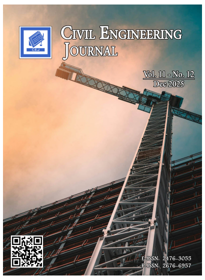
Available online at www.CivileJournal.org

Civil Engineering Journal

(E-ISSN: 2476-3055; ISSN: 2676-6957)

Vol. 11, No. 12, December, 2025



The Effect of Fiberglass Paint Coating on the Shear and Flexural Strength of Concrete Blocks

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Received 20 June 2025; Revised 04 November 2025; Accepted 12 November 2025; Published 01 December 2025

Abstract

This study uses an experimental method to investigate the behavior of concrete blocks coated with fiber paint, focusing on their shear and flexural strength, ductility, stiffness, and energy dissipation to enhance their mechanical performance. The fiber paint coatings used in this study were applied in different thicknesses, namely 1 mm, 2 mm, and 3 mm. The results show that a 3 mm coating provided the highest improvement, with shear and flexural strengths increasing by 47.36% and 66.06%, respectively. Flexural ductility improved by up to 32%, while stiffness increased by 12% in flexure and 13% in shear. Energy dissipation also showed significant enhancement; total flexural energy increased from 1.38 kNmm to 10.76 kNmm at 3 mm, and shear energy dissipation reached 50.72 kNmm at 3 mm. These results confirm that fiber paint can enhance the shear and flexural strength, ductility, stiffness, and energy dissipation of concrete blocks. This study introduces fiber paint as a practical reinforcement method for concrete block materials, offering a simple, easy-to-apply, and cost-effective alternative that improves both mechanical and aesthetic performance.

Keywords: Concrete Blocks; Fiber Paint; Fiberglass; Shear Strength; Flexural Strength.

1. Introduction

In buildings, masonry functions as room dividers and provides protection for occupants from external disturbances such as weather. National regulations often designate masonry as a non-structural component, so its design is often not given sufficient structural consideration. Damage to masonry often occurs due to the lack of sufficient structure to support the walls against the lateral direction of the earthquake. The material commonly used in the construction of masonry walls is brick, which includes clay bricks/red bricks, lightweight concrete blocks (AAC/hebel), and concrete blocks [1–4].

Concrete blocks are one type of building material used for constructing walls. They are produced from Portland cement, sand, water, and aggregates, and unlike red bricks that undergo a firing process, they are only sun-dried. As an alternative to red bricks, concrete blocks have gained popularity in residential construction due to their ease of installation and low cost, especially in developing countries. In general, concrete blocks exhibit higher strength and density compared to red bricks; however, this may vary depending on production processes and mix proportions [5, 6]. For example, the compressive strength of blocks in the Philippines is reported to be only 10% of those in Japan [7]. In Indonesia, earthquake damage records often show flexural and shear failures, as well as damage to non-structural components, primarily due to the low strength of concrete blocks [3, 8].

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http://dx.doi.org/10.28991/CEJ-2025-011-12-04

Cracking and collapse are prevalent forms of deterioration in masonry walls, characterized by cracks or diagonal fractures in the masonry plane. Damage to masonry walls may result from the materials employed in their construction and inconsistencies in the brick mixture. Moreover, the low level of awareness regarding building regulations is one of the factors contributing to the large number of constructions that do not meet safety standards in earthquake-prone areas. Juliafad & Andayono (2020) [9] reported that approximately 70% of building officials in West Sumatra lacked adequate technical competence, and 80% had never read the main regulation related to building permits. This condition indicates weaknesses in the implementation of technical policies, causing construction quality to often rely on field practices without strict supervision. In this context, efforts to enhance building resilience should be supported not only through regulations but also through strengthening innovations that are simple, affordable, and applicable to existing buildings. Therefore, wall strengthening emerges as a practical approach to mitigate damage in masonry structures [10]. The wall reinforcement methods implemented include polypropylene band mesh, Textile Fiber Composite, interlocking with Petung bamboo, and interlocking with steel reinforcement, among others [11–14].

