Evaluating the Impact Resistance Performance of Masonry Wallets Internally Reinforced With Waste Fibres

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ABSTRACT

The internal mortar reinforcement technique is gradually picking up the pace in the construction industry due to its proven performance in recent years. Nylon and coir fibres are becoming popular reinforcement materials for their favourable mechanical properties. Most of the previous studies have focused on concrete structures subjected to seismic loading. However, there is a rise in vehicle impacts on roadside structures and rockfall and debris flow impacts in hilly regions. A significant portion of the population still resides in masonry structures, which are more affordable to the common man than reinforced concrete structures. In the current study, a simple and cost-effective drop-weight impact testing machine was developed to evaluate the impact resistance of masonry wallets measuring 500 mm in length, 500 mm in breadth, and 120 mm in depth. Nylon (textile waste) and coir fibres (agro waste) were used for mortar reinforcement to strengthen the wallets, and a comparative analysis was carried out between the impact resistance of unreinforced and reinforced masonry. Coir fibres of 15 mm in length were added to the mortar at concentrations of 0.25%, 0.3%, and 0.4% by weight. Similarly, the nylon fibre's length was fixed at 18 mm and was added at concentrations of 0.15%, 0.2%, and 0.25%. The results showed that regardless of the type and concentration of fibres used, the flexural strength of all fibre-reinforced mortar prisms and the impact resistance of the masonry wallets were significantly enhanced. Therefore, it can be concluded that nylon and coir fibres effectively strengthen masonry structures against impact loading by internally reinforcing the mortar with fibres.

KEYWORDS

Masonry, impact, nylon, coir, fibre, strengthening

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INTRODUCTION

Masonry is one of the most widely used construction materials globally, particularly in developing countries where financial constraints often hinder the adoption of reinforced concrete (RC) structures. Masonry structures are especially popular due to their affordability, ease of construction, and the abundance of its constituent materials. Load-bearing masonry walls are extensively used in residential dwellings due to their good compressive strength, effective sound and heat insulation, and minimal labor requirements [1-3]. These walls serve as both load-bearing and non-load-bearing partition walls, with applications ranging from standalone walls to infill panels in RC-framed buildings. Depending on the orientation of the load, masonry walls are subjected to either in-plane loading, where the load is parallel to the surface, or out-of-plane loading, where the load is perpendicular to the wall's surface [4].

Brick masonry, a composite system of brick units and mortar joints, relies on the properties of these individual components and their interaction as one unit [5-8]. Despite its strengths, unreinforced masonry (URM) exhibits limited post-crack resilience, making it vulnerable to brittle failure. This weakness manifests in poor tensile and shear strength, inadequate bonding between adjacent walls, and susceptibility to bond failure at the critical brick-mortar interface under lateral loads [9-12]. These inherent deficiencies make masonry structures vulnerable to dynamic forces such as seismic events and impact loading.

Although much research has been carried out to improve masonry's resilience against lateral forces, the focus has predominantly been on seismic events. However, impact events such as vehicle collisions, rockfalls, and debris flow pose an increasingly significant threat to masonry structures. Unlike seismic or serviceable loads, impact loads involve high strain rates, presenting unique challenges in understanding and improving masonry's response to such forces [13]. Recent studies have focused on cost-effective solutions for masonry reinforcement, such as polypropylene (PP) fibres, textile-reinforced mortar, geogrids, and steel wire mesh [14-18]. These materials balance between affordability and improved structural performance, making them viable for broader application. Among these, natural and recycled fibres have emerged as promising alternatives.

Coir fibres, derived from coconuts, have significantly enhanced the mechanical properties of cementitious composites. They reduced the self-weight of structures by 5–12%, increased flexural strength by up to 12%, and improved toughness and ductility ninefold, demonstrating their efficacy in enhancing mortar tensile strength and crack control under seismic loads [19]. Similarly, recycled nylon fibres, obtained from waste products such as fishing nets and carpets, offer both environmental and structural benefits. Using nylon fibres in construction reduces landfill waste and mitigates marine pollution while also improving the mechanical properties of masonry. Studies have shown that nylon-reinforced mortar achieved a 19.7% increase in flexural strength and substantial enhancements in tensile strength and post-crack performance [19,20]. Further research demonstrated that incorporating nylon fibres into masonry mortar and plaster layers improved compressive strength by 28%, shear bond strength by 125%, and flexural strength by 150%. These improvements extended to in-plane and out-of-plane load-carrying capacities, which increased by 106.3% and 161%, respectively [8].

