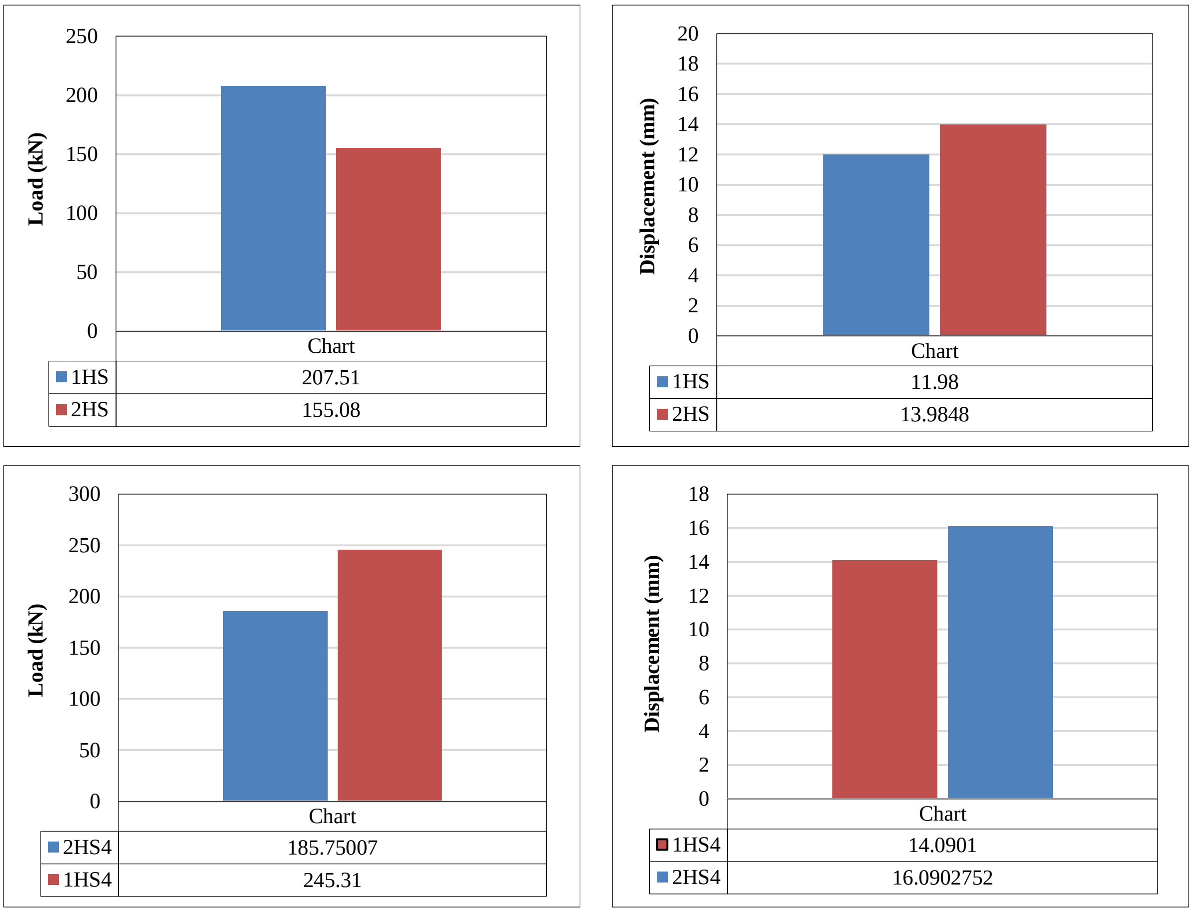
Figure 4. Load displacement relationship of ferrocement beams