Umair et al. (2015) conducted research that provided a solution through the development of composite materials utilizing FRP and polypropylene (PP-band). PP-band is a low-cost material with good ductility, and when combined with FRP, it can enhance not only the initial strength but also the ductility, deformation capacity, and residual strength of URM walls. Experimental results indicated that the FRP + PP-band composite is more effective in the seismic performance of URM compared to the use of FRP or PP-band individually [11]. Boen et al. (2021) proposed the use of Textile Reinforced Concrete (TRC) and Fiber Reinforced Cementitious Matrix (FRCM) as alternatives for masonry wall strengthening. These materials are mortar-based composites with textiles or discontinuous fibers that can enhance the tensile strength, ductility, and deformation capacity of structures. Experimental studies have shown that TRC and FRCM can improve structural performance, including stiffness, toughness, and resistance to damage [12].

Previous studies have explored the use of interlocking techniques to improve the mechanical performance of brick masonry. Rino & Juliafad (2023) investigated the application of bambu petung as an interlocking element, reporting significant improvements in compressive, shear, and especially flexural strength, with shallower interlocking depth (0.5 cm) yielding better performance than deeper penetration. This approach highlights the potential of locally available, low-cost, and sustainable materials for wall strengthening [14]. However, the use of raw bamboo still faces challenges, including susceptibility to fungi, pests, humidity, and dimensional changes due to environmental conditions [15, 16]. In contrast, Junior & Juliafad (2022) examined the use of plain steel bars (BJTP Ø6) as interlocking reinforcement. Their experimental results showed that while shear strength improved, compressive strength decreased compared to unreinforced specimens. Nonetheless, compressive strength exhibited varying gains depending on the penetration depth, with the highest improvement (31%) observed at 0.5 cm. Both studies emphasize that interlocking, whether using natural or steel-based materials, can enhance the structural behavior of brick masonry, although further investigations are required, particularly regarding flexural performance and long-term durability [13].

Multazam et al. (2025) reported that the application of reinforcement (rebar) in hollow block concrete masonry with weak structural performance significantly improved its seismic behavior, particularly in terms of deformation resistance and earthquake energy absorption capacity [17]. Similarly, Wang et al. (2025) investigated unreinforced masonry (URM) walls strengthened with surface-applied basalt fiber mortar under different loading conditions. Their results indicated that specific reinforcement strategies could enhance energy dissipation while simultaneously delaying stiffness degradation [18]. In another study, Yavartanoo et al. (2025) examined the strengthening of dry-stack masonry walls using fiber-reinforced polymer (FRP) bars, demonstrating that different reinforcement configurations (horizontal, vertical, and diagonal) effectively increased lateral load-bearing capacity, stiffness, and energy dissipation capacity in a cost-efficient manner [19]. Moreover, Tekeli et al. (2024) analyzed the hysteretic behavior of reinforced concrete frames with masonry infill strengthened by stucco containing rebar. Their findings highlighted improvements in energy dissipation as well as effective control of damage in regions around openings [20].

Some materials used in previous research are difficult to obtain and require relatively high costs. Methods such as polypropylene band mesh are challenging to install and still require a mortar coating to improve the wall's appearance and durability against environmental effects like heat and rain [21]. In addition, existing strengthening techniques also demand considerable implementation time and involve a wide variety of material types. Ideally, wall strengthening in developing countries should be able to improve the strength and deformation capacity of buildings while considering several characteristics, including the assured availability of materials, ease of application (meaning that it can be carried out by the community), cultural acceptance and adaptability, as well as economic affordability. Considering the building safety issues and reinforcement criteria discussed above, this study proposes a method for the seismic reinforcement of concrete block walls, commonly used in residential and low-rise buildings, through the application of fiber-reinforced paint. In this study, the fiber paint was mixed with fiberglass. Fiberglass is a synthetic liquid glass formed into thin, strong fibers with a diameter of approximately 0.005 mm to 0.01 mm, which are then woven into yarn or fabric. The fiberglass is infused with resin to increase its strength and durability. Fiberglass paint can serve as a method for reinforcing masonry walls due to its simple application [17, 22, 23].

