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Flexural Behavior of Reinforced Concrete Beams Strengthened with High-Performance Ferrocement

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ABSTRACT

Purpose:
This study investigates the flexural behavior of reinforced concrete beams strengthened with high-performance ferrocement laminates, with emphasis on the effects of modified mortar matrices and the number of wire-mesh layers on structural performance.

Method:
Seven reinforced concrete beams measuring 150 mm x 250 mm x 2100 mm were tested, including one unstrengthened control beam and six beams strengthened with 25 mm ferrocement laminates. Fly ash (10-30%) and silica fume (5-20%) were used as partial cement replacements in the mortar matrix. Material tests and third-point flexural loading were used to evaluate compressive and flexural strength, ferrocement tensile response, first-crack load, ultimate load, deflection, crack development, and failure mode.

Results:
The mortar containing 5% silica fume and the mortar containing 10% fly ash showed the strongest performance among the modified mixes. All strengthened beams exceeded the control beam in first-crack and ultimate load. The SFW4 beam achieved the highest beam first-crack load of 33.5 kN and ultimate load of 145.2 kN, approximately 30.9% and 20.3% above the control values of 25.6 kN and 120.7 kN, respectively. Strengthened beams also developed finer and more closely spaced cracks, and all specimens failed in flexure.

Practical Implications:
High-performance ferrocement laminates provide a practical strengthening option for existing reinforced concrete beams. Increasing the number of wire-mesh layers and using an optimized supplementary-cementitious mortar can improve load capacity and crack control without increasing beam width.

Originality/Novelty:
The study evaluates the combined influence of supplementary cementitious materials and wire-mesh layering in externally applied ferrocement laminates, linking mortar-level performance with the flexural response of strengthened reinforced concrete beams.

Keywords: Ferrocement; reinforced concrete beams; high-performance mortar; silica fume; fly ash; flexural strengthening; wire mesh

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1. Introduction

Many civil engineering structures worldwide are now considered unsafe or structurally deficient due to poor construction practices, design errors, excessive loading, aging, or their combined effects. To ensure continued serviceability and safety, existing structures often require repair, rehabilitation, or strengthening so that their performance can satisfy present and future structural requirements.

From both environmental and economic perspectives, strengthening or repairing an existing structure is generally more desirable than complete replacement, especially when the strengthening technique is rapid, practical, cost-effective, and easy to apply. Several cement-based repair materials are currently available for structural rehabilitation. Among these materials, ferrocement has gained attention because of its high tensile strength-to-weight ratio, improved toughness, ductility, durability, and crack-resistance capacity compared with many conventional cementitious materials. These properties make ferrocement a suitable alternative for strengthening and rehabilitating reinforced concrete structures.

According to the American Concrete Institute Committee 549, ferrocement is a thin reinforced concrete system made with hydraulic cement mortar and reinforced with closely spaced layers of continuous wire mesh having relatively small wire diameters [1]. Previous studies have shown that ferrocement has considerable potential as a repair and strengthening material. The use of ferrocement for repair applications was first introduced by Romualdi and Iorns [2] in the early 1980s, mainly for relining and repairing liquid-retaining structures such as pools, sewer lines, tunnels, and similar facilities.

The early use of ferrocement as a strengthening material for reinforced concrete beams was investigated by Andrews and Sharma [3]. Their results showed that beams strengthened with ferrocement performed better and more consistently than beams repaired using conventional concrete. The first-crack load increased by approximately 24%, while the mid-span deflection under service load decreased by about 10% compared with beams repaired using ordinary concrete. In addition, the flexural strength of ferrocement-strengthened beams exceeded that of the original beams, with an increase of approximately 28%.

Ong, Paramasivam, and Lim [4] also studied the strengthening of simply supported reinforced concrete beams using thin ferrocement laminates attached to the tension face of the beams. Their experimental results, based on eight beams, indicated that all strengthened beams achieved higher ultimate flexural capacity and improved stiffness. The flexural strength increased by about 15–25%, while the first-crack load increased by nearly 67% compared with the unstrengthened control beams. Furthermore, crack spacing and crack width were reduced by approximately 50% and 25%, respectively, showing that ferrocement laminates can effectively improve both strength and cracking behavior.

Although several researchers have investigated ferrocement as a repair and strengthening material for reinforced concrete beams, the efficiency of this strengthening system depends on several factors, including the type of strengthening material, the number of wire mesh layers, the mortar matrix composition, and the method of application. A major objective in strengthening reinforced concrete beams is to enhance their structural performance compared with conventional or unstrengthened beams.

The mortar matrix plays a dominant role in the behavior of ferrocement, since the final mechanical performance of the system strongly depends on the mortar composition. Supplementary cementitious materials such as silica fume and fly ash are known to improve mortar strength through pozzolanic reactions. When these materials partially replace cement in mortar, they can enhance the strength and durability of the mortar matrix, which may subsequently improve the load-carrying capacity of ferrocement-strengthened beams.

Silica fume and fly ash are pozzolanic by-products that may otherwise contribute to environmental pollution if not properly utilized. The first studies on the use of silica fume, an industrial by-product generated during the production of silicon metal and ferrosilicon alloys, began in Norway in the 1950s as part of environmental protection efforts [5]. Today, silica fume is commonly used as a cementitious additive in concrete and mortar, either as a partial replacement for Portland cement or as an admixture blended with cement during production.