4.3. Effect of the Steel Wire Mesh

Regarding the steel wire mesh layers, the effect of the presence of the steel wire mesh was significant on the cracking and ultimate load in addition to the maximum displacement as presented in Figure 4. Concerning the first group, the addition of the steel wire mesh with 4 and 8 layers enhanced the cracking load by 9.5 and 21.5% approximately and respectively. The ultimate load carrying capacity was increased by 20 and 60% when the beam was strengthened by four and eight layers of wire mesh. While the displacement, the enhancement occurred only with the minimum number of layers which increased by 15% and decreased when the layers of the steel wire mesh increased to eight as revealed in Figure 4-a. Concerning the second group, the cracking load was enhanced by 11.3%, 22.6%, and 28.3% when the beams were strengthened by 4, 8, and 10 layers respectively. Regarding the ultimate load, the enhancement was higher than those of cracking values which increased by 18.4%, 31%, and 44.5% when the beams strengthened by 4, 8, and 10 layers respectively. While the displacement, the enhancement occurred only with the minimum number of layers which increased by 17.6% while the strengthened beams with 8 and 10, the displacement decreased by 11.2% and 20.5% respectively as revealed in Figure 4-b. Group three showed a dissimilar behavior in comparison with the first and second groups which more enhancements were obtained due to the less compressive strength of these beams. The cracking and ultimate load of the RC reference beam 2NS was 31 and 137 kN which addition of four and eight steel layers of wire mesh upgraded the cracking load by 16.1% and 32.3% respectively. While the ultimate load-carrying capacity was enhanced by 16.1% and 46% when the beam was strengthened by four and eight layers respectively. The displacement was the most sensitive property by the addition of the steel wire mesh which the strengthening by four layers increased the maximum displacement by 13.5% otherwise the eight layers decreased the displacement by 5.8% approximately as seen in Figure 4-c. Comparing the obtained results with Mansur et al. [15], it found that the increase of steel wire mesh layers enhances the mechanical properties to some extent, and then the increase in wire mesh percentages causes a negative effect

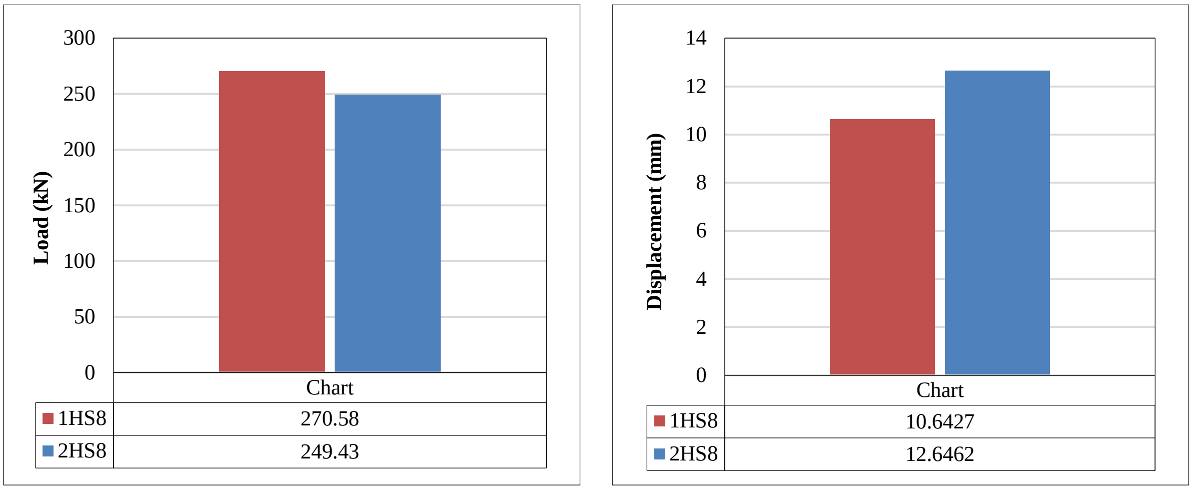
4.4. Effect of the Shear Span to Depth Ratio

The effect of a/d on the behavior of ferrocement strengthened beams was significant and the first and second series showed a variance in the behavior of the control and parametric beam specimens. The change in the a/d ratio from 1.8 to 2.5 in the control beam revealed a decrement in the cracking and ultimate load by 21 and 25% approximately and the displacement increased by 17% as revealed in Figure 5-a. Regarding the strengthened beams, changing of the a/d ratio to 2.5 reduced the ultimate load-carrying capacity 24% and 8.5% when the strengthened beams with 4 & 8 layers as presented in Figures 5-b and 5-c. Comparing the obtained results with Mansur et al. [15], it found that the increase a/d enhance the ultimate strength capacity.