Research on fiber paint as a wall-strengthening material is still limited in Indonesia. Yamamoto et al. (2020) investigated the use of fiber-reinforced paint for wall strengthening in Japan [24]. Similarly, Juliafad et al. (2024) studied the application of fiberglass and polypropylene fibers on red brick masonry, demonstrating that combining fiberglass with waterproof paint at an 8% fiber ratio and a 3 mm coating thickness significantly improved both compressive and shear strength [10]. However, this research was limited to red brick materials. Therefore, further studies are needed to investigate the use of fiberglass paint for strengthening concrete blocks. This study aims to evaluate the effect of fiberglass fiber paint on the shear and flexural strength, ductility, stiffness, and energy dissipation of concrete blocks. Juliafad et al. (2019) demonstrated that the application of carbon fiber strips could effectively restore and enhance the performance of fire-damaged reinforced concrete beams, highlighting the potential of fiber composites in structural rehabilitation [25]. Building on this concept, the present study applies a similar strengthening approach to masonry walls, but with the use of fiber paint as an alternative. The novelty of this research lies in the method developed as an alternative technique for reinforcing concrete block walls through the application of fiber paint-based coatings. This approach is expected to meet the criteria of being simple to apply, cost-effective, and aligned with common community practices where painting buildings is a regular activity. Thus, fiberglass paint not only improves structural performance but also enhances the aesthetics and surface finish of walls.

2. Materials and Experimental Methods

2.1. Materials

The materials used in this study were Concrete Block, paint, and fiberglass.

2.1.1. Concrete Block

According to SNI 03-0349-1989, a concrete block is a brick-like construction component composed of Portland cement, water, and aggregate utilized in wall masonry. Concrete Block is categorized into two varieties based on its shape: hollow Concrete Block (hollow block) and non-hollow Concrete Block (solid block) [5, 6]. Nofriadi (2021) asserted that a Concrete Block is a type of molded stone composed of a mixture of trass, lime, and water, or a combination of cement, lime, sand, and water in a viscous state, shaped into blocks of predetermined dimensions [26]. High-quality blocks should have a compact, dense pore structure and be free from surface cavities. The surface should be level and smooth. The edges must be sharp and able to resist damage from hand pressure (SNI 03-0349-1989) [5].

SNI 03-0349-1989 stipulates the following quality requirements for concrete blocks: the surface area must be impeccable. Alternative surface configurations are allowed. The ribs intersect at right angles, and the rib angles cannot be readily straightened by manual force. Concrete blocks must conform to the dimensions specified in Table 1 of SNI 03-0349-1989.

Table 1. Concrete blocks Size According to SNI 03-0349-1989

Type	Size			Minimum Hole Wall Thickness	
	Length (mm)	Width (mm)	Thickness (mm)	Outside (mm)	Inside (mm)
Solid	390 + 3 − 5	90 ± 2	100 ± 2	-	-
Small hole	390 + 3 − 5	190 + 3 − 5	100 ± 2	20	15
Big hole	390 + 3 − 5	190 + 3 − 5	200 ± 2	25	20

According to SNI 03-0349-1989, Concrete blocks must have the following physical requirements (see Table 2).

Table 2. Physical Requirements of Concrete Blocks According to SNI 03-0349-1989

Physical Requirements	Unit	Solid Brick Quality Level				Quality Level of Hollow Bricks			
		I	II	III	IV	I	II	III	IV
Minimum average gross compressive strength	kg/cm^2	100	70	40	25	70	50	35	20
Gross compressive strength of each test object	kg/cm^2	90	65	35	21	65	45	30	17
Gross compressive strength of each test object	%	25	35	-	-	25	35	-	-

2.1.2. Fiberglass Fiber Paint

Fiberglass fiber paint is a composite of paint and fiberglass filaments. Fiberglass is a manufactured liquid glass drawn into slender, robust fibers with a diameter ranging from around 0.005 mm to 0.01 mm, subsequently woven into yarn or fabric. Fiberglass is infused with resin to enhance its strength and durability, and glass fiber is the predominant fiber utilized in polymer composites for structural applications. It is more economical than carbon and aramid fibers. Most commercially available glass consists of silica (SiO). Glass fibers or filaments are created by extruding molten glass through apertures, resulting in around 200 filaments constituting a strand. The strands are processed into fabric rovings or mats for convenient handling [22, 23, 27, 28].