Lee et al. [6] reported that incorporating silica fume within the range of 5–10% can have a beneficial effect on the strength performance of Portland cement mortar. Similarly, Nedwell and Nakassa [7] compared the flexural strength of ferrocement made with ordinary Portland cement mortar and mortar containing 10% silica fume. Their results showed that the addition of silica fume increased the first-crack flexural strength of ferrocement.

Fly ash has also been widely studied as a partial cement replacement material. Several investigations have shown that replacing a portion of cement with fly ash can improve the properties of cementitious composites. Mehdi and Ahmed [8] examined the tensile and flexural behavior of ferrocement exposed to seawater. Their findings indicated that Karachi seawater reduced tensile strength by 13% and flexural strength by 11%. Fraay and Bijen [9] studied the strength development of fly ash concrete compared with ordinary Portland cement concrete and observed that strength after 28 days continued to increase significantly. They also noted that the optimum fly ash replacement ratio depends on the chemical composition of both fly ash and ordinary Portland cement. In current practice, many specifications permit cement replacement with fly ash in the range of 15–25% [10]. Vimal Kumar and Chandi Nath Jha [11] also investigated the production of lightweight aerated concrete using fly ash, quicklime, or gypsum mixed at high speed to form a thin slurry.

In ferrocement, the mortar matrix has a highly significant influence on the final behavior of the composite, and its performance is largely governed by the mortar mix composition. Although many studies have examined the strengthening of reinforced concrete members using ferrocement, most of them have used ordinary mortar. In contrast, the present study uses high-performance mortar incorporating silica fume and fly ash as supplementary cementitious materials to improve the mechanical performance of ferrocement laminates and increase the strengthening capacity of reinforced concrete beams.

Therefore, this study investigates the strengthening of simply supported reinforced concrete beams using high-performance ferrocement laminates attached to the soffit, or tension face, of the beams without increasing the beam width. The main objectives of the study are:

1. To evaluate the influence of different modified cementitious mortars on the behavior of strengthened beams.
2. To examine the effect of the number of wire mesh layers on the structural performance of strengthened beams.
3. To observe and identify the failure modes of reinforced concrete beams strengthened with high-performance ferrocement laminates.

2. Experimental Program

2.1 Specimens

A total of seven rectangular reinforced concrete beams were prepared and tested in this experimental program. Each beam had dimensions of 150 mm × 250 mm × 2100 mm. All beams were reinforced using the same steel arrangement, consisting of two 16 mm diameter deformed bars at the top and two 16 mm diameter deformed bars at the bottom. Shear reinforcement was provided using 9 mm diameter bars spaced at 125 mm center-to-center.

For the ferrocement strengthening system, galvanized hexagonal wire mesh with a wire diameter of 0.9 mm and an opening size of 19 mm was used. The ferrocement laminate thickness was kept constant at 25 mm. In addition, 6 mm diameter mild steel bars were used as skeletal reinforcement in all ferrocement laminate configurations bonded to the beams. Among the seven beams, one beam was kept unstrengthen as the control specimen, while the remaining six beams were strengthened using ferrocement laminates, as summarized in Table 1.

2.2 Material Properties

Ordinary Portland cement Type I was used in the concrete mix. Natural sand passing sieve No. 8 and crushed limestone aggregate with a maximum size of 20 mm were used as fine and coarse aggregates, respectively. The concrete mix proportion was 1.0:2.0:2.83 by weight, with a water-to-cement ratio of 0.55.

The longitudinal reinforcement consisted of 16 mm diameter steel bars with a characteristic strength of 460 N/mm². Plain mild steel bars with a diameter of 9 mm and a yield strength of 280 N/mm² were used as shear reinforcement. The ferrocement laminates were reinforced with galvanized hexagonal wire mesh having a diameter of 0.9 mm, an opening size of 19 mm, and a tensile strength of 432 N/mm².

For the strengthening mortar, cement and natural sand were mixed in a ratio of 1.0:2.0 by weight, with a water-to-cement ratio of 0.40. Densified silica fume in powder form, supplied by Sika Limited, was used as one of the supplementary cementitious materials. Fly ash obtained from the Mae Moh lignite power plant was also used as a cement replacement material in selected mortar mixes.

Table 1. Details of Mortar Matrix Proportions

Type of Mortar Mix	Cement	Sand	W/C ratio	Supplementary Cementitious Matrix %	
				Fly ash	Silica fume
Control	1	2	0.44		
Modified 1	1	2	0.44	10%	
Modified 1	1	2	0.44	20%	
Modified 1	1	2	0.44	30%	
Modified 2	1	2	0.44		5%
Modified 2	1	2	0.44		10%
Modified 2	1	2	0.44		20%

2.3 Fabrication of Specimens

The reinforced concrete beams were cast in molds made from plywood bases and steel side plates. Concrete compaction was carried out using a poker vibrator to ensure proper consolidation and minimize voids. Along with each beam, three concrete cubes of 100 mm size were cast to determine the compressive strength of the concrete.

For the high-performance ferrocement mortar incorporating supplementary cementitious materials such as silica fume and fly ash, cube specimens were also prepared. A total of twenty-four 50 mm mortar cubes were cast for each beam group to evaluate the compressive strength of the ferrocement mortar, as indicated in Table 2.

After casting, the beams and their companion cube specimens were covered and cured with wet Hessian burlap for three days before demolding. After demolding, the specimens were kept under wet Hessian for an additional 8 to 10 days before the ferrocement strengthening process was applied.

2.4 Strengthening with Ferrocement Laminate

The ferrocement laminates were applied to the soffit, or tension face, of the reinforced concrete beams. Plywood boards were clamped to the sides of the beams to serve as temporary formwork during casting of the ferrocement layer.