(a)

(b)

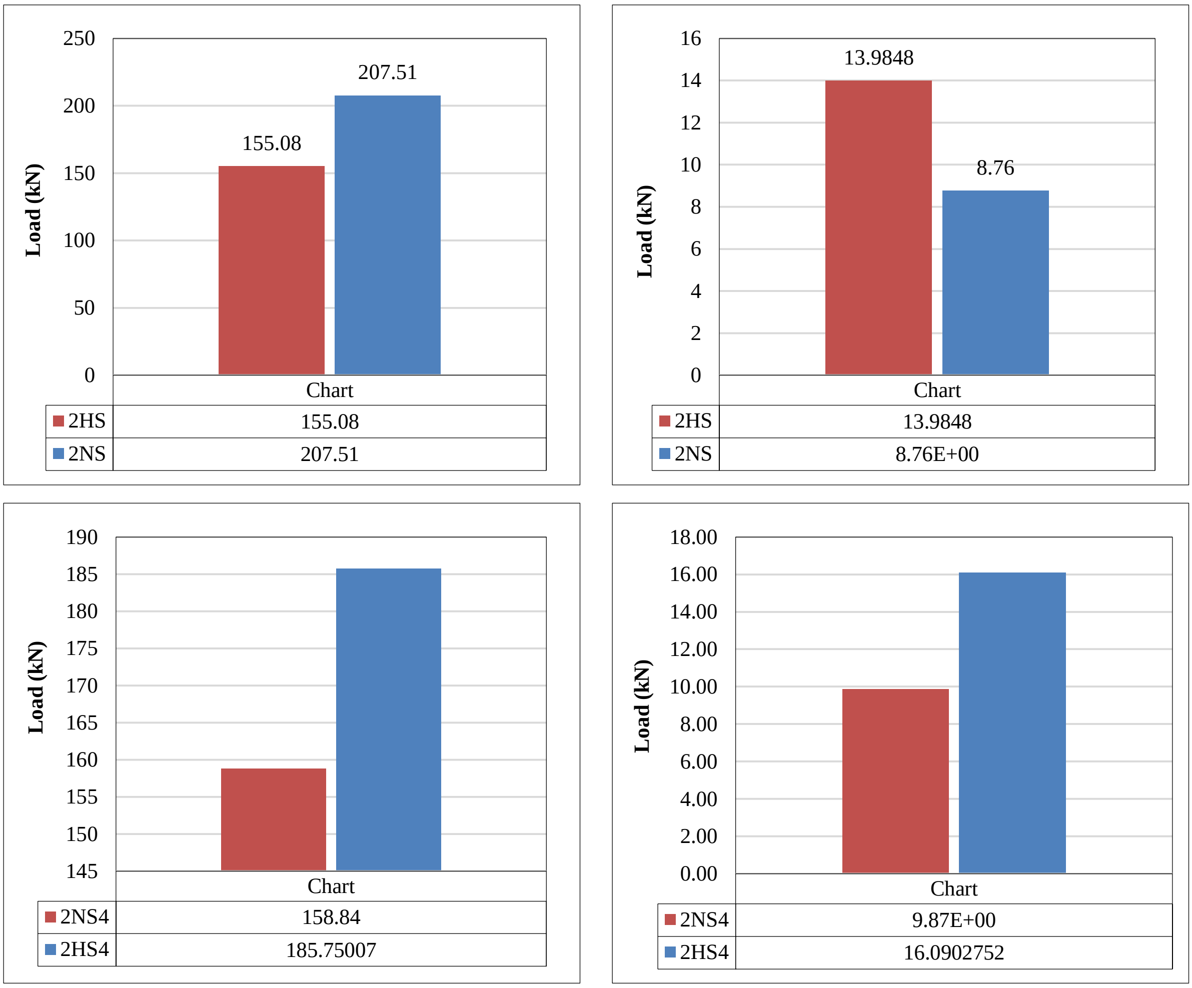


(c)

Figure 5. Effect of (a/d) on the ultimate load and maximum displacement of the tested specimens

