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SUSTAINABILITY IN RETROFITTING: THE ROLE OF FERROCEMENT IN STRENGTHENING BRICK MASONRY BUILDING

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Abstract

The use of ferro cement for brick masonry retrofitting is the subject of this study. Perhaps the earliest material created by humans for building construction is brick. The compressive strength of the mortar and bricks employed determines the strength of brick masonry. The main application for brick masonry is as load-bearing walls to support vertical loads. There is a lot of current study on the rehabilitation of ancient and damaged brick masonry. Encasing these masonry walls with ferro cement is one way to strengthen or improve them. The current study aims to ascertain if encasing damaged brick masonry walls with ferrocement increases their load-bearing capability. Brick masonry walls with various forms, bonding, and techniques for fastening mesh for ferrocement were examined in this study. Fifteen samples were prepared. The wall is 18 inches tall, 18 inches long, 4.5 inches wide, and has a 2-inch cement coating at the top and bottom. There are six control samples: two for compression, two for diagonal, two for flexural or out-of-plan loads, and three for restricted. Additionally, mesh has been used in several samples with a diameter of 10 mm and a thickness of 1 mm. Crack pattern, crack width, first crack load, and maximum load were all noted. The results indicate a significant increase in load at the first fracture and final load following encasement.

Introduction

Modern structural rehabilitation and retrofitting methods have been significantly impacted by the construction industry's increasing desire for sustainable development. Retrofitting has become an essential engineering procedure since a large percentage of the world's building stock is made up of antiquated and structurally flawed buildings, especially in developing nations. Because of their intrinsic structural constraints, unreinforced masonry (URM) buildings are particularly vulnerable among these structures. Reducing materials consumptions, increasing economic viability, and enhancing structural performance while minimizing environmental effects are the main goals of sustainability in retrofitting. Ferrocement has thus become a practical and long-lasting way to reinforce brick masonry structures [1], [2].

Brick masonry is one of the most widely used building materials worldwide due to its affordability, accessibility, and ease of construction. However, URM constructions have poor tensile strength, low ductility, and inadequate resistance to lateral loads such as seismic and wind pressures. These shortcomings make them very susceptible to brittle collapse during earthquakes and other extreme occurrences [3], [4]. Recent seismic disasters have highlighted the critical need for effective retrofitting methods that can improve the functionality of existing masonry structures without requiring complete reconstruction.

To strengthen masonry structures, traditional retrofitting methods including steel bracing, shotcrete overlays, and reinforced concrete jacketing have been used extensively. Although these techniques are effective in increasing stiffness and strength, they frequently have high costs, higher dead loads, and problems with compatibility with current materials [5]. Furthermore, because of their substantial embodied energy and carbon effect, these methods could not be in line with sustainability objectives. Consequently, there has been an increase in interest in lightweight, reasonably priced, and ecologically friendly alternative materials and methods.

Composite-based retrofitting techniques have attracted a lot of attention lately. The potential of materials like fiber-reinforced polymers (FRP), textile-reinforced mortar (TRM), and ferrocement for structural strengthening has been thoroughly investigated. Despite being strong and resistant to corrosion, FRP systems' use is restricted in many areas because of their high cost and susceptibility to fire and temperature [6]. Conversely, ferrocement provides a more affordable and accessible option, especially in developing nations with limited resources.

A cementitious mortar matrix is used to support the numerous layers of closely spaced wire mesh that make up ferrocement, a thin composite material. Its unique composition results in high tensile strength, improved ductility, and superior fracture management. These qualities make ferrocement particularly suitable for retrofitting applications, where enhancing energy absorption and deformation capability is essential [7]. Additionally, thin coatings of ferrocement can be applied to reduce additional loads on the existing structure and minimize structural geometry alterations.

Applying a jacket or overlay to the wall surface is a popular method of using ferrocement to strengthen masonry constructions. It has been demonstrated that this method greatly enhances masonry blocks' in-plane and out-of-plane performance. Ferrocement retrofitting can improve ductility and energy dissipation while simultaneously increasing shear strength, stiffness, and load-bearing capacity, according to recent experimental research [8], [9]. For example, research on ferrocement-reinforced masonry walls has shown significant gains in lateral load resistance and delayed fracture propagation.

One of ferrocement's primary advantages is its support to sustainability. Ferrocement reduces embodied energy and carbon emissions because it requires less material than conventional retrofitting methods [10]. Furthermore, the ingredients needed to create ferrocement, such as cement mortar and steel mesh, are easily accessible and often bought locally. Ferrocement reduces the need for transportation and promotes the use of local labor, making it a viable option for sustainable building.

Compatibility with current masonry materials is one of the most crucial elements of retrofitting projects. Ferrocement offers better bonding qualities with masonry substrates due to its cement-based matrix, ensuring effective load transfer and reducing the likelihood of debonding [11]. Ferrocement is particularly suitable for historic building renovations where preserving the original materials and appearance is essential. The aesthetic integrity of a building can be preserved with the aid of ferrocement overlays, which is important for conservation efforts.