For specimens strengthened with U-shaped anchors, holes were drilled into the beams at the required spacing and depth before applying the ferrocement laminate. The ferrocement reinforcement was then positioned on the soffit of the beam. The U-shaped connectors were passed through the wire mesh and inserted into the predrilled holes. These connectors were fixed using a high-viscosity, fast-setting epoxy resin adhesive. After installation, the connectors were bent and tied securely to the wire mesh, as illustrated in Figure 3.

2.5 Testing Program

2.5.1 Preliminary Material Testing

Preliminary tests were conducted to determine the mechanical properties of the concrete, mortar, and wire mesh used in the experimental program. These tests included compressive strength, flexural strength, and tensile testing of the ferrocement laminate.

2.5.2 Compressive Strength Test

Concrete cylinders with dimensions of 150 mm × 300 mm were used to determine the compressive strength of the concrete used in the beams. These cylindrical specimens were cast and cured under the same conditions as the beam specimens.

For the mortar matrix, 50 mm × 50 mm × 50 mm cube specimens were prepared to evaluate compressive strength. The mortar cubes were also cast and cured under the same conditions as the strengthened beam specimens to ensure consistent comparison.

2.5.3 Flexural Strength Test

Prismatic concrete specimens with dimensions of 100 mm × 100 mm × 500 mm were prepared to determine the flexural strength of the concrete. These prisms were cast and cured under the same conditions as the reinforced concrete beams.

For the ferrocement mortar matrix, prism specimens measuring 40 mm × 40 mm × 160 mm were used. The flexural strength of these mortar specimens was evaluated at 3, 7, and 28 days to study strength development with curing age.

2.5.4 Direct Tensile Test of Ferrocement

Direct tensile tests were carried out to evaluate the tensile behavior of the high-performance ferrocement laminate used for strengthening the beams. The main purpose of this test was to determine the tensile capacity, first cracking load, ultimate load, and load–deformation response of the ferrocement specimens. Deformations were measured on both faces of each specimen using displacement transducers.

The main test variables were the number of wire mesh layers and the type of mortar matrix. The mortar mixes included supplementary cementitious materials such as fly ash and silica fume as partial cement replacement materials.

The effective tensile testing region of each specimen was 250 mm long and 75 mm wide, while the overall thickness was maintained at 25 mm as shown in Figure 1. Curved end portions with a radius of 20 mm were provided at both ends to allow proper transfer of tensile force during testing. A 6 mm diameter skeletal reinforcement was placed while maintaining a 10 mm cover. The wire mesh was cut with a 10 mm offset from the specimen edges and placed on both sides of the skeletal reinforcement.

Two ferrocement configurations were prepared, consisting of either two or four layers of wire mesh. The specimens were tested using a Universal Testing Machine. During testing, the applied load and corresponding displacement were recorded using a load cell, displacement transducers, and a data logger. Special attention was given to the first visible cracking load and the ultimate load to evaluate the effect of mesh layers and mortar composition on the tensile behavior of the ferrocement laminate.

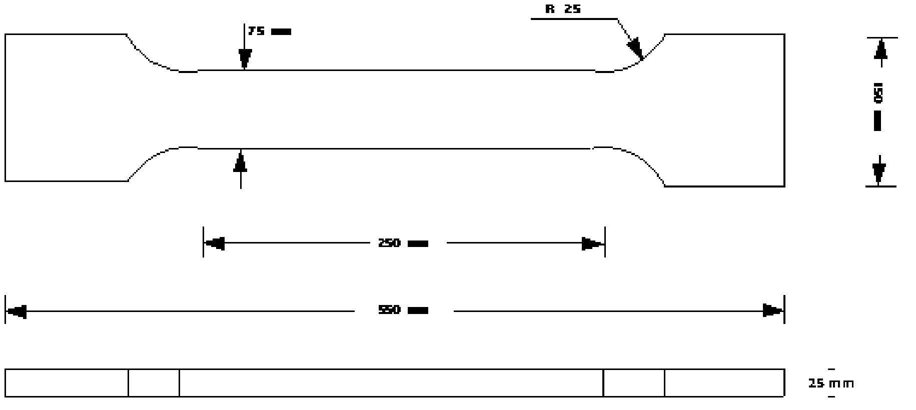

Figure 1. Tension rig specimen with dimensions

2.6 Testing of Reinforced Concrete Beams

All beam specimens, as shown in Figures 2 to 5, were tested as simply supported beams over a span of 2100 mm using a third-point loading arrangement. The load was applied through a 50-ton hydraulic jack. Mid-span deflection was measured using a linear displacement transducer with a 50 mm travel capacity. The deflection readings were recorded automatically using a portable data logger. Before testing, the displacement transducer was carefully positioned to ensure proper contact with the soffit of the beam.

Strains in the test beams were measured using 20 mm long electrical strain gauges. These strain gauges were attached to the flexural reinforcement before casting to monitor reinforcement strain during loading.

During testing, crack development was carefully observed along the soffit level of the beams. Crack widths and crack spacing were marked along the full length of the beam using a magnifying glass, and the corresponding load levels were recorded. To improve crack visibility, the surfaces of the beams were painted before testing.

The ultimate load, failure mode, load–deflection response, strain behavior, crack width, and crack spacing were recorded for each specimen.