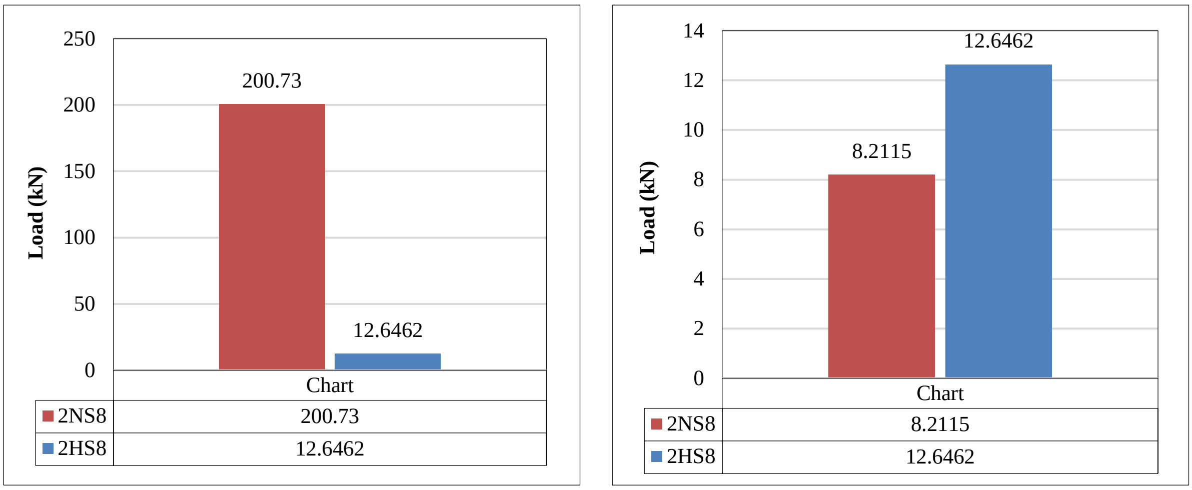
4.5. Effect of the Compressive Strength

The influence of the compressive strength on the cracking and ultimate load beside the displacement was significant in the ferrocement beams with wire mesh which increase the compressive strength of the control beams (2HS and 2NS) from 35 MPa to 65 MPa provided higher cracking load by 35.5% and ultimate load by 13% respectively. While the displacement was higher by 60.7% as presented in Figure 6-a. Regarding the strengthened beams (2HS4 and 2NS4), the compressive strength changing provided a higher cracking load by 27.8% and increment in the ultimate load by 17% otherwise the displacement which the increment ratio was by 63% as seen in Figure 6-b. regarding the strengthened beams with eight layers (2HS8 and 2NS8), the compressive strength changing provided higher cracking load by 27.8% and increment in the ultimate load by 17% and in the displacement was by 63% as seen in Figure 6-c. Comparing the results with Mansur et al [15] showed that the compressive strength increment led to higher strength capacity.



(a)

(b)



(c)

Figure 6. Effect of the compressive strength on the ultimate load and maximum displacement of beams

4.6. Stiffness of the Tested Beams

The term "*Beam Stiffness*" is an index to the ability of the concrete to resist the deformation to the applied loads, i.e., or the rigidity of this member that is used to define the required force to realize a certain deformation, as described by Baumgart [27]. The stiffness can be calculated by obtaining the slope of the load-deflection curve. As shown in Figure 7, Marzouk and Hussein (1991) [28] proved that the load-deflection curves for any members consisted of two straight lines, each one has a slope; the first one refers to the uncracked status of the beam which is considered as an initial stiffness, Ki and the second one refers to the post-cracking stiffness (secant stiffness Ks). Initial stiffness can be calculated as the slope of the load-displacement curve reaching up to the yielding point (first change in the slope), while secant stiffness is defined by the slope of the load-displacement curve extending up to the first yielding of the flexural reinforcement. As a result, determining the yielding displacement is critical in determining both starting stiffnesses [28]. In this paper, initial stiffness was calculated as revealed in Figure 7. The addition of the steel wire mesh to the beams with 65 MPa and a/d equal to 2.5 increased the stiffness by 10% for the four layers of the wire mesh and 26.3% for the eight layers as presented in Figure 8. while the beams with a/d equal to 1.8, the comparison between the stiffness of the beams (1HS4, 1HS8 and 1HS10) explored that the stiffness increased by the addition of steel wire mesh by 10.8% for the four layers only but when the layers of wire mesh increased to eight and ten layers the stiffness upgraded by 19% and 26.6% respectively as revealed in Figure 8 concerning the beams in series three (2NS4 and 2NS8) with compressive strength of 35 MPa, the stiffness increased when four and eight by 10.3% and 32.5% respectively as presented in Figure 8.