Yamamoto et al. (2014) conducted the first test of fiber paint as a reinforcement for brick walls. The research employed a fiber-reinforced coating known as SG-2000. SG-2000 is a coating composed of conventional acrylic-silicone resin paint and fiberglass. The experiment involved constructing a small house, applying SG-2000 to the interior and exterior walls with a thickness of 1 mm and fiber content of 1.5% of the paint's weight, followed by agitation using a shake table apparatus at IIS, University of Tokyo. The shaking table measures 1.5 m × 1.5 m, with 6 degrees of freedom, and can generate waves between 0.1 and 50 Hz. The test concluded that the reinforcement material does not enhance structural strength. However, the SG-2000 holds the bricks together after the mortar seams rupture. SG-2000 enhances the structure's deformation and energy dissipation capability, making it resilient to significantly larger ground movement [29]. Juliafad et al. (2024) have also investigated the application of fiberglass paint as a wall reinforcement layer. Juliafad et al. (2024) conducted a study in which red bricks were coated with fiberglass paint to evaluate their compressive and shear strength. The study determined that the enhancement in shear strength between the control test specimen and the fiberglass paint reinforcement specimen against red bricks was 1.34% for a thickness of 1 mm, 30.47% for 2 mm, and 26.34% for 3 mm [10].

2.2. Experimental Methods

This work employs an experimental method to assess the shear strength and flexural strength of Concrete Block material by applying fiberglass fiber paint to its surface layer. The flow diagram of this investigation is illustrated in Figure 1.

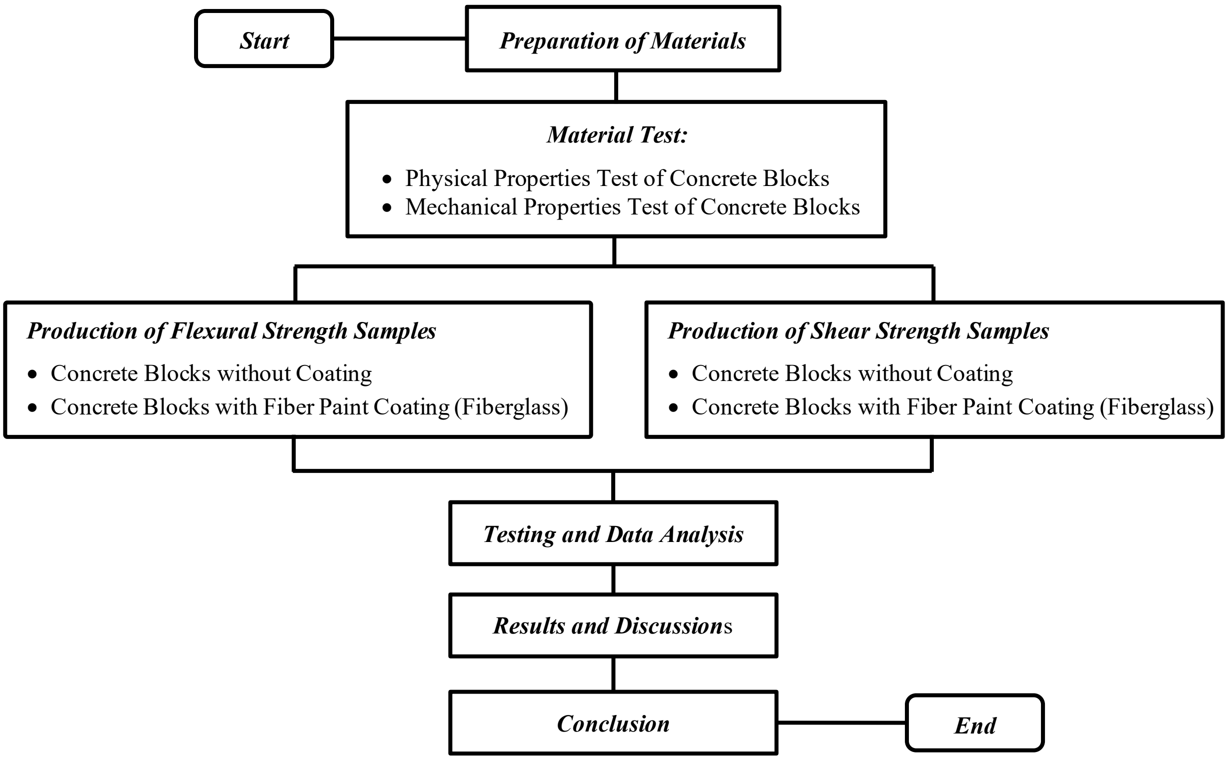

Figure 1. Research Flowchart

2.2.1. Inspection of Concrete Block Characteristics

This examination seeks to ascertain the attributes of the bricks utilized in the study, wherein the standard physical characteristics of bricks, as per SNI 03-0349-1989, stipulate that the surface must be impeccable, the ribs must form right angles with one another, the right angles should not be easily altered by finger pressure, and the bricks must be composed of a mixture of cement, sand, and water, exhibiting a grayish-white hue when dry [5].