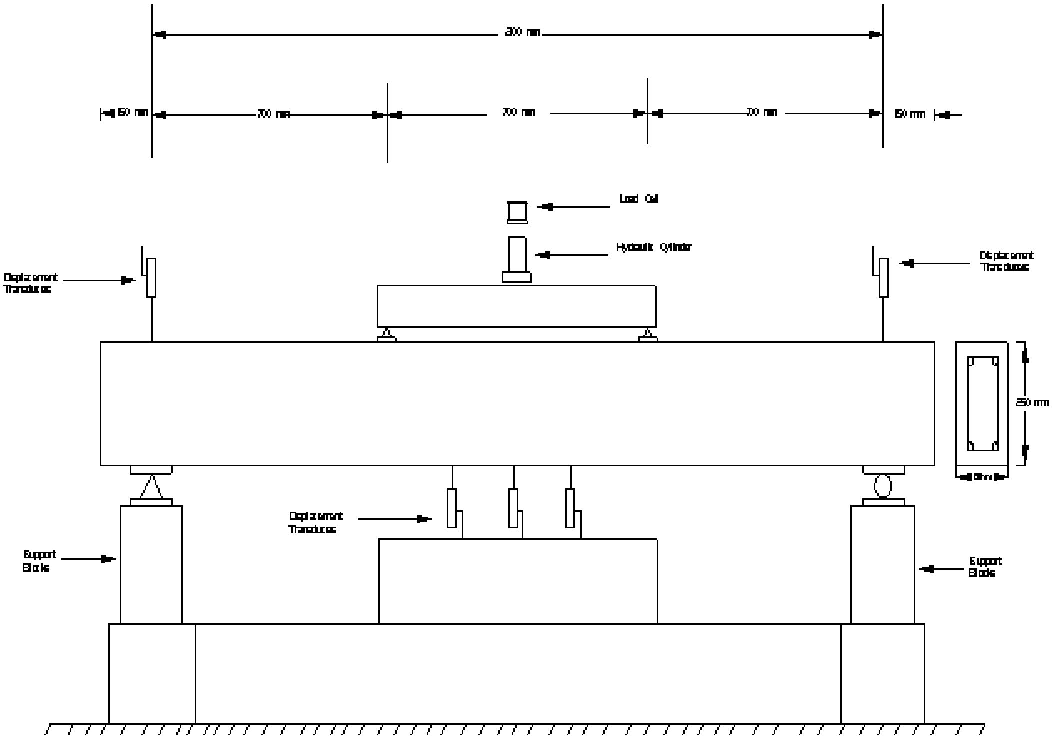

Figure 2. Beam testing setup

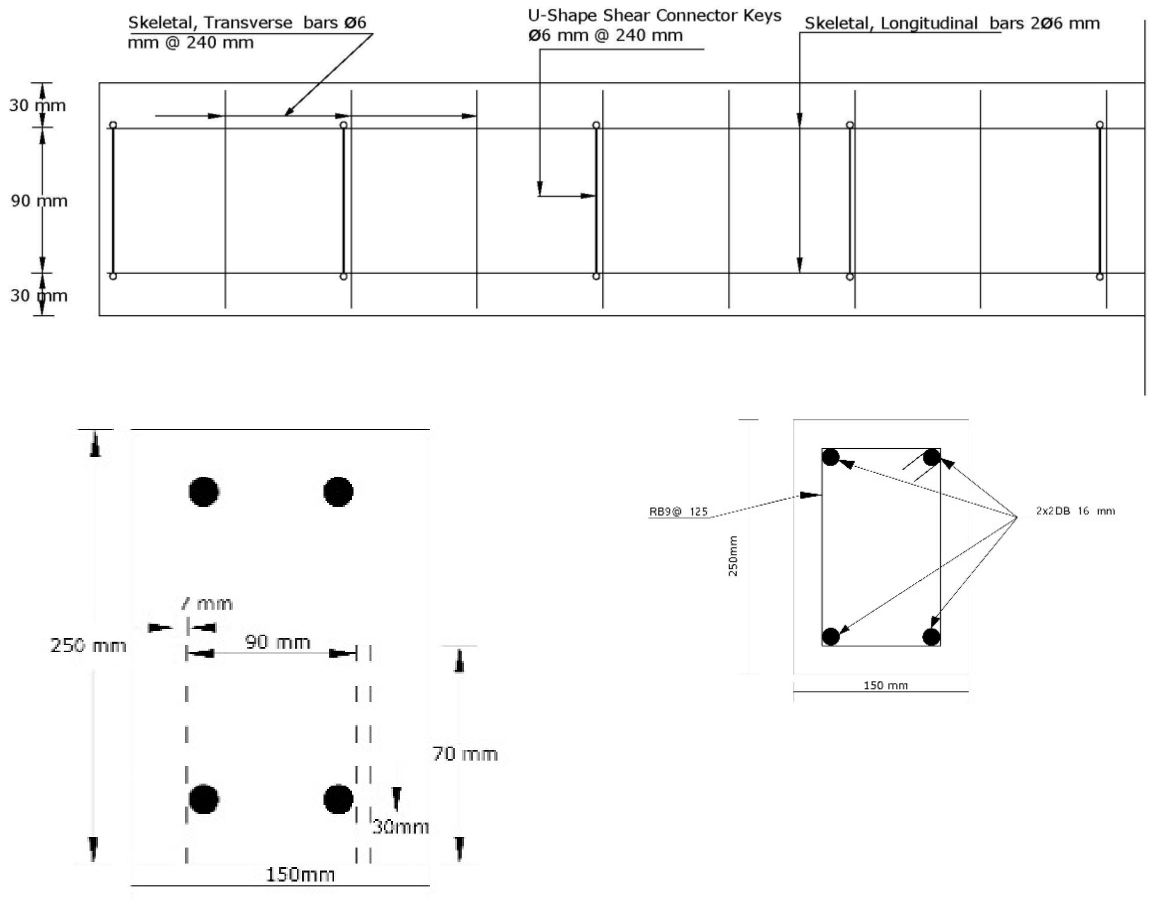

Figure 3. Detail of top view of beam

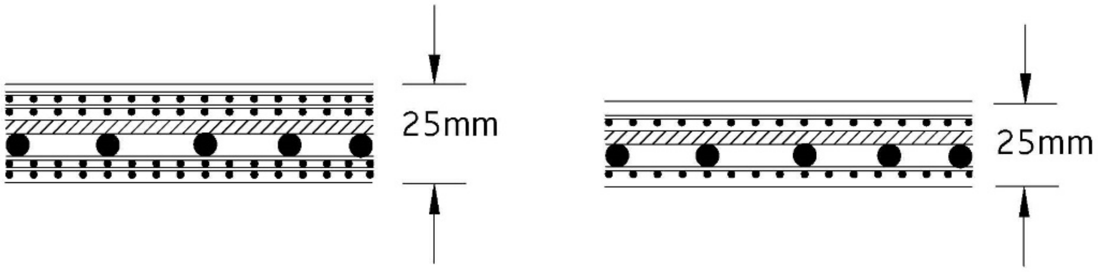

Figure 4. Details of cross-section

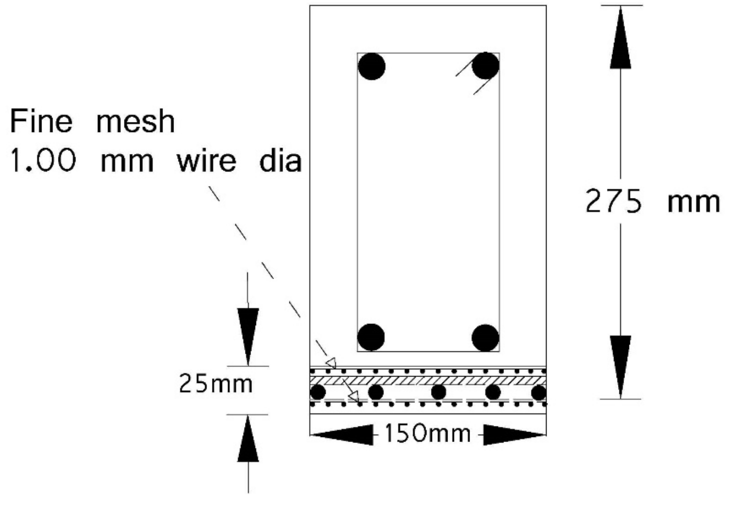

Figure 5. Typical section of strengthened beam for two and four layers of wire mesh

3. Results and Discussion

The details of this experiment include the optimization of material strength (compressive & flexural strength of mortar matrices), direct tensile strength of ferrocement laminate, and the behavior of strengthened beams, including the first crack loads, ultimate loads, deflection characteristics, and failure pattern.

3.1 Compressive Strength of Mortar

The study evaluated the influence of fly ash and silica fume as supplementary cementitious materials on the compressive strength of mortar. Fly ash was used as a partial cement replacement at 10–30%, while silica fume was incorporated at 5–20%.

For each mix, three 50 mm × 50 mm × 50 mm cube specimens were prepared and tested at 3, 7, and 28 days. The results indicated that the inclusion of fly ash and silica fume noticeably affected the strength development of the mortar over time. The compressive strength values were reported in Table 2.

Table 2. Compressive Strength of Mortar Matrix at the Ages of 3, 7, and 28 Days.