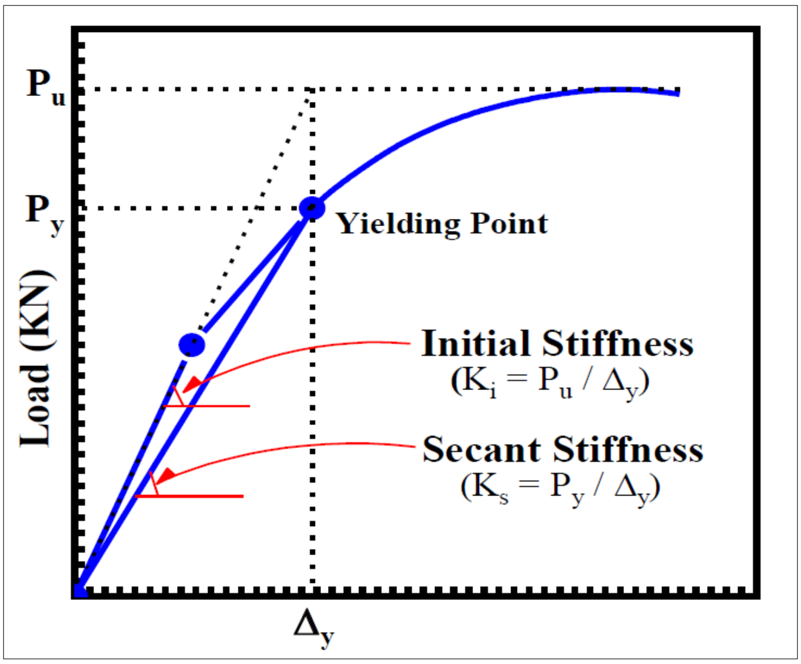


Figure 7. Stiffness Calculation [28]

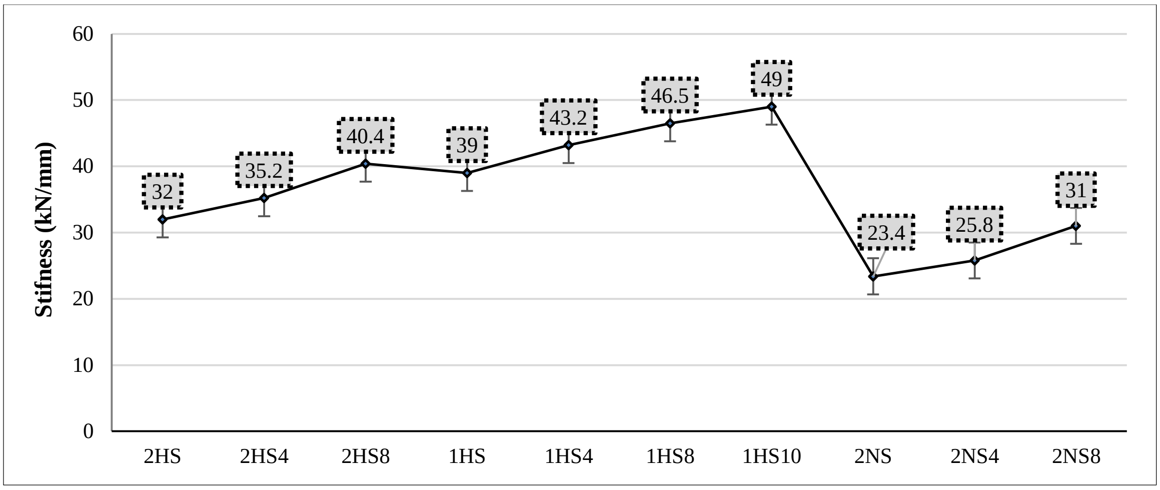


Figure 8. Effect of the variables on the stiffness of beams

4.7. Ductility of the Tested Beams

The word ductility was defined by Marzouk and Hussein [28] and Liberti et al. [29] as the ratio between the displacement associated with the ultimate load (Pu) and the displacement associated with the initial yielding of the flexure reinforcement (Δy). The tested beams' ductility was computed using a method devised by Priestley and Park [30] and approved by Robertson and Durrani (1991) [31]. The addition of the steel wire mesh to the beams with 65 MPa and a/d equal to 2.5 increased the ductility by 16.7% for the four layers of the wire mesh but the addition of eight layers decreased the ductility by 6.7% as presented in Figure 9. while the beams with a/d equal to 1.8, the comparison between the ductility of the beams (1HS4, 1HS8 and 1HS10) explored that the ductility increased by the addition of steel wire mesh by 14.7% for the four layers only but decreased when the layers of wire mesh increased to eight and ten layers by 13% and 26.4% respectively as revealed in Figure 9. concerning the beams in series three (2NS4 and 2NS8) with compressive strength of 35 MPa, the ductility increased when four layers were used and decreased when the layers doubled as presented in Figure 9.