Furthermore, it is essential to verify the specific gravity of the bricks as stipulated by SNI 15-2094-2000; the specific gravity of red brick masonry is 1700 kg/m³. This brick testing will adhere to the SNI 15-2094-2000 standard due to the absence of a defined standard for the specific gravity of bricks [5, 30]. Figure 2 presents the process of testing the characteristics of Concrete Blocks.

(a) Measuring Brick Dimensions (b) Soaking the Bricks (c) Saturated Weight Weighing

(d) Drying of Bricks (e) Sample Drying With an Oven (f) Surface Dry Saturated Weight Weighing

Figure 2. Concrete Block characteristics inspection process

Figure 3 shows the granulation diagram of the used material (fine aggregate). Based on the sieve analysis results according to ASTM C136-06 [31], the sand gradation curve (blue line) lies between the minimum (red line) and maximum (green line) limits specified by ASTM C33 [32], indicating that the particle size distribution of the fine aggregate is within the required range. This means the tested sand is well-graded, neither too coarse nor too fine, and can therefore be used as fine aggregate in concrete or mortar mixtures, as it provides good workability, reduces voids, and enhances the overall strength of the mix.

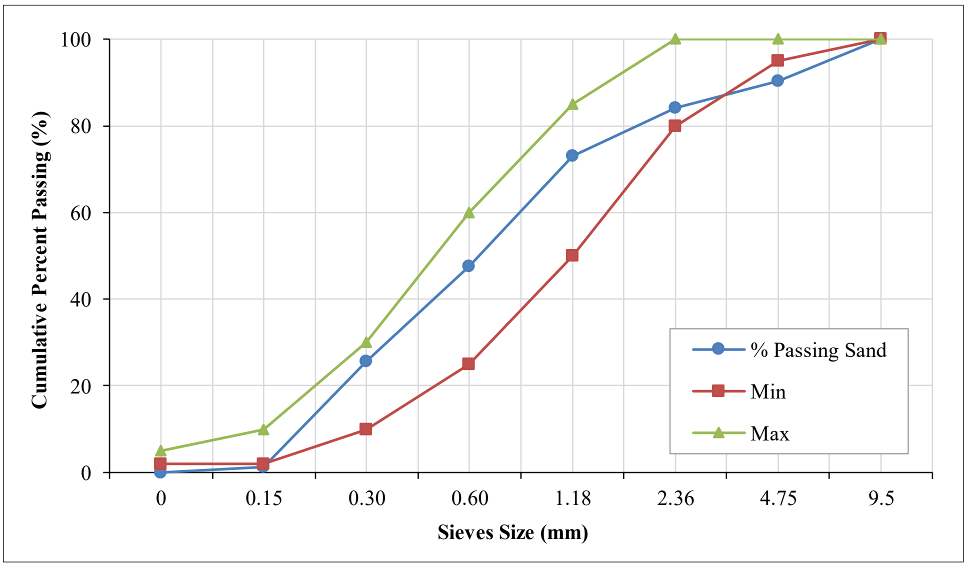

Figure 3. Fine Aggregate Granulation Diagram

2.2.2. Sample Production

The flexural test specimens in the study comprised 12 samples: uncoated bricks and bricks coated with 8% fiberglass fiber paint at layer thicknesses of 1 mm, 2 mm, and 3 mm, with three samples produced for each type. The shear test comprised 16 samples: uncoated bricks and bricks coated with 8% fiberglass fiber paint at 1 mm, 2 mm, and 3 mm, with four samples for each type. Each sample type is assigned a code: control bricks (without fiber paint covering) are flexural samples as "LN," and shear samples as "GN." Samples with a fiber paint coating are designated as LFG for flexural and

GFG for shear. A numerical designation is assigned based on the layer's thickness to differentiate the code corresponding to each thickness level. For instance, flexural and shear samples coated with a 1 mm thick fiber paint are designated LFG 1 and GFG 1, respectively. The specifications of the test objects are presented in Table 3.