Mortar Mix	Average Compressive Strength at the Age of Psi (MPa)		
	3-day	**7-day**	**28-day**
NM00	4713 (32.50)	5095 (35.14)	5484 (37.82)
FA10	4658 (32.12)	5280 (36.41)	5989 (41.30)
FA20	4626 (31.90)	4756 (32.80)	5568 (38.40)
FA30	4510 (31.10)	4669 (32.20)	5162 (35.60)
SF05	4742 (32.70)	5410 (37.31)	6351 (43.80)
SF10	4584 (31.61)	5236 (36.11)	5684 (39.20)
SF20	4656 (32.10)	4858 (33.50)	5467 (37.70)

Identification Code Specimens as follows:

NM00= Normal mortar (no replacement of supplementary cementitious materials)

FA10= Modified mortar replaced the ordinary Portland cement with 10% fly ash

FA20= Modified mortar replaced the ordinary Portland cement with 20% fly ash

FA30= Modified mortar replaced the ordinary Portland cement with 30% fly ash

SF05= Modified mortar replaced the ordinary Portland cement with 5% silica fume

SF10= Modified mortar replaced the ordinary Portland cement with 10% silica fume

From the test results, the effect of fly ash and silica fume on compressive strength development is investigated. Increasing the percentage of fly ash and silica fume (as replacements for ordinary Portland cement) did not contribute significantly to the strength development of mortar. The modified mortar, with 5% silica fume and 10% fly ash, showed potential to enhance compressive strength compared to other mortars.

