Evaluation of Flexural resistance and Ductility of Masonry wall strengthened using Flax and Sisal fibres

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Abstract—**Masonry walls are widely used in low and medium-rise buildings due to their cost-effectiveness and sustainability. However, their low tensile and shear strength makes them vulnerable to seismic damage. This study investigates the flexural resistance and ductility of masonry walls strengthened with natural fibres flax and sisal using externally bonded fibre-reinforced polymer (FRP) technique. Masonry specimens were subjected to two-point loading tests. Experimental results show that sisal fibre reinforced masonry walls (S-RMW) exhibited 3.4 times increase in flexural strength, while flax fibre reinforced masonry walls (F-RMW) showed 2.6 times higher than the unreinforced walls. The ductility ratio of F-RMW and S-RMW was 3.22 and 2.886, respectively. The experimental result shows that the specimen S-RMW possess higher strength but displays brittle behavior, while the specimen F-RMW demonstrates comparatively lower strength but greater ductility. This shows that, the choice of strengthening material should depend on the specific functional needs of the structure**

Index Terms—**Ductility, Flax fibre, Fibre Reinforced Polymer, Flexural capacity, Masonry walls, Sisal fibre**

I. INTRODUCTION

Unreinforced masonry (URM) walls, built using bricks, stones, or concrete blocks with mortar, have been employed for centuries due to their simplicity and durability. Despite their widespread use, these walls possess inherent structural vulnerabilities, particularly in seismic regions, due to low tensile and shear strength. Earthquakes often result in catastrophic failure of URM buildings, especially in out-of-plane wall bending or diagonal cracking.

Several studies have demonstrated that URM walls cannot adequately resist lateral forces, leading to sudden collapse during extreme loading events. Enhancing the flexural resistance and ductility of masonry walls is therefore critical for both new constructions and retrofitting existing structures. Various strengthening techniques have been explored, that includes Externally Bonded Fibre Reinforced Polymer (EB-FRP), Textile Reinforced Mortar (TRM), Natural fibres embedded in mortar, Ferrocement, Near-Surface Mounted (NSM) FRP bars. This study focuses on the use of natural fibres (flax and sisal) in EB-FRP systems, considering their strength, durability, and environmental benefits. Flax and sisal fibres are renewable, biodegradable, and require lower energy to produce compared to synthetic fibres, making them suitable for sustainable construction practices.

The aim of this study is to evaluate the flexural capacity, ductility, and failure behaviour of masonry walls strengthened with flax and sisal FRP composites, providing a comparative assessment to determine the optimal natural fibre for structural strengthening applications.

II. LITERATURE REVIEW

Masonry walls have been extensively studied due to their susceptibility to seismic forces. Hamoush et al. (2001) reinforced walls using E-glass and Kevlar FRP in distinct patterns, noting that web-pattern reinforcement improved bending strength relative to unidirectional patterns. Sathiparan et al. (2013) studied polypropylene (PP) band mesh reinforcement, observing improved strength and deformation post-cracking. Natural fibres have been explored as sustainable alternatives. Bitar et al. (2020) used hemp FRP composites, showing enhanced flexural resistance, though shear failures were observed in masonry units. Ferrara et al. (2020) reported that flax fibre textile reinforced mortar improved masonry wall shear strength, with non-linear increases in performance relative to fibre layers. Similarly, Furtado et al. (2020) compared glass and polypropylene meshes, noting that mesh selection should account for masonry unit strength to avoid premature crushing. Comparisons between EB-FRP and FRCM techniques have revealed that both methods significantly enhance flexural resistance (Al-Jaberi et al., 2018). However, failure modes differ, increasing FRP layers shifts failure from debonding to shear in EB-FRP, and from slippage to debonding in FRCM. Triwiyono et al. (2015) reinforced concrete brick walls with steel bars, noting increased flexural capacity but emphasizing the importance of ductility in seismic response.

These studies collectively highlight the potential of fibre-reinforced composites for masonry strengthening while underscoring the need for sustainable alternatives like flax and sisal fibres to reduce cost and environmental impact.

The important goals that are drawn after reviewing the papers related to this experimental study are,

1. To study the tensile strength of flax and sisal fibre reinforced polymer.
2. To study the performance of masonry walls without reinforcement under static loading.
3. To improve the flexural and ductile behaviour of masonry wall strengthened using flax and sisal fibre as external reinforcement.
4. To study the failure mode and debonding behaviour of strengthening materials.
5. To compare the behaviour of reinforced masonry wall with the unreinforced masonry wall.

III. MATERIALS & EXPERIMENTAL METHODS

A. Materials

The following sections present the materials utilized in this project, which aims to enhance the flexural and ductile behaviour of masonry walls with natural fibres.