RESEARCH SIGNIFICANCE

Masonry structures are particularly vulnerable to dynamic incidents such as rockfalls and vehicle collisions, where sudden and intense impact forces can cause severe damage or complete structural failure. Due to their brittle nature and inadequate bond strength between mortar and bricks, masonry structures exhibit low flexural and shear strength. Sudden force generated due to impact within a short interval of time poses a significant risk of catastrophic failure, especially in the flexural direction. Despite the increasing frequency of such events, limited research has been conducted to understand the impact response of masonry structures and develop effective mitigation measures.

The present study addresses the critical gap by conducting a comprehensive experimental investigation to evaluate the impact resistance of masonry structures. Seven groups of masonry wallets were constructed, including one unstrengthened group of wallet acting as control wallet and six groups of reinforced wallets with varying concentrations of coir and nylon fibres. Additionally, mortar cubes and prisms were cast to evaluate compressive and flexural strengths, further examining the effectiveness of fibre reinforcement. The study focuses on critical parameters such as number of blows leading to the first crack and ultimate failure, impact energy exerted on the specimens and impact resistance of the specimens. By comparing the performance of unstrengthened and fibre-reinforced wallets, this research highlights the potential of coir and nylon fibres as cost-effective and practical reinforcement-strengthening materials. The findings aim to contribute to developing safer, more resilient masonry structures capable of withstanding dynamic loading scenarios.

EXPERIMENTAL PROGRAM

Experimental Design

Experimental investigations were conducted to evaluate the behavior of the unreinforced and reinforced masonry wallets under drop-weight impact loading. For this purpose, six groups of masonry wallets were fabricated. Additionally, 14 groups of mortar cubes and 14 groups of mortar prisms were prepared to determine the compressive and flexural strength of both unstrengthened and strengthened mortars.

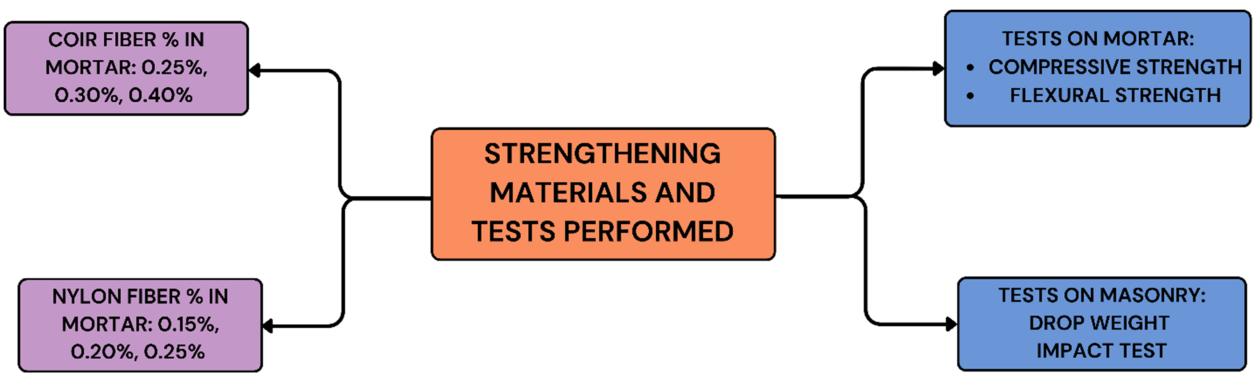


Figure 1: Experimental Plan of Drop Weight Impact Loading on Masonry.

The mortar cubes and prisms were tested at two curing intervals, 7 and 28 days, to assess the strength development over time. In total, 35 groups of specimens were cast and tested, with each group consisting of three individual specimens. The results presented in this study represent the average values for each group, supplemented by data from one representative specimen per group. The experimental setup and specimen arrangements are illustrated in Fig. 1.

Material Characterization

Brick and Sand

Fly ash bricks were used for constructing the wallets, and their physical and mechanical properties are summarized in Table 1. River sand from Zone II served as the fine aggregate, and its properties are detailed in Table 2.