3.2 Flexural Strength of Mortar

Three mortar prism specimens measuring 40 mm × 40 mm × 160 mm were prepared for each mix and tested for flexural strength at 3, 7, and 28 days. The results, presented in Table 3, were used to evaluate the influence of fly ash and silica fume on the flexural strength development of different mortar mixes. The flexural performance was discussed separately at each curing age for clearer comparison.

Table 3. Flexural Strength of Mortar Matrix at the Ages of 3, 7, and 28 Days

Mortar Mix	Average Flexural Strength at the Age of Psi (MPa)		
	3-day	**7-day**	**28-day**
NM00	103 (0.712)	123 (0.850)	160 (1.100)
FA10	105 (0.725)	148 (1.020)	180 (1.240)
FA20	98 (0.674)	123 (0.850)	162 (1.120)
FA30	71 (0.492)	90 (0.621)	128 (0.882)
SF05	111 (0.765)	152 (1.050)	181 (1.250)
SF10	94 (0.645)	128 (0.880)	162 (1.120)
SF20	79 (0.542)	101 (0.698)	115 (0.790)

The mortar containing 10% replacement of fly ash and 5% replacement of silica fume gained higher flexural strength compared to other types of mortars. In addition, the flexural strength of the mortar matrix decreased when the replacement of silica fume and fly ash is more than 5% and 10%. The FA10 and SF5 modified mortar matrices are selected for the strengthening of RC beams.

3.3 Tensile Strength and Load Capacity of Ferrocement Rig Specimen

The ferrocement rig specimens are tested at the ages of 3 and 10 days using a UTM. From the test results, the load-displacement variations are measured for a particular number of wire mesh layers and modified mortar matrices. Based on the measurements, the first crack load and ultimate load capacities are analyzed. At the moment of cracking, the load is suddenly transferred to the reinforcement. As the load is already large, an immediate visible crack was ensured. The strains on both sides of the specimens were measured using a displacement transducer at every loading stage. When the cracking load was attained, the elongation of the specimens increased at a higher rate. One or several transverse cracks appeared in the crack range with increasing load. It was observed that the specimens with more mesh layers had higher stresses at the first crack and developed a higher ultimate load. The influencing factors on the first crack loading are the number of layers of wire mesh and the effect of modified mortar matrices. Comparison among all specimens, including the controlled ferrocement specimen, the specimen with 4 layers of wire mesh and having modified mortar replaced with silica fume, showed the highest capacity at the first crack and ultimate stage, both at 3- and 10-day age, as shown in Table 4. Furthermore, in specimens using 4-layers of wire mesh and replacement of 10% fly ash in the mortar matrix, a relatively high value was shown both in the first crack and ultimate stages. It can be explained by the fact that the higher mechanical properties of wire meshes and modified mortar enhanced the tensile properties of the ferrocement specimen.

Table 4. Tensile Strength of Ferrocement Rig Specimens at the Age of 3 and 10 Days

Age	Specimen	First crack load Kips (kN)	Ultimate Load Kips (kN)
3-day	NMW2	0.36 (1.60)	0.96 (4.31)
3-day	FAW2	0.32 (1.42)	1.07 (4.80)

3-day	SFW2	0.47 (2.10)	1.19 (5.34)
3-day	NMW4	0.48 (2.15)	1.50 (6.66)
3-day	FAW4	0.61 (2.75)	1.82 (8.16)
3-day	SFW4	0.57 (2.55)	1.75 (7.82)
10-day	NMW2	0.88 (3.93)	2.28 (10.20)
10-day	FAW2	1.1 (4.93)	2.48 (11.10)
10-day	SFW2	1.19 (5.31)	2.41 (10.78)
10-day	NMW4	1.41 (6.30)	2.60 (11.60)
10-day	FAW4	1.81 (8.10)	2.71 (12.10)
10-day	SFW4	2.07 (9.24)	2.90 (12.94)

Identification Code Specimens as follows:

NMW2= Strengthened specimen having normal mortar with two layers of wire mesh

NMW4= Strengthened specimen having normal mortar with four layers of wire mesh

FAW2= Strengthened specimen having modified mortar (fly ash) with two layers of wire mesh

FAW4= Strengthened specimen having modified mortar (fly ash) with four layers of wire mesh

SFW2= Strengthened specimen having modified mortar (silica fume) with two layers of wire mesh

SFW4= Strengthened specimen having modified mortar (silica fume) with four layers of wire mesh

3.4 Cracking Behavior of Beams

From the test results shown in Figures 6 and 7, it is seen that the strengthened beams by all patterns have shown an increase in the first crack and ultimate loads with respect to the beam without a ferrocement laminate (control beam). The largest increase in the load-carrying capacity of the beam is in BSFW4 (replaced with 5% of silica fume and having four-layer wire mesh). It indicates that the influence of increasing the number of layers of wire mesh has a beneficial effect on both the first crack load and the ultimate load. Besides this, the use of high-performance mortar has also affected the load-carrying capacity.