By changing design parameters such mortar composition, number of reinforcement layers, mesh arrangement, and application procedures, current research has tried to maximize ferrocement performance. The mechanical performance of ferrocement-strengthened brickwork has been found to be significantly impacted by these characteristics [12], [13]. For example, adding more mesh layers boosts strength and ductility, while utilizing high-performance mortar enhances bonding and endurance.

The seismic performance of masonry structures that have been upgraded with ferrocement has been the subject of extensive investigation in recent years. Experimental and numerical studies have shown that ferrocement significantly enhances stiffness, deformation capacity, and lateral load capacity [14]. Finite element analysis has also illuminated failure processes, stress distribution, and fracture propagation in ferrocement-strengthened structures [15]. These findings show that ferrocement can improve the earthquake resistance of masonry constructions.

Ferrocement has been utilized both alone and in combination with other materials in hybrid strengthening systems. For example, it has been shown that the mechanical performance and durability of the ferrocement matrix are enhanced by the addition of synthetic or natural fibers [9]. These hybrid systems offer superior protection against cracking, impact loading, and environmental deterioration. However, these systems may not be feasible to utilize in circumstances with limited resources due to their higher cost and complexity.

Despite its advantages, the use of ferrocement in retrofitting has certain disadvantages. Appropriate surface preparation is required to ensure adequate adhesion between the ferrocement layer and the existing brickwork. Inadequate surface preparation might lead to debonding and reduced retrofit performance [11]. Additionally, quality monitoring is crucial during the construction process since variations in mortar composition and craftsmanship can have a significant impact on performance. Long-term resistance to environmental stresses such moisture, temperature fluctuations, and corrosion is another area that requires further study.

The absence of thorough design standards and established regulations that particularly address the retrofitting of masonry structures with ferrocement is another drawback. Even while generic concepts exist, more thorough and widely recognized design techniques are required to enable wider application [2]. These recommendations and the validation of ferrocement systems' long-term performance through field and experimental studies are the main goals of current research.

From a sustainability standpoint, ferrocement is essential for prolonging the life of existing structures, which lessens the need for demolition and reconstruction. This is consistent with the circular economy and sustainable development concepts, which prioritize environmental preservation, waste minimization, and resource efficiency [10]. Ferrocement retrofitting reduces construction waste and conserves embodied energy by maintaining existing buildings.Ferrocement is a workable and scalable way to increase structural safety in developing nations where non-engineered masonry structures make up a sizable component of the building stock. It is especially appropriate in these situations due to its low cost, simplicity of use, and dependence on locally accessible resources [16]. In parallel with experimental and material-based retrofitting approaches, recent research has also explored data-driven techniques to better understand and predict material behavior. For instance, large-scale studies on concrete compressive strength prediction have demonstrated that embedding-based neural networks can effectively capture complex interactions in material properties and outperform traditional models [17].

Retrofitting public infrastructure, schools, and residential structures using ferrocement may greatly increase resistance to natural disasters, lowering the risk of disaster and improving community safety.

Following are the research objectives.

- To determine the brick masonry wall's compressive strength both before and after wire mesh.
- To ascertain the brick masonry wall's tensile strength both before and after wire mesh.
- To assess the brick masonry wall's flexural strength both before and after wire mesh.

Materials and Method

Following are the materials used and methods adopted for this research project.

Material Collection

To finish this study assignment, all the information was carefully gathered. tiny-scale bricks, fine and coarse aggregate, cement, steel bars with a tiny diameter, shear connections, and wire mesh are among the materials gathered.

Bricks

Small-scale special bricks of 4.5 inches in length, 2.5 inches in width, and 1.5 inches in height were made. For this study, a total of 1450 bricks were created, and they were tested in a concrete lab at UTM using the technique ASTM Certification: C67: Standard Test Procedure for Brick Compressive Strength.

Cement

Cement for this research was taken from the local market of Peshawar, Khyber Pakhtunkhwa, Pakistan.

Fine Aggregate

This sample of fine aggregate was taken from the local market of Peshawar, Khyber Pakhtunkhwa, Pakistan.

Cement Mortar

In this study, two different kinds of mortar were used. One kind was used for brick masonry, while another was utilized for plastering and ferrocement to enclose wire mesh. Cement to sand ratios for brick production are 1:6 and 1:4, respectively.

Small Diameter Meter Steel

Small diameter steel of bar #2 in a DPC has been used in this research. This steel is also used in column in confined sample.

Materials Selection

First, specific bricks with a tiny diameter were chosen and gathered from the neighborhood market. Bricks are three inches long, one and a half inches wide, and one inch high. In a similar manner, wire mesh, sand, cement, and shear connections were chosen and bought. Mesh thickness is 18 mm, wire mesh opening size is 25 mm, and mesh thickness is 1 mm.

Sample Preparations

Six control samples and a total of fifteen brick masonry samples were created. The prism is 18 inches long, 18 inches height, and 3 inches thick. For the control sample, which has dimensions of 14 inches for length, 14 inches for height, and 3 inches for thickness, the mortar ratio is 1:6. For plastering, the ratio of ferrocement is 1:4, and the ratio of PCC is 1:4:6. Seven examples are retrofitted with 2-inch PCC top and bottom.