Table 1. Physical and Mechanical Properties of Bricks.

Property	Value
Density	1800 kg/m^3
Dimension (mm)	230 × 110 × 80
Compressive strength (MPa)	8.23 (CoV: 6.9, SD: 0.48) (IS 13757:1993) [21]
Water absorption (%)	14.96 (CoV: 5.9, SD: 0.79)
Tensile strength (MPa)	0.91 (CoV: 6.2, SD: 0.07)

Table 2. Physical Properties of Sand.

Property	Value
Grading zone	II
Fineness modulus	2.7
Specific gravity	2.6
Water absorption	1.03%
Free surface moisture contact	0.49%
Bulk density	1.48 kg/m^3
Bulking of sand	10.30%

Strengthening Techniques

Coir fibre

Coir fibres, derived naturally from coconut husks, were untreated when purchased. These fibres were thoroughly cleaned, washed, and dried at room temperature before use. Based on prior research [22], these fibres have demonstrated significant mechanical properties, making them suitable for reinforcement.

Nylon fibre

Recycled nylon fibres, sourced from discarded fishing nets, carpets, and plastic ropes, were used as reinforcement materials due to their significant enhancement in load-carrying capacity and bond strength [19,20]. Their physical and mechanical properties, as provided by the manufacturer, are listed in Table 3.

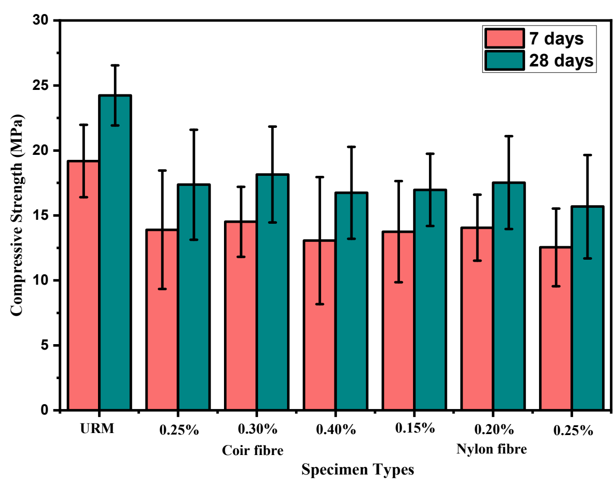
Table 3. Physical and Mechanical Properties of Fibres.

Fibre	Property	Value
Coir	Length	15 mm
	Diameter	0.20 mm
	Aspect ratio	75
	Tensile strength	180 MPa
Nylon	Length	18 mm
	Effective diameter	25 – 40 µ
	Specific gravity	1.12-1.15 g/cc
	Tensile strength	400 MPa
	Melting point	220 ℃