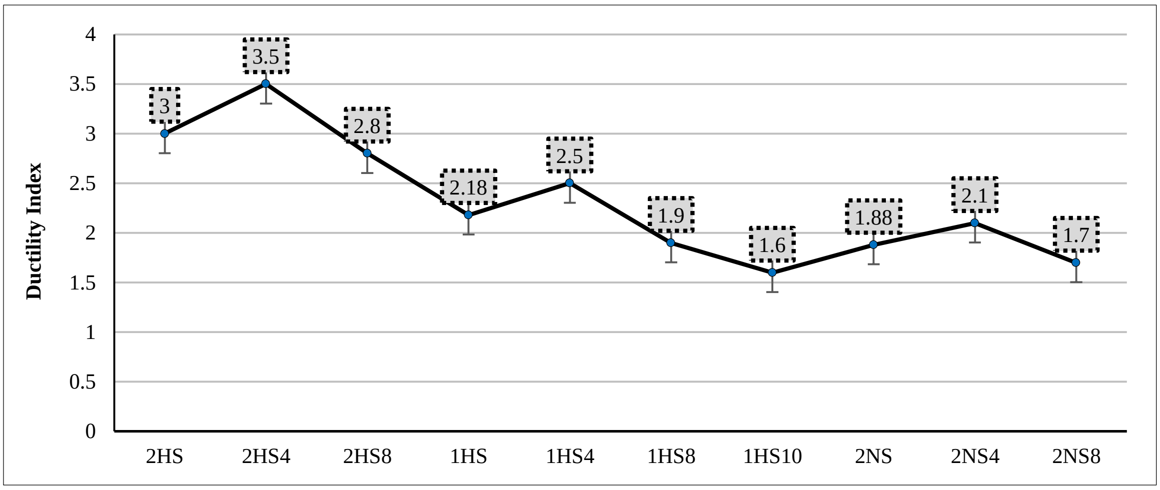


Figure 9. Effect of the variables on the ductility of beams

4.8. Energy Absorption Index

Energy Absorption capacity can be defined as the area under the load-displacement diagram of the tested beams. This region was calculated through a numerical integration up to the ultimate load and corresponding displacement. Ohno and Nishioka (1984) [32] identified the energy absorption capacity of reinforced concrete members as a measure of absorbed energy up to its ultimate state. The authors supposed that the energy absorption capacity up to the final status of the beam is the most appropriate index in the structural response loads. The energy absorption index (Tni) is defined by Marzouk and Hussein [28] as the ratio of the total area under the load-displacement diagram to that under the ascending portion only. The energy absorption addition of steel wire mesh for the with a/d equal to 2.5, the energy absorption enhanced by 17.2% and 39.8% respectively as seen in Figure 10 regarding the same parameter but with less a/d, the enhancement was less than gotten by the four and eight layers for four and eight layers, but higher ratio occurred for the ten layers which were by 43.2% as presented in Figure 10 higher enhancement occurred during these tests for the normal concrete beams.