Table 3. Types of Samples

No.	Type	Code	Test Type	Materials	Number of Samples
1	Concrete Block Control (without coating)	LN	Flexural	Concrete Block	3
		GN	Shear		4
2	Concrete Block with 8% Fiberglass Paint Coating, 1 mm Thickness	LFG 1	Flexural	Concrete Block, Fiberglass Paint 1 mm	3
		GFG 1	Shear		4
3	Concrete Block with 8% Fiberglass Paint Coating, 2 mm Thickness	LFG 2	Flexural	Concrete Block, Fiberglass Paint 2 mm	3
		GFG 2	Shear		4
4	Concrete Block with 8% Fiberglass Paint Coating, 3 mm Thickness	LFG 3	Flexural	Concrete Block, Fiberglass Paint 3 mm	3
		GFG 3	Shear		4
Total Number of Samples					28

Fiberglass Paint Production

The fiberglass utilized in this investigation was the Fiberglass/Fiber Matt brand, possessing a specific gravity of 0.31 g/cm³ and a length of 53 mm. The paint utilized is Nippon Paint Elastex Waterproof 3-in-1, combined with fiberglass fibers. The fiber content constitutes 8% of the paint's weight. The procedure for preparing fiberglass paint is illustrates in Figure 4.

(a) Fiberglass Preparation (b) Weighing Paint and Fiberglass (c) Mixing Paint and Fiberglass

Figure 4. Fiberglass Paint Production Process

Flexural Strength Samples Production

Flexural test specimens were fabricated by coating entire concrete blocks' upper and lower surfaces. Figure 5 illustrates the sample fabrication procedure for flexural testing. The design of the flexural samples is presented in Figures 6 and 7.

(a) Coating Samples with Fiber Paint (b) Dry Samples Ready to Test

Figure 5. Flexural Strength Samples Production Process

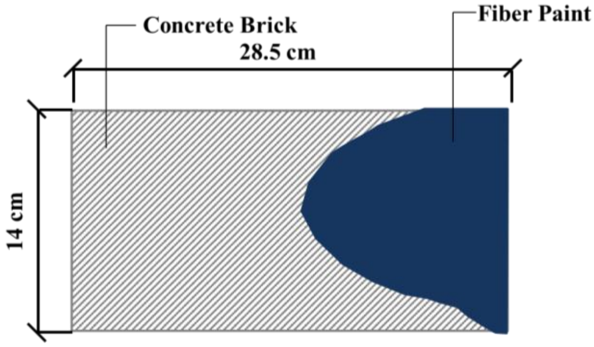

Figure 6. Flexural sample with fiber paint coating

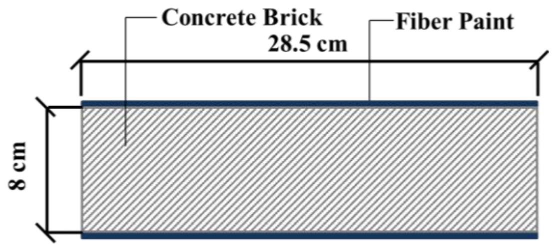

Figure 7. Flexural sample with fiber paint coating

Shear Strength Samples Production

Shear test specimens were created by dividing a concrete block and applying a coating to the upper and lower surfaces. Figure 8 displays the sample manufacturing procedure for shear testing. Shear photographs are presented in Figures 9 and 10.

(a) Sample cutting (b) Coating Samples with Fiber Paint (c) Dry Samples Ready to Test