Sample Curing

After preparation of samples, curing to the samples to consecutive 28 days was done. Curing for all samples 4 times in each day was done.

Sample testing

After the curing of samples, different tests in UTM lab were performed like compression, flexural and

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diagonal tests. For compression and flexural tests, the length, height and thickness is 18in, 18in and 3inch respectively while for the diagonal test, the length, height and thickness of prism is 14in, 14in and 3in respectively.

Results and Discussion

Following are the results along with discussions as under.

Compressive Strength of Bricks

ASTM Designation: C67-03: Standard Test Method for Compressive Strength of Bricks.

Purpose of Experiment

To find the Compressive strength of Bricks, three samples of the bricks are tested in the UTM lab. The graphical representation of the test is given below.

Table 1: *Compressive Strength of Bricks*

S. No.	Load (KN)	Compressive Strength (N/mm^2)	Average (N/mm^2)
1	41.6	14.35	
2	39.5	13.60	13.84
3	39.4	13.57	

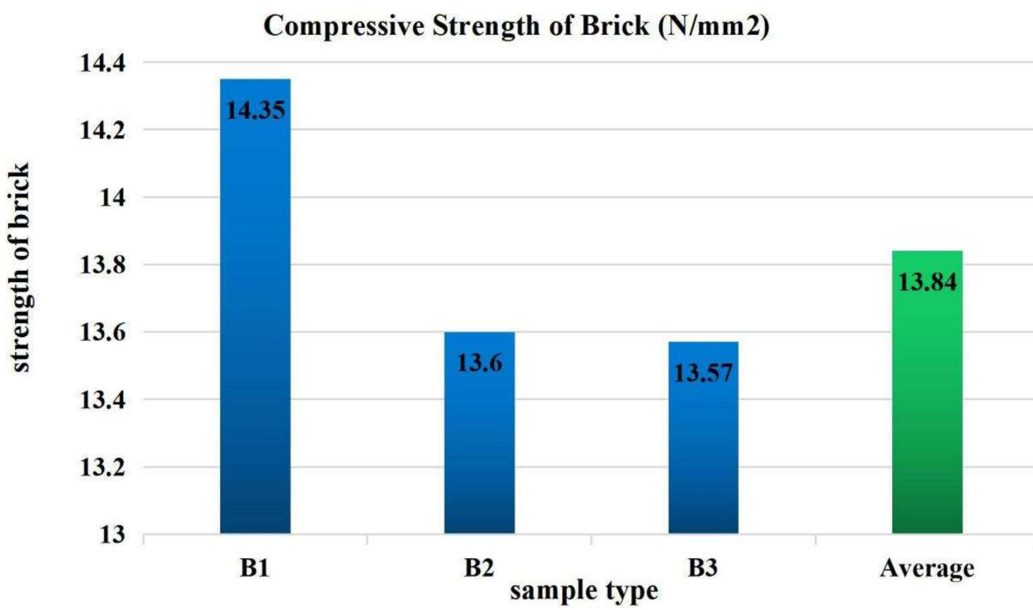

Figure 1: Graphical representation of the compressive strength of bricks

Water Absorption of Brick

ASTM Designation: C67

Purpose of Experiment

To find the water absorption of the bricks

Saturated Weight=476.13g

Dry weight of the brick=401g

Calculation

Absorption (%) = 100 × (Ws - Wd) / Wd

Where:

Wd = Dry weight of the specimen, and

Ws = Saturated weight of the specimen after submersion in water

Table 2: *Water absorption of brick*

S. No.	Dry Weight, Wd (g)	Saturated Weight, Ws (g)	Absorption (%) 100 × (Ws - Wd) / Wd
1	401	476.13	18.7%

Compressive Strength of Mortar

Compressive Strength of Mortar Used in Brick Masonry cement sand ratio is 1:6.

ASTM STANDARD: C 109

Purpose of Experiment: To find the compressive strength of cement mortar.

Table 3: *Compressive Strength of 1:6 Mortars*

S. No.	Load (KN)	Compressive Strength (N/mm^2)	Compressive Strength (Psi)	Average (N/mm^2)
1	2	0.8	116	
2	1.9	0.76	110.2	0.74
3	1.7	0.68	98.6	