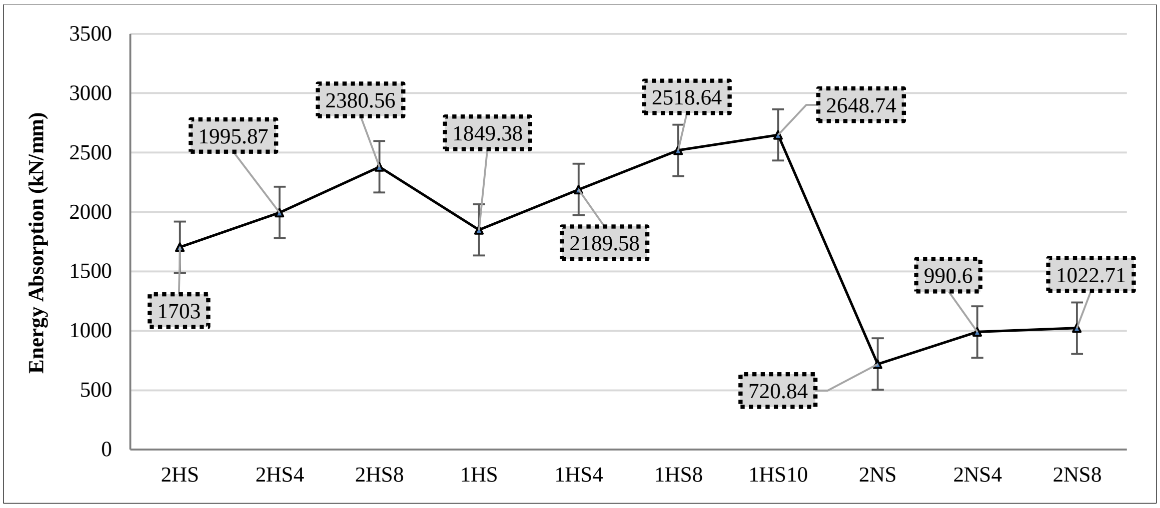


Figure 10. Effect of the variables on the energy absorption of beams

4.9. Strain Results

The diagonal shear strain and compressive strain at failure of each specimen are summarized in Table 5 and Figure 11 and 12.