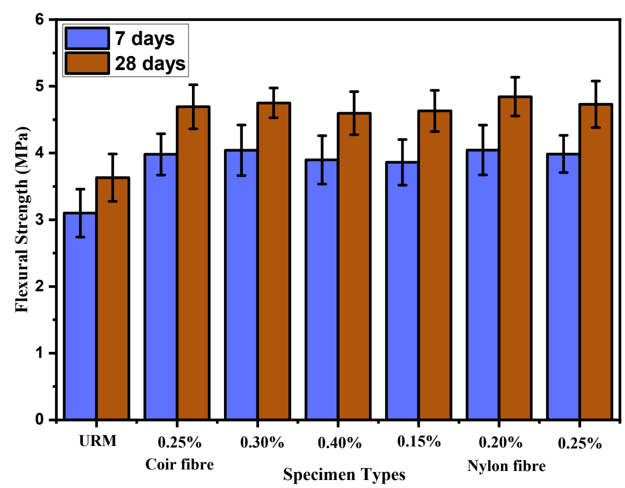
Mortar

The mortar mix was prepared using a cement-to-sand ratio of 1:4. The cement and sand were thoroughly dry-mixed initially. Following this, the fibres were added and uniformly blended into the mixture. Coir fibre was incorporated at concentrations of 0.25%, 0.3%, and 0.4% by weight of the control mortar, while nylon fibre was added at 0.15%, 0.2%, and 0.25% by weight. Water was gradually introduced during the final stage to achieve a consistent mixture. Compressive and flexural strength tests were conducted on mortar cubes and prisms at 7 and 28 days to evaluate the effectiveness of fibre reinforcement. Mortar cubes measuring 70.6 mm × 70.6 mm × 70.6 mm and prisms of 500 mm × 100 mm × 100 mm were cast according to standard testing guidelines. As shown in Fig. 2, a slight decrease in compressive strength was observed in the fibre-reinforced mortars. The compressive strength of the specimens reinforced with coir and nylon fibres decreased by up to 25.12% and 35.3%, respectively, across all tested samples. In contrast, fibre addition significantly improved flexural strength, as depicted in Fig. 2. The flexural strength of coir and nylon fibre-reinforced specimens increased by up to 30% across all fibre concentrations.

The reduction in compressive strength for fibre-reinforced mortar cubes can be attributed to increased porosity caused by adding fibres and the corresponding reduction in cement content. However, this decrease has a negligible effect on the structural integrity of masonry, given its inherent strength in enduring compressive loads. Conversely, fibre reinforcement led to notable improvements in flexural strength, significantly enhancing the lateral load-carrying capacity and resistance to flexural stresses. These findings affirm the suitability of coir and nylon fibre for improving the structural performance of masonry under lateral loads.



(a)



(b)

Figure 2: (a) Variation in Compressive Strength for Unreinforced and Fibre-Reinforced Cubes; (b) Variation in Flexure Strength for Unreinforced and Fibre-Reinforced Prisms.

Construction Details

In this study, fly ash bricks were used to construct masonry wallets with dimensions of 500 mm × 500 mm × 120 mm. The mortar used for joints and plastering was prepared with a cement-to-sand ratio of 1:4. The present study investigated masonry strengthening using nylon and coir fibres incorporated into the control mortar mix to assess their performance under drop weight impact tests.

The nylon and coir fibres were mixed with the cement and sand to produce a reinforced mortar applied to the masonry. This reinforced mortar resulted in a composite material with improved mechanical properties. The construction of each masonry wallet involved laying six layers of bricks, with two bricks per row. The bed and head joint thickness and the plastering layers were maintained at 10 mm for the wallets. Following the casting process, the masonry wallets were cured in a water tank for 28 days to ensure sufficient strength development before the experiments were conducted.

EXPERIMENTAL SETUP

Drop weight test

A drop-weight impact test setup was designed and locally fabricated for this study to evaluate the impact resistance of masonry wallets. The specimens were securely placed on the floor of the setup, with a hardened steel ball measuring 130 mm fixed to the top face of the wallet. A hammer weighing 4.54 kg was then released from a height of 300 mm, as illustrated in Fig. 3. The hammer was guided to strike the center of the specimen. The test involved subjecting the specimen to repeated impacts, with the hammer systematically delivering successive blows. During the experiment, the number of blows required to initiate the first visible crack in the specimen was carefully recorded. Additionally, the number of blows leading to the ultimate failure or complete fracture of the specimen was also documented. This process provided valuable insights into the material's impact resistance and fracture behavior.