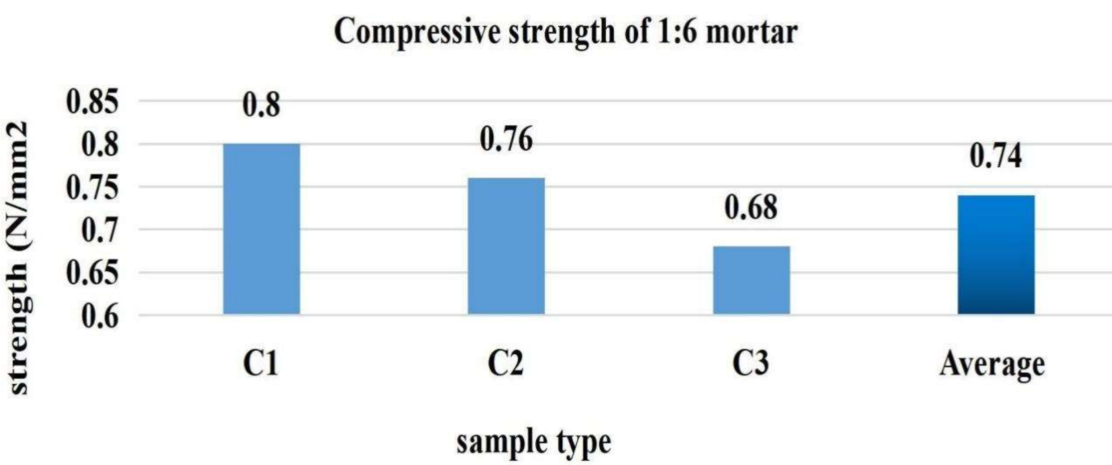

Figure 2: Graphical representation of compressive strength of 1:6 mortars

Compressive Strength of Mortar used in Ferrocement Cement Sand Ratio of 1:4

ASTM STANDARD: C 109

Purpose of Experiment: To find the compressive strength of cement mortar.

Table 4: *Compressive Strength of 1:4 Mortar Cube*

S. No.	Load (KN)	Compressive Strength (N/mm^2)	Compressive Strength (Psi)	Average (N/mm^2)
1	4	1.6	232	
2	4.2	1.68	243.6	1.8
3	5.3	2.12	307.4	

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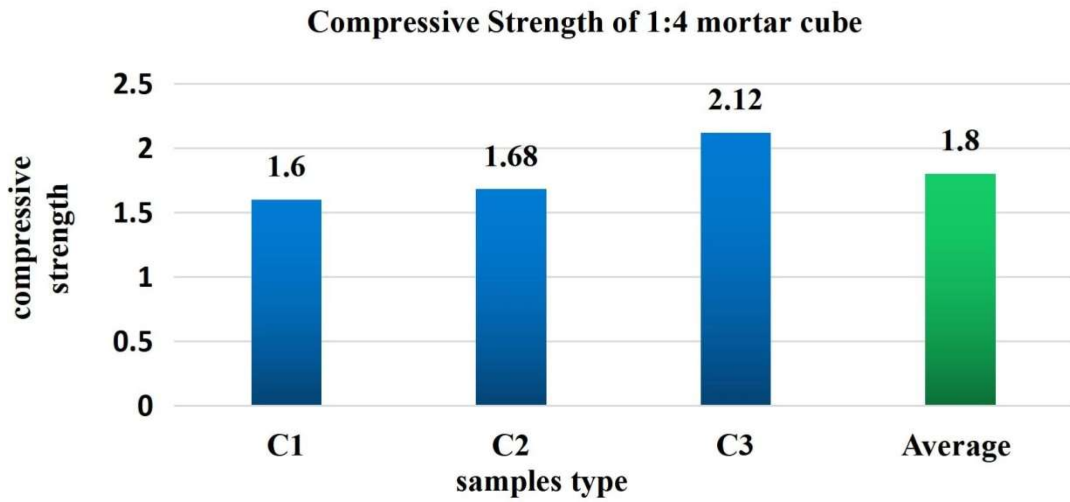

Figure 3: Graphical representation of compressive strength of 1:4 mortar cubes

Compressive Strength Test of Brick Masonry

Compressive Strength of Control Sample

The control samples were tested for compressive strength as per ASTM C1314-12 in universal testing machine.

Calculation

S=P/A = 199.19KN/34.86in^2

S = 5.7N/mm2

Correction Factor = hp/tp = 18/3 = 6

S= 4.11N/mm^2

S (act) = 1.22×4.11

S (act) = 5 N/mm^2

Table 5: *Compressive strength of control sample*

S. No.	Load (KN)	Compressive strength (N/mm^2)	Compressive strength (Psi)
CO1	199.19	6.96	1009.2
CO2	142.90	5	725.725
Average		5.98	867.75