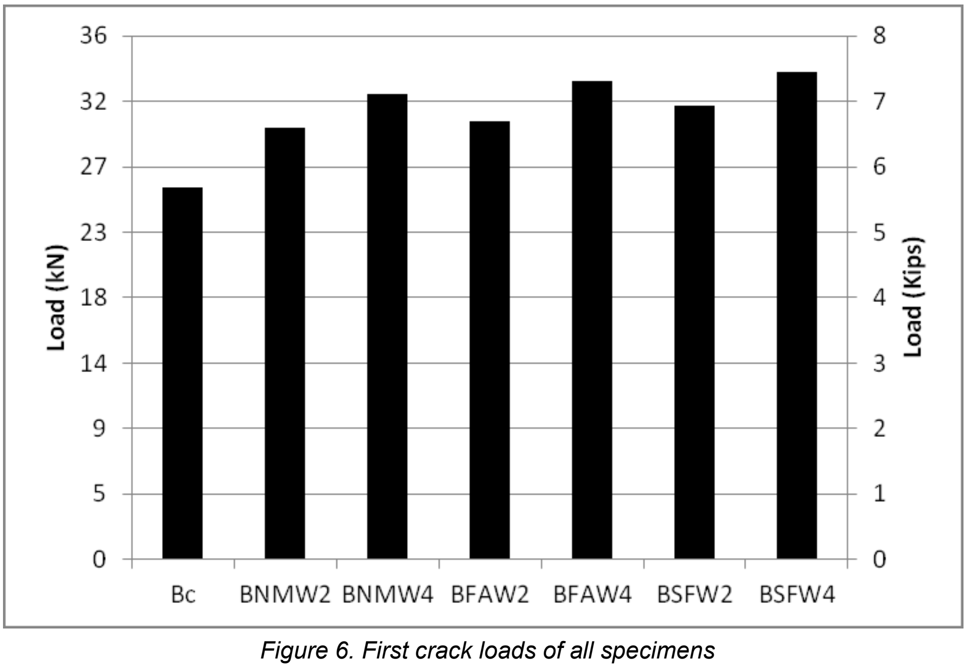

Figure 6. First crack loads of all specimens

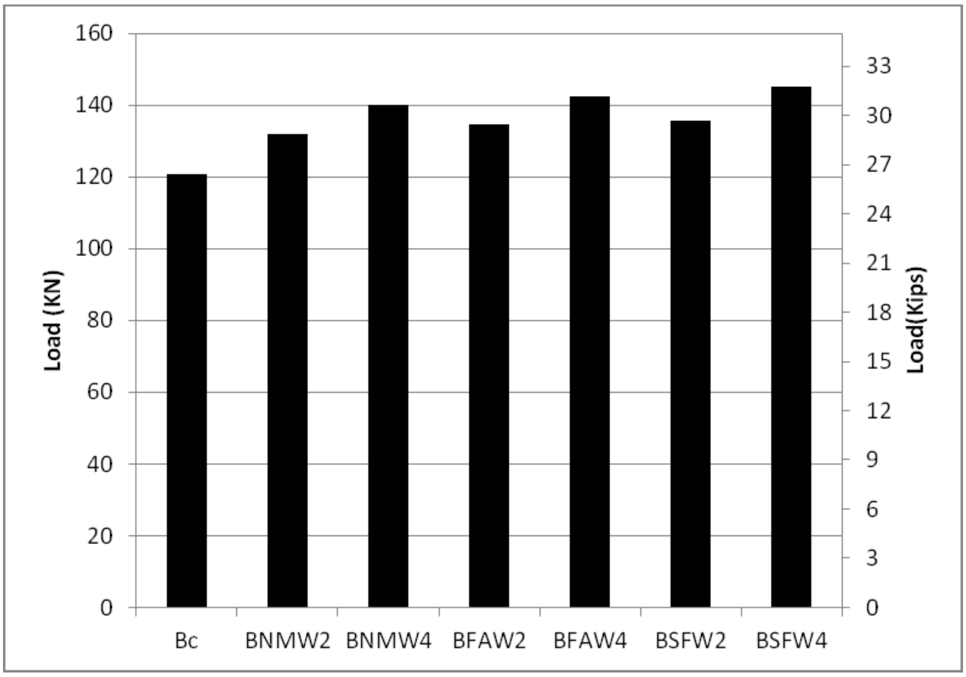

Figure 7. Ultimate loads of all specimens

3.5 Effect of High-Performance Ferrocement Laminate on Deflection

From the results, the load-deflection relation of all specimens was linear until cracking occurred. After the first crack, the slope of the load-deflection curve for the control and strengthened specimens until failure is shown in Table 5 and Figure 8. It is observed that the deflection at the first crack load of strengthened specimens (FAW2, SFW2, FAW4, and SAW4) was lower compared to the specimens (Bc, NMW2 & NMW4) because of the effect of more wire mesh layers and high-performance mortar matrix.

Table 5. First Crack, Ultimate Load, and Deflection of All Beam Specimens

Group Designation	Deflection of Beams			
	First Crack Load Kips. (kN)	**Deflection in (mm)**	**Ultimate Load Kips. (kN)**	**Deflection in. (mm)**
Bc	5.75 (25.6)	0.04 (0.96)	27.1 (120.7)	0.89 (22.2)
NMW2	6.67 (29.7)	0.035 (0.89)	29.6 (131.8)	0.5 (12.5)
FAW2	7.22 (32.1)	0.04 (1)	31.43 (139.9)	0.5 (12.6)
SFW2	6.75 (30)	0.044 (1.1)	30.22 (134.5)	0.5 (12.48)
NMW4	7.42 (33)	0.04 (0.96)	31.97 (142.3)	0.57 (14.39)
FAW4	7.1 (31.2)	0.04 (1.03)	30.51 (135.8)	0.7 (17.5)
SFW4	7.52 (33.5)	0.042 (1.05)	32.62 (145.2)	0.66 (16.5)