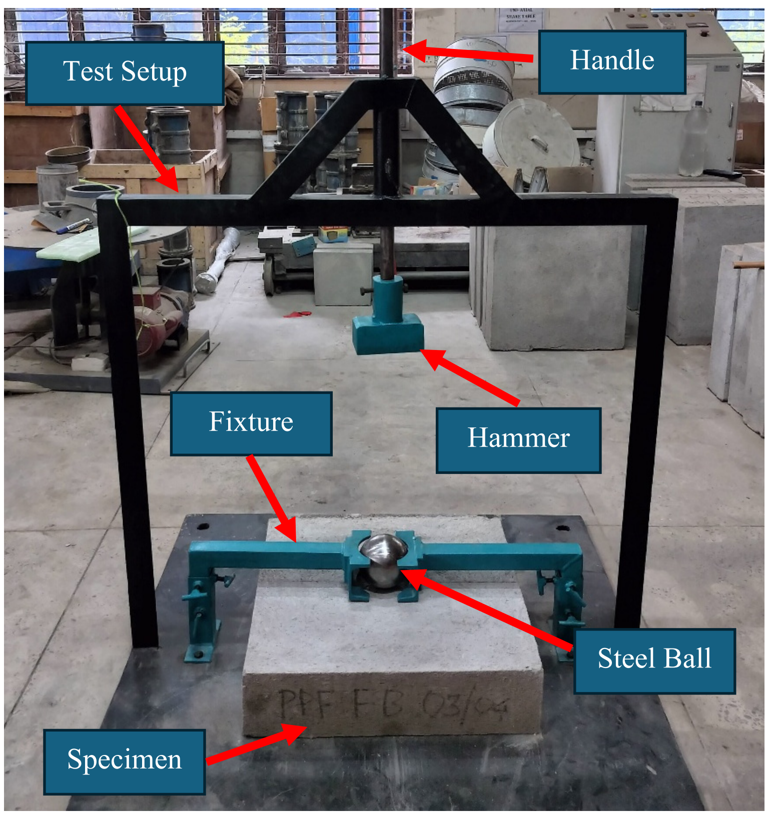


Figure 3: Drop Weight Test Setup.

RESULTS AND DISCUSSIONS

The impact strength results, expressed in terms of the number of blows required for the first crack impact (N1) and ultimate load impact (N2), along with the coefficient of variation (COV) for all masonry specimens, are presented in Table 3. Fig. 4 illustrates the variation in N1 and N2 across different masonry specimens. The findings indicate that the addition of coir and nylon fibres significantly improved both impact loads.

Table 3. Results of first cracking and ultimate failure load.

Specimen Type	First Crack (No. of blows, N_1)	COV%	Ultimate failure (No. of blows, N_2)	COV%	RNPB	N_2/N_1	U = mghN
URM	6	18.1%	6	23.3%	-	1	80.16
Coir (0.25%)	11	6.5%	17	7.5%	6	1.54	227.14
Coir (0.30 %)	15	8.3%	22	13.6%	7	1.46	293.94
Coir (0.40 %)	13	10.4%	20	13.1%	7	1.53	267.22
Nylon (0.15 %)	9	10.8%	14	10.9%	5	1.55	187.05
Nylon (0.2 %)	10	6.9%	19	14.5%	9	1.9	253.86
Nylon (0.25 %)	10	5.5%	17	8.3%	7	1.7	227.14

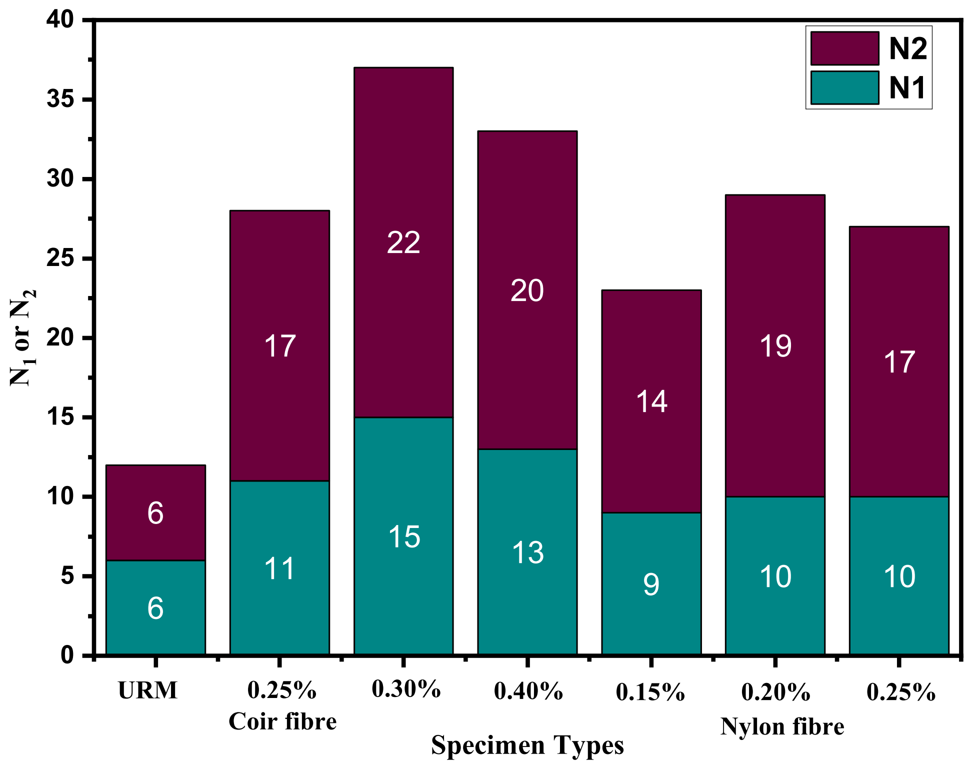
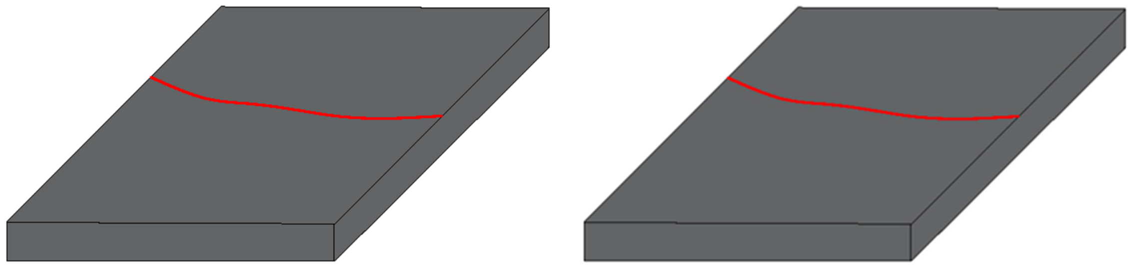