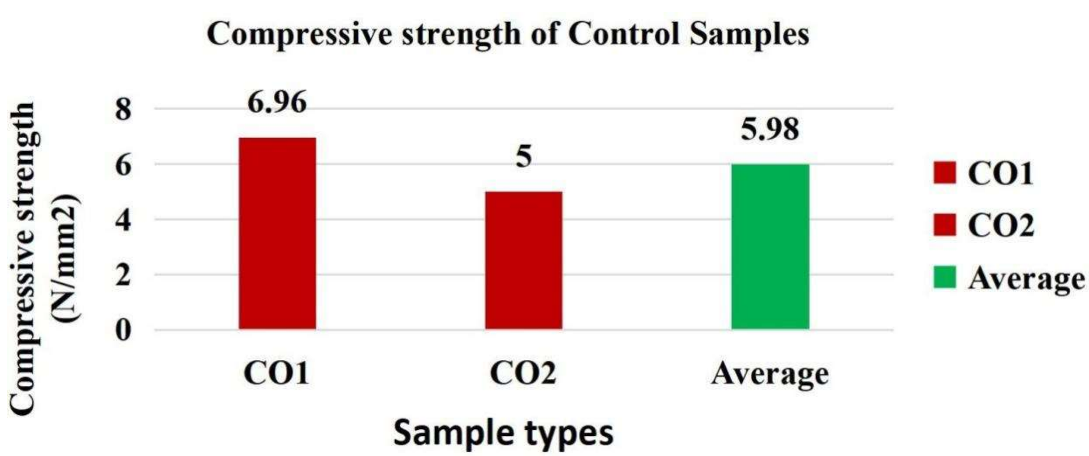

Figure 4: Graphical representation of compressive strength of control sample

Discussion

2 control samples were selected and tested on UTM achieving strength values. A steel plate was used for the load distribution while the width and length of the plate is 3in and 18in respectively. From the graphs, CO1 sample got 6.96 N/mm^2 while CO2 got 56.96 N/mm^2 of strength with average value of these samples as 5.98 N/mm^2.

Loading rate 0.042ksi/sec

Compressive strength of Brick Masonry Retrofitted with Square Wire Mesh

The reinforced masonry wall was the subject of this compression strength test. Square wire mesh was installed on the wall. The compressive strength of the square wire mesh was adequate. Three brick masonry samples total that were reinforced with square wire mesh ferro-cement. In a universal testing machine (UTM), samples were evaluated for compressive strength in accordance with ASTM C1314-12. For this ferro-cement overlay, an average improvement of roughly 10% was obtained.

Calculation

$S = 6.96 N/mm^2$

$S (act) = 1.22*6.96 = 8.49 N/mm^2$

$S = 7.70 N/mm^2$

$S (act) = 7.70 \times 1.22 N/mm^2 = 9.3 N/mm^2$

Table 6: ***Compressive strength of brick masonry retrofitted with square wire mesh***

S. No.	Load (KN)	Compressive Strength (N/mm^2)	Compressive Strength (Psi)
SWM1	242.67	8.49	1231.05
SWM2	168.67	5.88	841
Average		7.18	1036
Confined	266.42	9.39	1361.55

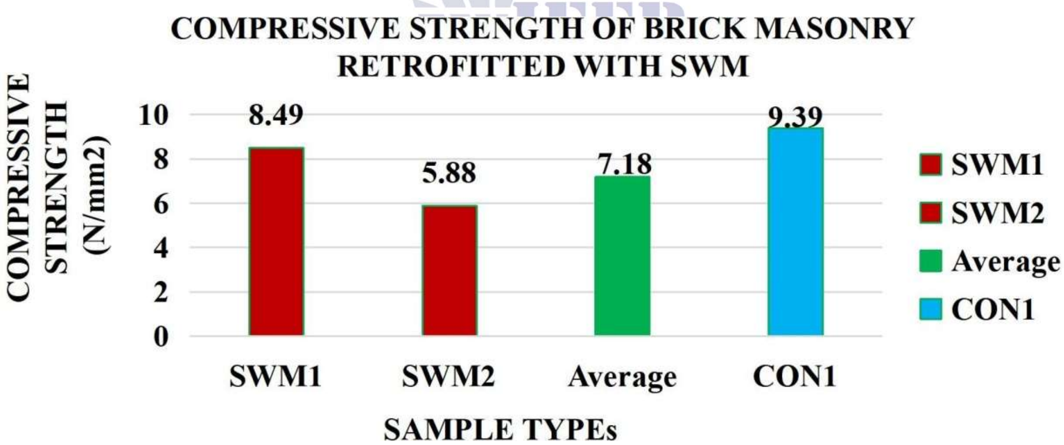

Figure 5: Graphical representation of compressive strength of brick masonry retrofitted with SWM

Discussion

2 retrofitted square wire mesh samples were taken and then tested on UTM achieving a compressive strength. From the above graph it is indicated that SWM1 sample achieved 8.49N/mm^2 strength and SWM2 achieved 5.88N/mm^2 strength so, the average of these sample is 7.18N/mm^2 with 1 confined sample tested achieved 9.39N/mm^2 of strength. The above given results for compression strength shows that an increase of about 14% in compressive strength of brick masonry is achieved, by strengthening the brick masonry with square wire mesh.

Diagonal Load Test

Following are the results of the diagonal load test.

Control Sample

The diagonal load test of brick masonry control sample were tested as per ASTM C1314-12 in universal testing machine (UTM) lab and the detailed results of the test are given below in table.

ASTM Designation: E519/E519M — 10

Calculation

Calculate the shear stress for specimens on the basis of net area. Calculate the shear stress of the specimen as follows:

Ss = 0.707×P/An where:

Ss = shear stress on net area, MPa [psi]

P = applied load, N [lbf], and

An = net area of the specimen, mm^2 $[in^2]$, calculated as follows:

An = (w+h)×tn /2 where:

w = width of specimen, mm [in.], h = height of specimen, mm [in.],

t = total thickness of specimen, mm [in.], and

n = percent of the gross area of the unit that is solid, expressed as a decimal.