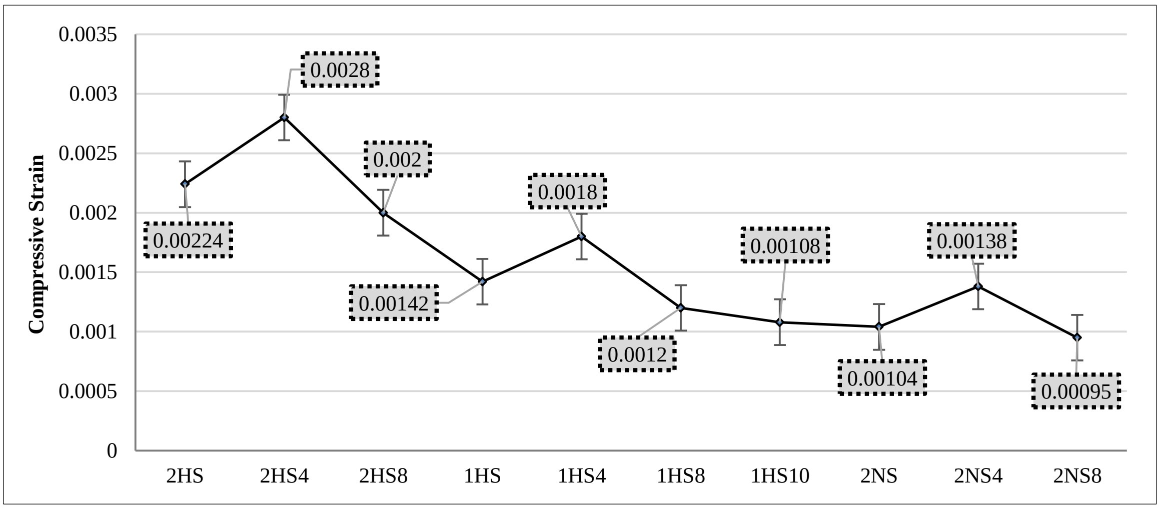


Figure 11. Effect of the variables on the diagonal strain of beams

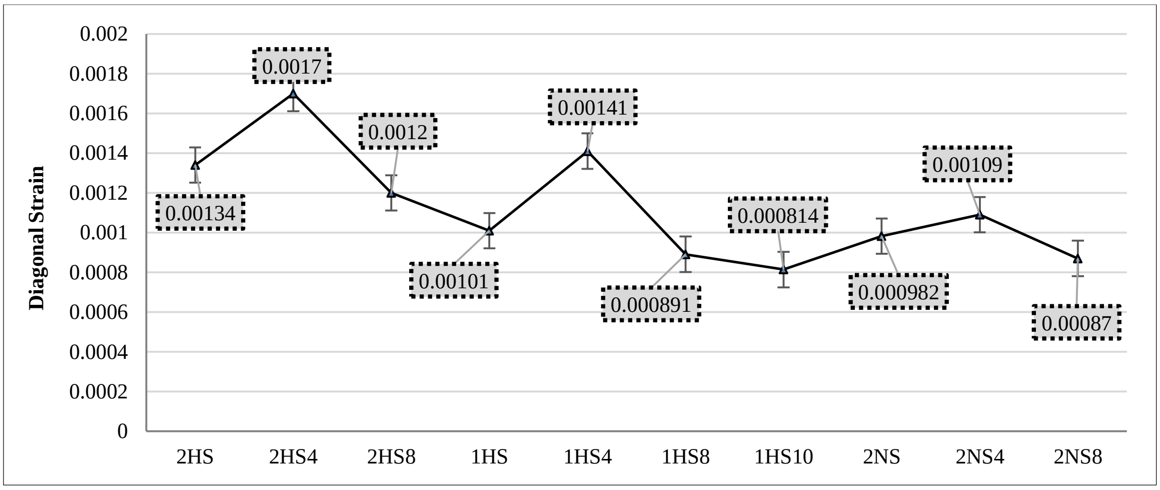


Figure 12. Effect of the variables on the compressive strain of beams

According to the obtained results, a decrement in the diagonal shear and the compressive strain occurred when the number of wire mesh layers was increased. Compared the high-strength concrete beams with four layers of wire mesh with the control beams showed that the strengthening revealed a higher increment ratio in the diagonal and compressive strain, while the strengthening with eight and ten layers exposed a decrement in the strains. An increase of steel wire mesh layers from four to eight and ten layers revealed a decrement in the diagonal and compressive strains by (12% and 21.5%) and (33.4% and 40%) respectively, as revealed in specimens (1HS4, 1HS8, and 1HS10). Regarding the normal strength RC beams, the higher enhancement occurred in the beam with four layers of wire mesh (2NS4), which was by (11%) and (32.7%) in the diagonal and compressive strains in comparison with the control beam (2NS). An increase of more layers in such types of concrete beams caused more decrement, which was by (11.4%) and (8.7%) for the diagonal and compressive strains, respectively, as presented in beam (2NS8). Figures 11 and 12 reveal the diagonal and compressive strains.

5. Conclusions

In this manuscript, the results of 10 RC-strengthened beams were discussed. Based on this experimental study, the following conclusions are drawn:

- The use of steel wire mesh in the form of U-shaped layers in the shear zone was efficient in strengthening the shear zone. In addition, the obtained results were matched when compared with previous studies.
- The addition of steel wire mesh redistributed the internal stresses and enhanced the ultimate strength, load-carrying capacity, stiffness, ductility, and energy absorption of the concrete beam.
- The presence of the steel wire mesh was significant to the cracking and ultimate load in addition to the maximum displacement. While the displacement occurred, the enhancement occurred only with the minimum number of layers and decreased when the layers of the steel wire mesh increased to eight to ten layers.
- An increase in the a/d ratio led to decreases in the cracking and ultimate load-carrying capacities for the control and strengthened beams. In the case of the strengthened beams with steel wire mesh, fewer enhancements were obtained when the a/d ratio was increased. The change in the a/d ratio from 1.8 to 2.5 in the control beam revealed a decrement in the cracking and ultimate load by 21 and 25% approximately, and the displacement increased by 17%. When the ratio was changed to 2.5, the ultimate load-carrying capacity of the strengthened beams with 4 and 8 layers was reduced by 24 and 8.5%, respectively.
- The effect of the compressive strength on the cracking and ultimate load carrying capacity leads to more enhancement in the mechanical properties of the concrete beam when the compressive strength is increased to 65 MPa.
- Stiffness, ductility, energy absorption, and diagonal and compressive strength were enhanced by strengthening the beams by four steel wire mesh, but an increase of more than four steel wire mesh layers led to little enhancement or decrement in the properties of ductility.

6. Declarations

6.1. Author Contributions

The authors discussed the idea of this work and made scientific contributions. S.H.H. and A.A.J. designed the experimental work as well as wrote the paper, A.A.J. reviewed and corrected the paper. The authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available in article.

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6.5. Conflicts of Interest

The authors declare no conflict of interest.

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