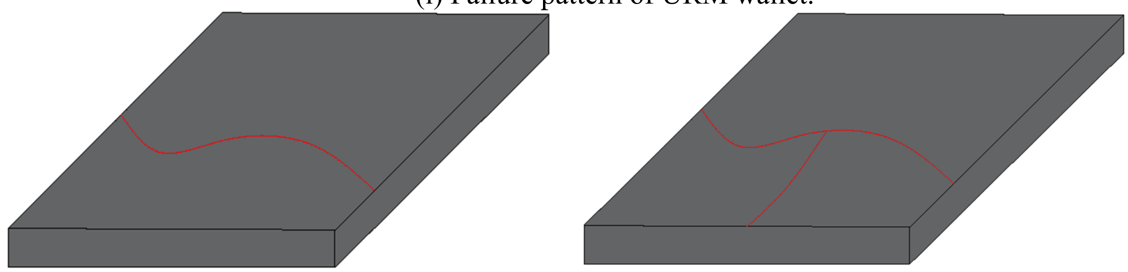
Figure 4: Variation of impact loads for all the specimens.

The control specimen, when subjected to impact loading, primarily failed due to the formation of a single dominant crack. However, the number of cracks increased with the addition of fibres, causing the specimen to fracture into three or four segments, as shown in Fig. 5. This behaviour can be attributed to the fibre's ability to enhance the composite concrete's toughness. The 0.30% coir and 0.20% nylon fibre weight concentrations provided sufficient resistance against both first crack and ultimate load impacts. Specifically, the first crack impact (N1) improved by 150% and 67% for coir and nylon fibres, respectively, while the ultimate load impact (N2) improved by 267% and 216%. This enhancement is primarily due to the bridging effect of fibres, which enhances crack resistance and energy dissipation.



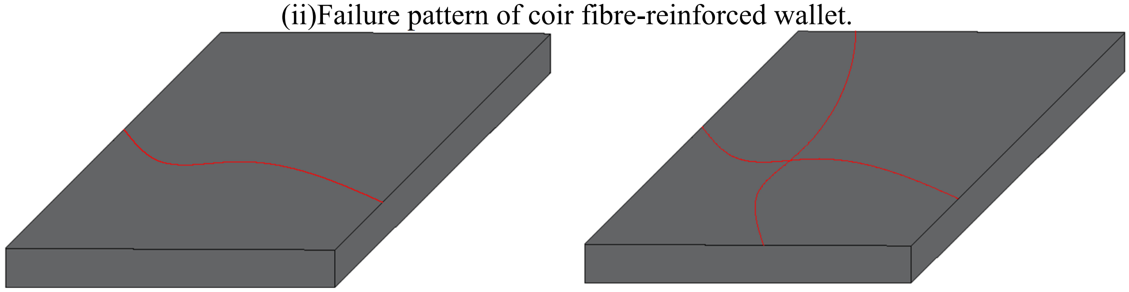
(a) First crack (b) Ultimate failure

(i) Failure pattern of URM wallet.