Table 7: *Diagonal load test of brick masonry*

S. No.	Load (KN)	Compressive Strength (N/mm^2)	Compressive Strength (psi)
CO1	41.89	0.85	123.25
CO2	38.55	0.47	24.65
Average		0.51	73.95

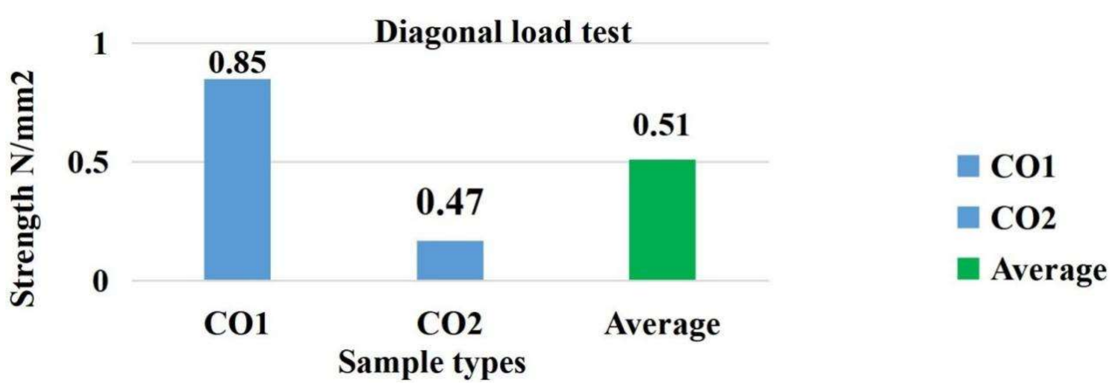

Figure 6: Graphical representation of diagonal load test

Discussion

2 control samples were taken and tested on UTM achieving a tensile strength. From the above graphical representation CO1 sample got 0.85N/mm^2 strength and CO22 get 0.47N/mm^2 strength while the average of these samples is 0.51N/mm^2 and Loading rate 0.021ksi/sec.

Brick Masonry Retrofitted with square Wire Mesh

The diagonal tensile strength test for reinforced masonry wall retrofitted with square mesh. Total two samples of brick masonry strengthened with ferro-cement of square wire mesh were tested for diagonal tensile strength as per ASTM C1314-12 in universal testing machine. The detailed results of each samples is given in the below table accordingly.

Calculation

ASTM Designation: E519/E519M — 10

Calculate the shear stress for specimens on the basis of net area. Calculate the shear stress of the specimen as follows:

Ss = 0.707×P/An where:

Ss = shear stress on net area, MPa [psi]

P = applied load, N [lbf], and

An = net area of the specimen, mm^2 $[in^2]$, calculated as follows:

An = (w+h)tn /2 where:

w = width of specimen, mm [in],

h = height of specimen, mm [in],

t = total thickness of specimen, mm [in], and

n = percent of the gross area of the unit that is solid, expressed as a decimal.

Table 8: *Brick masonry retrofitted with square wire mesh*

S. No.	Load (KN)	Compressive Strength (N/mm^2)	Compressive Strength (Psi)
SWM 1	44.72	0.907	131.5
SWM 2	42.31	0.92	133.4
Average		0.91	132.45

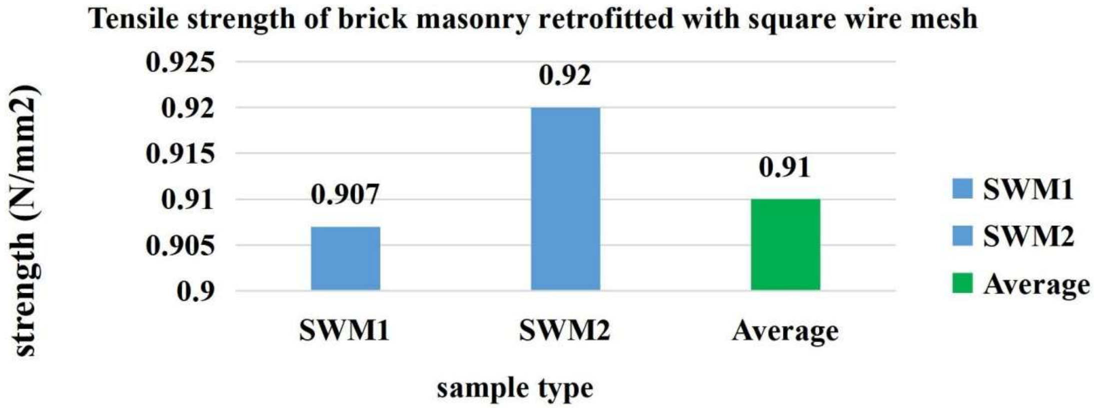

Figure 7: Graphical representation of brick masonry retrofitted with square wire mesh

Discussion

2 retrofitted square wire mesh samples tested on UTM and achieved a tensile strength values. From the above graph, SWM1 sample got $0.907N/mm^2$ strength and SWM2 got $0.92N/mm^2$ strength so the average of these samples is $0.91N/mm^2$.