1) Bricks

Bricks are the basic construction materials, commonly shaped as rectangular blocks used in masonry for construction of walls and various structures. The bricks used are non-modular bricks each of size 215mm X 102.5mm X 75mm.

2) Cement

Cement is a fine powder that serves as a binding agent in constructions. The cement used is Ordinary Portland Cement (OPC 53).

3) Fine Aggregate

Fine aggregates are small particles, usually less than 4.75mm. The fine aggregates used is M-sand, produced by crushing hard rocks like granite.

4) Flax fibres

Flax is a natural fibre derived from linseed plant, which is grown and harvested specifically for its fibre. This fibre is viable as a reinforcement material in the form of composites due to its long, continuous, cellulose fibres possessing higher strength and stiffness.

5) Sisal fibres

Sisal fiber is derived from leaves of sisal plant, making them a viable alternative to synthetic materials in construction applications, which help in enhancing the tensile strength, durability, flexibility and tolerance to cracking of structural elements.

6) Resin

The resin used is unsaturated polyester resin, particularly adopted in the production of fibre reinforced polymers to create strong, lightweight and corrosion resistant materials. And the other is epoxy resin used to bond the FRP laminates to the masonry wall externally.

The polyester resin should be used by mixing 5ml of accelerator (cobalt) and 15ml of catalyst (MEKP) per liter of polyester resin. Similarly, the epoxy resin should be used by mixing 10% hardener per kg of epoxy resin.

B. Experimental methods

The standard tests done on each material and test specimens are,

1) Specific Gravity

Specific gravity refers to the ratio of weight of a material to the weight of an equivalent volume of water. It helps in assessing the quality of materials.

2) Sieve Analysis of Fine aggregate

Sieve analysis of fine aggregate, also known as gradation testing, determines the particle size distribution within a sample.

3) Consistency test for Cement

Consistency refers to the degree of fluidity or stiffness of the cement paste, which helps to find out the quantity of water needed to achieve a paste of a specific consistency, which is essential for consistent and predictable results in subsequent tests on cement.

4) Fineness test of Cement

Cement fineness indicates the degree of how fine the cement particles are, essentially the particle size and the specific surface area, which significantly impacts hydration rate, strength development, and heat generation.

5) Setting time of Cement

The setting time of cement is the interval needed for a cement paste to harden once water is added.

6) Compressive strength of Bricks

Compressive strength is the property of a brick that represents the amount of load it can resist per unit area before breaking or deforming.

7) Water absorption test on Bricks

Water absorption capacity of bricks is a vital property of bricks, indicating their porosity and ability to withstand moisture.

8) Flexural strength test on Bricks

The flexural strength test on bricks is the measure of brick's strength to resist bending on application of load.

9) Compressive strength test of cement mortar cube Compressive strength in cement refers to its ability to withstand pressure or compressive loads without fracturing.

10) Flow table test of cement mortar

The flow table test of cement mortar is a standardized procedure to assess the workability and consistency of fresh mortar which is crucial for determining the appropriate water content necessary for required applications, such as strength testing of masonry cement and others.

11) Compressive strength test of masonry prisms

A masonry prism is a small representative assembly of brick units bonded with cement mortar, used to measure the compressive strength of masonry. The prism is constructed to show the behaviour of actual masonry construction, assuring that the test results are reflective of in-situ conditions.

12) Triplet shear test on bricks

Triplet test on bricks refers to a method for evaluating the shear strength of masonry bed joints, particularly when strong units are combined with weak mortar joints, using a constraint system to create a shear box. The test is necessary to understand the structural integrity of masonry walls under shear loading, which is crucial for seismic design and overall durability assessments.

13) Tensile strength test of FRPs

Tensile strength of FRP is an essential mechanical characteristic that indicates how much force a fiber can endure when stretched or pulled before it fractures or breaks.

14) Flexural strength test by two-point loading

Two-point loading involves applying two equal loads positioned at one-third points of the span. This test aims to evaluate the flexural resistance of the masonry wall specimen, measuring its resistance to cracking under bending.

C. Preparation of test specimens

In this section, preparation of test specimens required for conducting the experiment are detailed,

1) Masonry prism

The masonry prisms are constructed by placing the masonry units in a stretcher bond pattern ensuring the mortar joints are of uniform thickness. The masonry prisms constructed are of size 215mm X 102.5mm X 415mm. As per IS specifications, the aspect ratio must be between 2 and 5. For brickwork prisms with an aspect ratio below 5, the strength of masonry prism specimen under compression obtained from tests should be corrected by applying the appropriate correction factors. Here the aspect ratio is 4.05, hence the correction factor is given by 0.9525.