(a) First crack (b) Ultimate failure

(ii)Failure pattern of coir fibre-reinforced wallet.



(a) First crack (b) Ultimate failure

(iii) Failure pattern of nylon fibre-reinforced wallet.

Figure 5: Typical failure pattern of the unreinforced and reinforced specimens.

Fig. 6 presents the results for the rise in the number of post-initial crack blows (RNPB) for all tested mixes. The variation in RNPB was analyzed to better understand the bridging behaviour of different fibre weight concentrations under repeated impact loads. No RNPB was recorded for the control mix due to its inherently brittle nature, which resulted in sudden failure without prior warning, as both the first and ultimate cracks occurred at the same blow. However, different RNPB values were recorded depending on the fibre percentage for specimens reinforced with coir and nylon fibres, as presented in Fig. 6.

Another key indicator studied was the impact strength improvement ratio (N2/N1) after the first crack. Table 3 presents the variation of N2/N1 across unstrengthened and strengthened masonry wallets. The results demonstrate a significant increase in impact strength after the first crack for all fibre-reinforced masonry samples, regardless of fibre fraction volume. The control sample exhibited an N2/N1 ratio of 1.00, indicating no improvement in impact strength beyond the first crack. In contrast, fibre-reinforced specimens showed substantial increases in impact resistance, confirming the effectiveness of fibre reinforcement in improving structural performance under impact loading. The impact energy delivered per blow by the hammer was calculated using Eq. (1) and is illustrated in Fig. 7. Among the tested specimens, the 0.30% coir fibre volume demonstrated the highest impact energy absorption, as evidenced by the maximum number of blows it endured. This result highlights that coir fibre reinforcement is particularly effective in enhancing the impact resistance of masonry structures.

(1) $U = m \times g \times h \times N$

Where, U = impact energy exerted on the specimen m = mass of the hammer, g = acceleration due to gravity (9.81 m/s^2), h = drop height of the mass, N = total number of blows

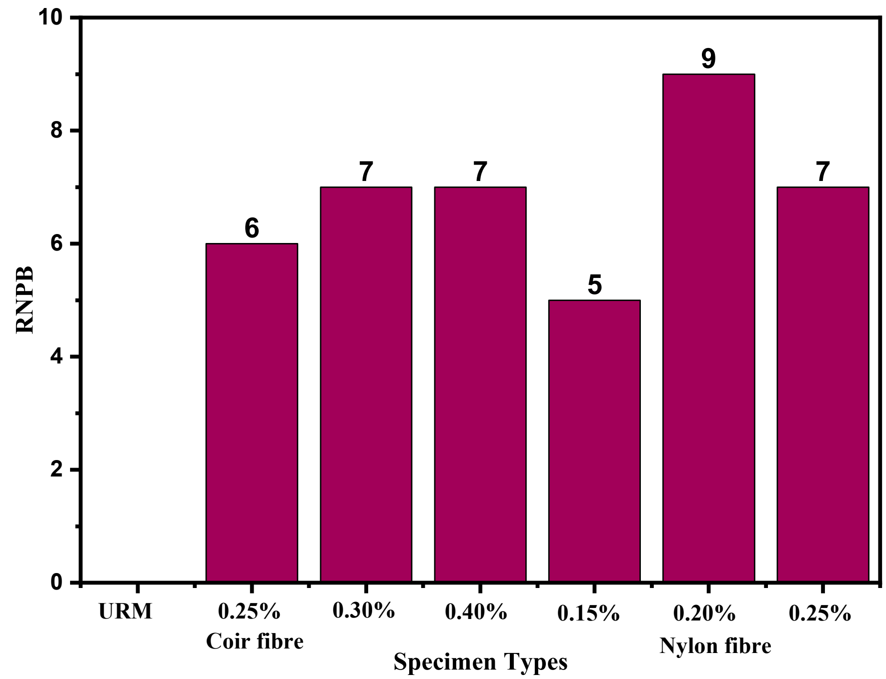


Figure 6: Variation of rise in the number of post-initial crack blows (RNPB) for all tested mixes.