Flexural Test of Brick Masonry

Following are the values of the results of the flexural test of brick masonry.

Control Sample of Brick Masonry

Two control samples of brick masonry were tested on universal testing machine (UTM) as per ASTM standard (ASTM Designation: E518/E518M – 10). The detailed results of each sample are given below in the table.

Calculation

Calculate the gross area modulus of rupture as follows:

For Test Method with third-point loading:

R = (P + 0.75 Ps) ×l /bd2

Where:

R = gross area modulus of rupture, MPa [psi],

P = maximum applied load indicated by the testing machine, N [lbf],

Ps = weight of specimen, N [lbf],

l = span, mm [in],

b = average width of specimen, mm [in], and

d = average depth of specimen, mm [in].

Table 9: *Flexural test of control sample*

S. No.	Modulus of Rupture (N/mm^2)	Load (KN)	Rapture in (psi)
CO1	2.11	18.404	305.9
CO2	1.94	16.948	281.5
Average	2.04		293.6

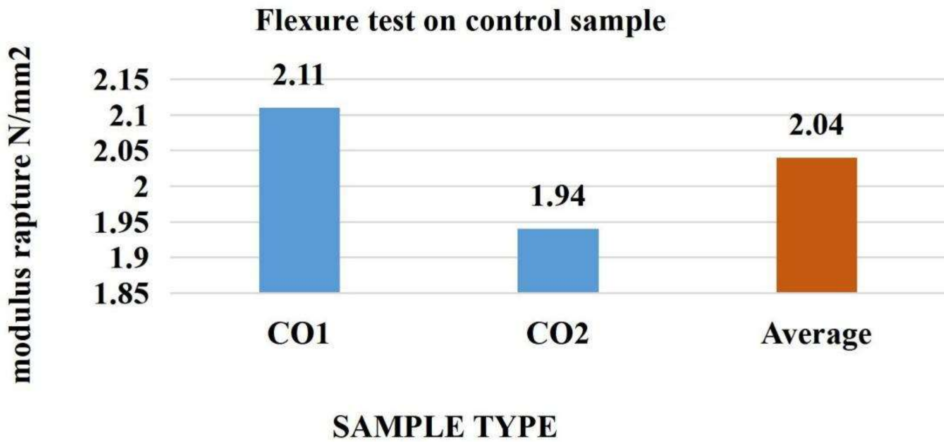

Figure 8: Graphical representation of flexural test on control sample

Flexural Test on Retrofitted Sample of Brick Masonry

Two Retrofitted samples of brick masonry strengthened with square wire mesh tested on universal testing machine (UTM) as per ASTM standard ASTM Designation: E518/E518M — 10. The detailed results of each sample are given below in the table.

Calculation

ASTM Designation: E518/E518M — 10

Calculate the gross area modulus of rupture as follows:

For Test Method with third-point loading:

R = (P + 0.75 Ps) ×l /bd2

Where:

R = gross area modulus of rupture, MPa [psi],

P = maximum applied load indicated by the testing machine, N [lbf],

Ps = weight of specimen, N [lbf],

l = span, mm [in],

b = average width of specimen, mm [in.], and

d = average depth of specimen, mm [in.].

Table 10: *Retrofitted sample with square wire mesh*

S. No.	Load (KN)	Modulus of Rupture (N/mm^2)	Rupture (Psi)
SWM1	17.25	1.98	287.1
SWM2	18.73	2.03	294.45
Average		2.005	290.72

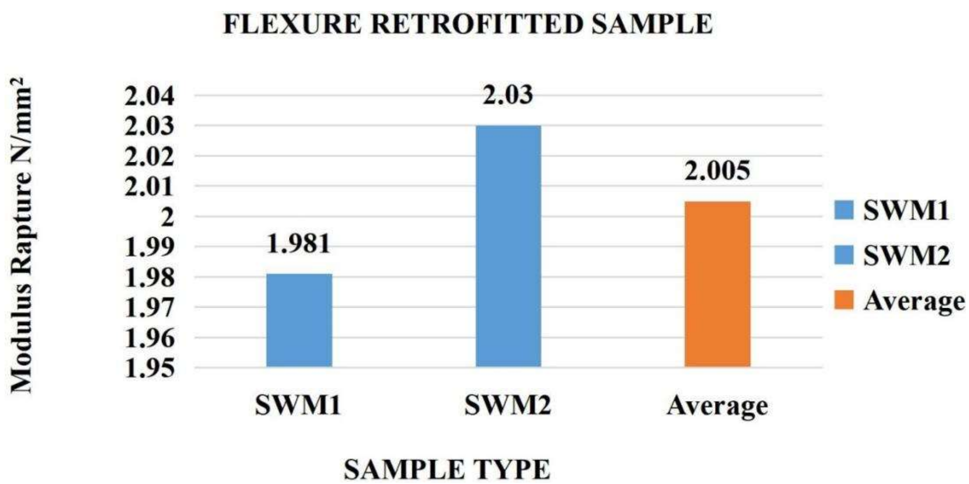

Figure 9: Graphical representation of retrofitted sample with square wire mesh

Discussion

2 retrofitted square wire mesh samples tested on UTM as per ASTM E518M-10 and got flexure strength. Now from the above graph SWM1 sample got 1.981N/mm^2 strength and SWM2 got 2.03N/mm^2 strength so, the average of these samples is 2.005N/mm^2.