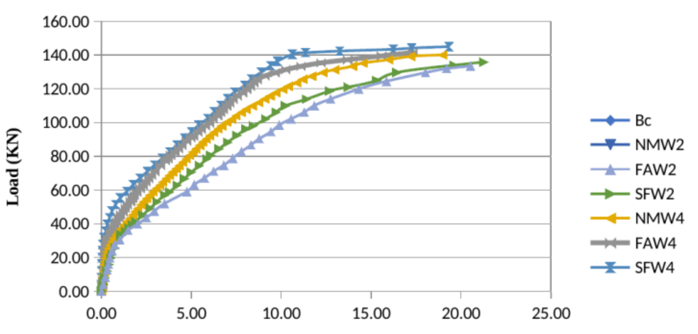

Figure 8. Load-deflection curves of all specimens

3.6 Failure Mode and Crack Pattern

All tested beams, including the control specimen, failed in flexure mode. Failure was mainly identified by the widening of major cracks within the constant maximum moment region, followed by cracking of the mortar at the beam soffit, yielding of tensile reinforcement near failure, and finally crushing of the concrete in the compression zone. No sudden or brittle failure was observed in any specimen, as shown in Figure 9.

The beams strengthened with ferrocement and high-performance ferrocement (HPF) laminates developed many fine and closely spaced cracks compared with the control beam. In strengthened beams, cracks first initiated at the bottom of the ferrocement laminate, then propagated toward the interface between the new mortar and the existing concrete beam, and gradually extended upward as the load increased. After steel yielding, the cracks widened further until final failure occurred by concrete crushing at the top of the beam.

Overall, the externally bonded HPF laminates significantly improved crack control. Because the reinforcement in the ferrocement layer was more uniformly distributed, the strengthened beams exhibited a greater number of finer cracks with smaller crack widths than the unstrengthened control beam.

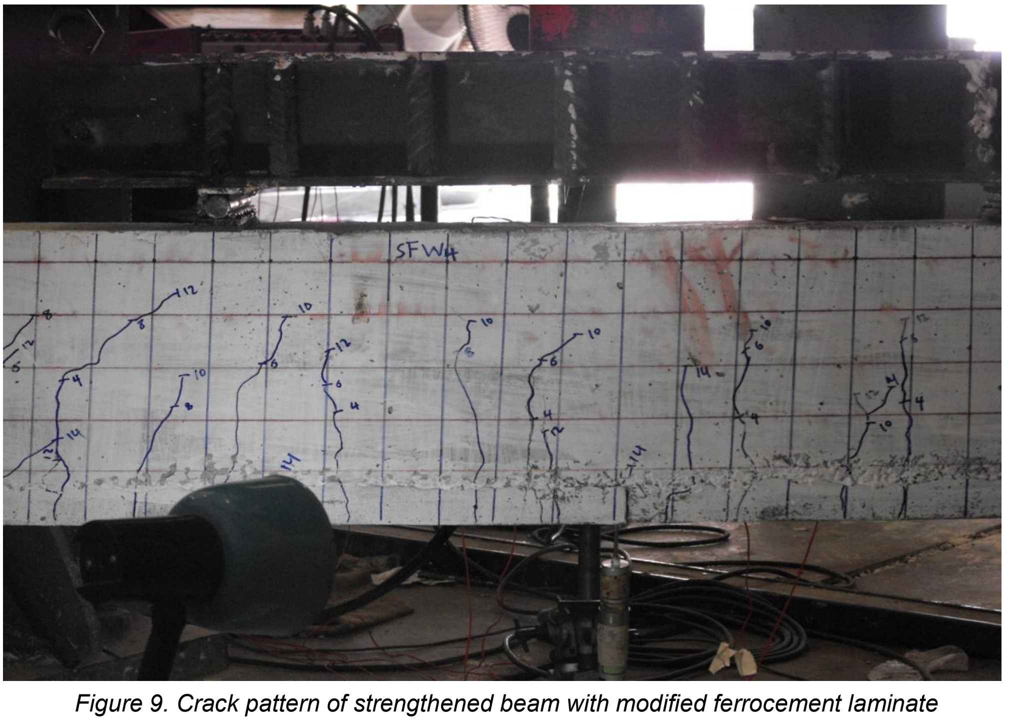

Figure 9. Crack pattern of strengthened beam with modified ferrocement laminate

4. Conclusion

Based on the results obtained in this study, the following conclusions can be drawn:

1. This study analyzed material strength in terms of compressive and flexural strength of mortar. It was found that the replacement of supplementary cementitious matrix (SCM) made an impact on both compressive and flexural strength of the mortar matrix. The replacement of ordinary Portland cement with 5% silica fume and 10% fly ash produced high compressive strength in each SCM.
2. The presence of wire mesh in the strengthened beams decreased the crack width and crack spacing of the beams. The increase in the cracking strength of the strengthened beams increased as the number of layers of wire mesh increased. More layers of wire mesh make the crack width and spacing smaller.
3. Strengthened beams have greater strength compared to ordinary RC beams with respect to both cracking and ultimate strength. The more layers of wire mesh in the strengthened specimens, the higher the strength can be achieved.

5. Recommendation

The recommendations for future work are as follows:

1. Investigate the long-term behavior of strengthened beams by using high-performance ferrocement laminates, namely durability, fatigue, and creep.

2. A study on the shear behavior of the beam strengthened by high-performance ferrocement laminates on the side of the beam is to be investigated.
3. Investigate the improvement of the flexural strength and ductility of ferrocement laminate by adding ground granulated blast furnace slag in the mortar matrix.

Acknowledgement

Not provided in the submitted manuscript.

Conflict of Interest

Not provided in the submitted manuscript.

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