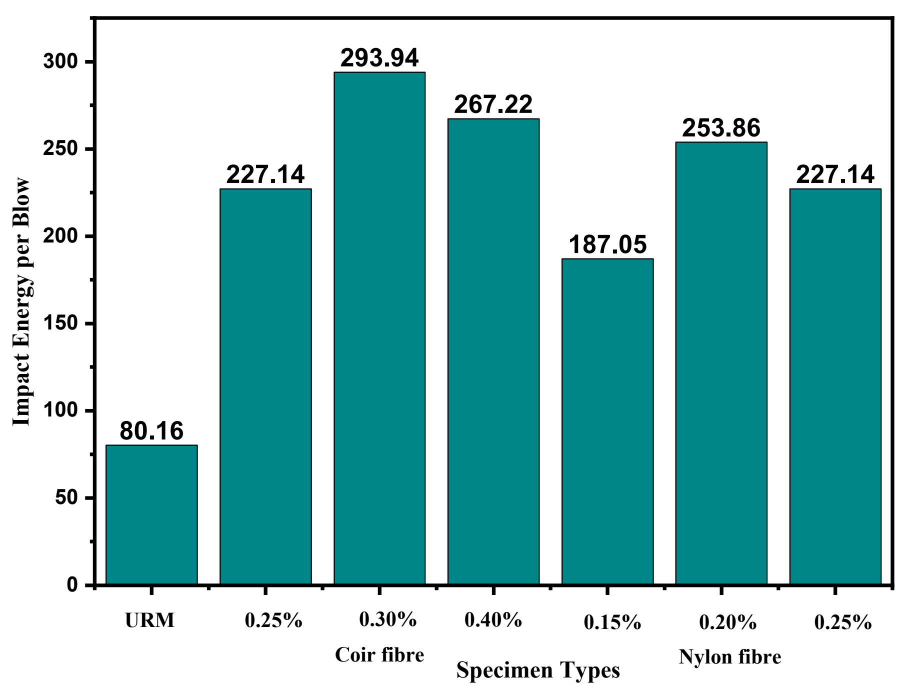


Figure 7: Variation in energy exerted per blow for all test specimens.

CONCLUSIONS

This study explored the drop weight impact loading behavior of masonry wallets constructed with fly ash bricks through a two-phase experimental program. The first phase involved casting unreinforced and reinforced mortar cubes and prisms, while the second phase focused on constructing wallets, including an unstrengthened control wallet and strengthened wallets reinforced with coir and nylon fibres. A comparative analysis evaluated their performance based on the number of blows leading to the first crack and ultimate failure, impact energy exerted on the specimen per blow, and overall impact resistance. The key findings from the study are as follows:

1. Including coir and nylon fibres in mortar cubes reduced compressive strength by up to 34.6% and 35.3% at 7 and 28 days, respectively. However, the flexural strength of reinforced mortar prisms improved significantly, increasing by 30.4% and 33.4% at the same intervals.
2. The fibre-reinforced wallets exhibited enhanced impact resistance, withstanding greater impacts than the unstrengthened wallet. Among the tested specimens, those reinforced with 0.30% coir fibre and 0.20% nylon fibre performed remarkably well than the other specimens.
3. The optimal fibre weight concentrations—0.30% for coir and 0.20% for nylon, provided sufficient resistance against both first crack and ultimate load impacts. Specifically, first crack impact (N1) improved by 150% and 67% for coir and nylon fibres, respectively, while ultimate load impact (N2) increased by 267% and 216%.
4. Among all tested specimens, the wallet reinforced with 0.20% nylon fibre demonstrated the highest rise in the number of post-initial crack blows (RNPB), indicating superior durability after the first crack formation.
5. The 0.30% coir fibre-reinforced wallet exhibited the highest impact energy absorption, as it endured the maximum number of blows before failure.

Overall, the fibre-reinforced wallets significantly performed better than the unstrengthened wallet in terms of impact resistance, delaying ultimate failure and withstanding higher impact energy. Additionally, using fibres derived from agro and textile waste enhanced structural performance and promoted environmental sustainability, reinforcing the potential for eco-friendly construction practices.

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