2) Triplet specimen

The triplet specimens are constructed using three units of bricks bonded together with two mortar joints. And the capping is provided with rich cement mortar on bottom of the outer bricks and on top of the middle brick.

3) Natural fibre reinforced polymer

Polymer reinforced with natural fibres is prepared using hand layup method. The mold surface was first cleaned and coated with a release agent (wax) to prevent the composite from sticking. The required amount of polyester resin was poured into a clean mixing beaker, to which 5 ml of accelerator (cobalt) and 15 ml of catalyst per liter of resin were added and mixed thoroughly to eliminate air bubbles and ensure homogeneity. The fibre mat was then laid onto the mold surface, and the resin mixture was poured over it to achieve full saturation. Laminating rollers were used to compact the laminate, remove trapped air, and ensure proper fibre-resin contact. The composite was allowed to cure at room temperature, after which the cured FRP was carefully removed from the mold.

4) Masonry wallets

In this project, masonry walls measuring 475 mm X 1050 mm with a single brick thickness were constructed using English bond and 1:6 (cement: sand) mortar. Nine specimens were prepared, including three unreinforced walls (URMW), three reinforced with flax fibre FRP (F-RMW), and three reinforced with sisal fibre FRP (S- RMW). After 28 days of curing, 100 mm wide FRP strips were externally bonded to the reinforced walls using epoxy resin to prepare the F-RMW and S-RMW specimens.

IV. RESULTS & DISCUSSIONS

The results obtained after testing the materials used required for the experiment are presented in Table 1,

Table 1 – Materials test results

Materials	Tests	Result
Cement	Initial Setting	70 min
	Final Setting	600 min
	Specific Gravity	3.02
	Standard Consistency	28%
	Fineness	4%
Bricks	Compressive Strength	5.194 N/mm²
	Water Absorption	11.314%
	Flexural strength	0.884 N/mm²
Fine Aggregate	Grading zone	II
	Specific Gravity	2.51
	Fineness Modulus	2.64
Flax FRP (290X80X2)	Tensile Strength	5.813 N/mm²
Sisal FRP (290X80X2)	Tensile Strength	17.657N/mm²

Similarly, the results obtained after testing the prepared specimens is given in the following sections,

A. Tests on cement mortar

The strength of cement mortar cube under compression of size 70.6mm having 1:6 cement to sand ratio after 28 days of curing is 15.42N/mm^2.

The other test conducted on cement mortar is flow table test, to identify the appropriate water content. From the test results it is found that, the water to cement ratio of 1.0 is required and the same is used for the construction of masonry wallets.

B. Compressive strength test on masonry prisms Prism compressive strength is a combined effect of masonry unit and mortar. The mean compressive strength obtained on applying the correction factor is

1.88 N/mm^2 and observed crushing and vertical splitting mode of failure in these specimens.

C. Triplet shear test

The shear bond strength obtained from the triplet shear test is 0.195 N/mm^2. Shear failure in the unit/mortar bond area on one face was observed. This type of failure shows the asymmetric failure pattern in the specimen showing the non-uniform distribution of stresses during loading.

D. Test on masonry wallets

The flexural strength of the masonry wall specimens are assessed by subjecting them to two point loading. The load versus deflection graph obtained for the specimens URMW, F-RMW and S-RMW are shown in Fig.1, Fig.2 and Fig.3 respectively.

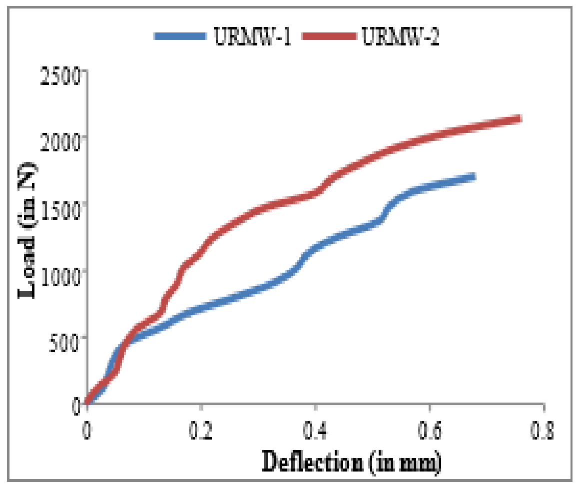

Fig.1 Load v/s Deflection plot for URMW specimens

The mean flexural strength of URMW specimen is 0.0831 N/mm^2.