Confined Samples of Brick Masonry

Total three confined brick masonry sample two control sample one sample are prepared retrofitted with square wire mesh and tested on universal testing machine (UTM) and got results. Detailed results are given below in the table.

Table 11: ***Confined sample of brick masonry***

S. No.	Compressive Strength (N/mm^2)	Compressive Strength (Psi)	Load (KN)
CO1	7.23	1048.35	236.3
CO2	7.54	1093.3	245.45
SWM	9.39	1361.55	266.42
Average	8.05	1167.73	

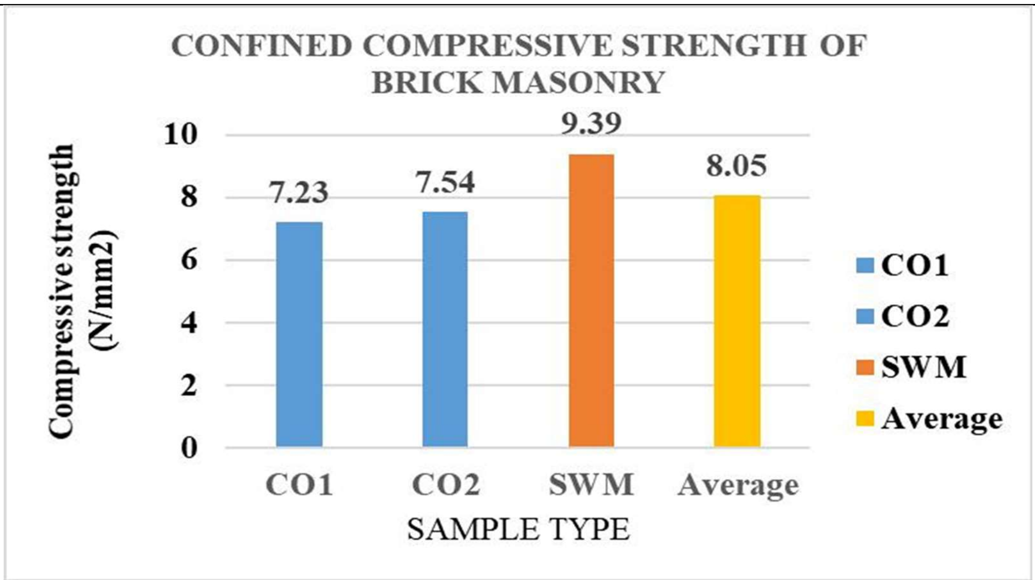

Figure 10: Graphical representation of confined sample of brick masonry

Comparison of Self Weight of Wall

Five different weights were sampled with the help of digital balance. Two samples were unreinforced while two were reinforced samples. The percent change was found out in weights using the following formula.

P = W2 - W1/ W1 × 100

Table 12: ***Comparison of self weight of wall***

S. No.	Sample Type	Size	Weight	% Change
1	Control Sample	1'.6"×1'.6"×3"	41.12	47.13
2	Retrofitted Sample	1'.7"×1'.7"×4"	60.50	
3	Control Sample	1'.4"×1'.4"×3"	26.60	28.7
4	Retrofitted Sample	1'.5"×1'.5"×4"	34.25	

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Conclusion and Recommendation

Following are the conclusions and recommendations of this investigation.

Conclusion

The following are the few conclusions that can be drawn from this research work.

- When brick masonry is strengthened with square wire mesh, its compressive strength increases by approximately 14% when compared to a control sample of brick masonry.
- When ferrocement is strengthened with square wire mesh, the flexure strength of brick masonry increases by approximately 16% when compared to a control sample.
- Using square wire mesh to strengthen the brick masonry also resulted in the greatest increase in diagonal tensile strength. Compared to the control sample, tensile strength increased by 14%.
- For the diagonal tensile strength test sample and the compressive strength test sample, the samples self-weight rose by 47% and 28%, respectively.

Recommendation

The following are the few recommendation points for future researchers.

- This analysis suggests that woven wire be preferred in order to increase both diagonal tensile strength and compression strength.
- In terms of diagonal tensile strength, square wire mesh performs better than welded wire mesh.
- Shear connector placement is crucial.
- It is advised to look at the effects of grout injection and excessive ferrocement on the functionality of other types of masonry, such as block masonry and stone masonry.
- It is advised to look at how ferro-cement overlay affects a full-scale room's self-weight.
- It is advised to look at the brick masonry reinforced with ferro-cement overlay's out-of-plan behavior.
- To assess the seismic performance of irregular (URM) structures retrofitted with the suggested system, a numerical study is advised..

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