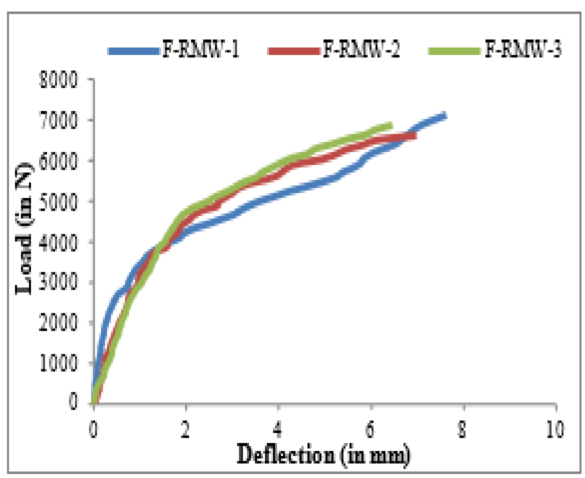

Fig.2 Load v/s Deflection plot for F-RMW specimens

The mean flexural strength of F-RMW specimen is 0.2962 N/mm^2.

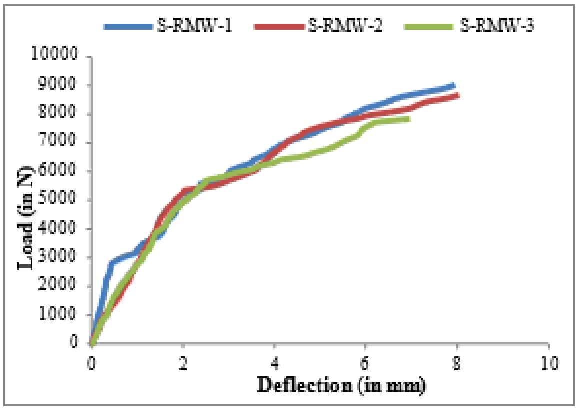

Fig.3 Load v/s Deflection plot for S-RMW specimens

The mean flexural strength of S-RMW specimen is 0.3654 N/mm^2.

A bar graph was also plotted to compare the strength of the different masonry wall specimens shown in Fig.4.

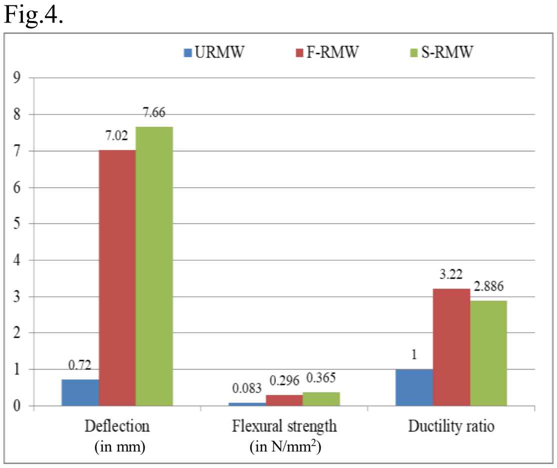

Fig.4 Comparison of structural performance of masonry wall specimens

V. CONCLUSIONS

On comparing the results, the following conclusions are drawn,

1. From the tensile test, the strength of Sisal FRP (17.657 N/mm^2) is found to be more than the Flax FRP (5.813 N/mm^2), that is, Sisal FRP has 2.04 times higher strength than the Flax FRP.
2. The flexural resistance of flax fibre reinforced masonry wall and sisal fibre reinforced masonry wall is 2.6 times and 3.4 times higher than the unreinforced masonry wall respectively.
3. The deflection of flax fibre reinforced masonry wall and sisal fibre reinforced masonry wall is 8.75 times and 9.64 times higher than that of unreinforced masonry wall respectively.
4. On comparing the masonry wall specimens strengthened using two different natural fibres, the flexural capacity of S-RMW (0.3654 N/mm^2) is 0.234 times higher than that of the F-RMW (0.2961 N/mm^2).
5. Similarly on comparing the mean ultimate deflection of strengthened specimens, the deflection of S-RMW (7.66 mm) is 0.091 times higher than that of the F-RMW (7.02 mm).
6. The ductility ratio of F-RMW (3.22) is 0.116 times higher than that of S-RMW (2.886).
7. The failure of masonry wall specimens occurred between the brick unit and mortar interface, showing the weak bond strength, and the crack propagation initiated from the soffit of the masonry wall specimens. Also, the applied load did not cause any damage or fracture in the FRP.

Hence on comparing the experimental results obtained it can be summarized that, the specimen S-RMW with higher flexural strength shows better load carrying capacity, but its lower ductility ratio indicates a brittle behaviour and limited deformation capacity. In contrast, the specimen F-RMW with lower flexural strength but higher ductility ratio provides improved energy absorption and flexibility, making it more desirable in applications where seismic resistance is critical.

Therefore, the results show that the strengthening material should be selected based on the functional requirements of the structure.

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