Figure 8. Shear Strength Samples Production Process

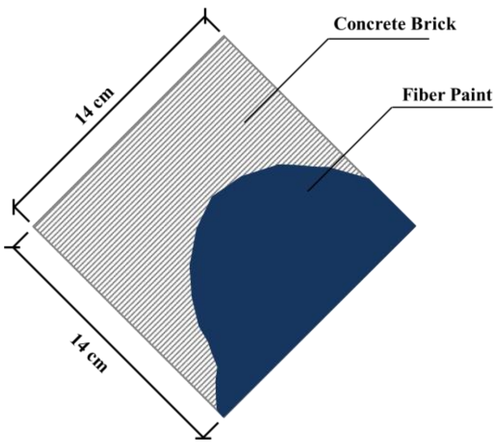

Figure 9. Shear sample with fiber paint coating

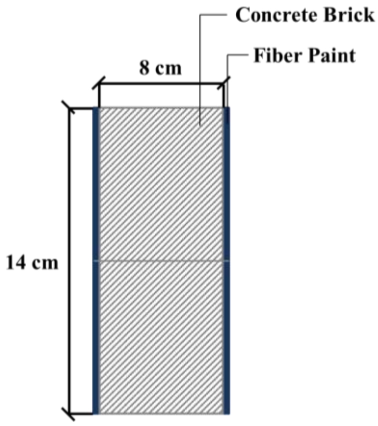

Figure 10. Shear sample with fiber paint coating

2.2.3. Experimental Design

Flexural Strength

According to SNI 03-4165-1996, the flexural strength of brick masonry walls is defined as the flexural force exerted on the wall masonry per unit area of the cross-section subjected to bending. The test specimen will undergo evaluation until it fractures or attains the maximum load of the testing apparatus, resulting in a graph depicting the correlation between stress and strain. The flexural strength assessment of brick masonry will adhere to the standards established in SNI 03-4165-1996 for brick masonry walls. The flexural strength of brick masonry can be derived from the maximum load value obtained using graph analysis using Equation 1 [33].

$$F_{lt} = \left(P_u + \frac{W}{2}\right) \times \left(\frac{1}{4}\right) \times \left(\frac{c}{I}\right) \tag{1}$$

F_{lt} represents the flexural strength (N/mm²), Pu denotes the maximum load (N), W indicates the weight of the tool (N), c signifies the distance from the neutral line to the surface (mm), and I refer to the moment of inertia of the flexural section (mm²). The flexural strength test of bricks is conducted in the laboratory utilizing a Universal Testing Machine (UTM). This test is conducted per SNI-03-4165-1996 [33], wherein the bricks are evaluated on their cross-section until failure occurs. Figure 11 illustrates the flexural test setup.

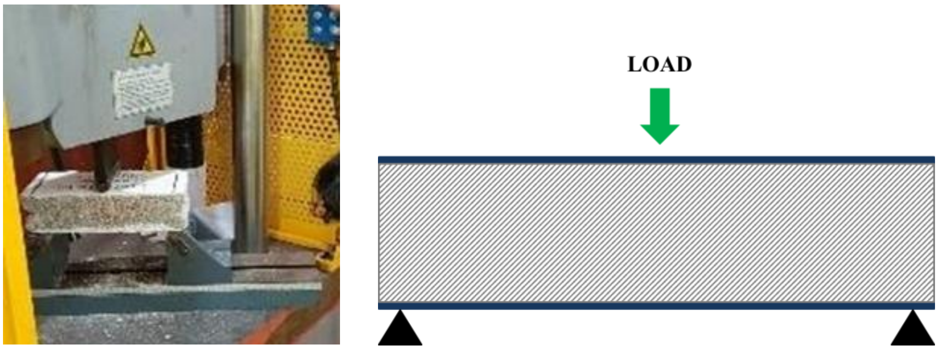

Figure 11. Flexural Sample Testing Setup

Shear Strength

Masonry wallet shear testing includes determining the diagonal tensile strength or shear along the diagonal axis in a vertical position, causing diagonal tensile failure parallel to the loading direction [34]. Several parameters are obtained from the test results, which can later be used to calculate the shear strength. The data obtained are the dimensions of the test object and the maximum load. According to ASTM E519- 02- 2002, the shear strength formula is in Equation 2 [35].

$$S = \frac{0.707 \times P}{A} \tag{2}$$

where, S is the Shear strength (kg/cm2), P is the maximum load (kg), and A is the surface area of the compression plane (cm^2).

The shear strength test of the Concrete Blocks was conducted in the laboratory using a Universal Testing Machine (UTM). The Concrete Blocks were given additional testing accessories in angle iron plates placed at the diagonal corners of the Concrete Blocks. The method for testing the shear strength of Concrete Blocks was done by positioning the shear test object diagonally. Figure 12 shows the shear test setup.

 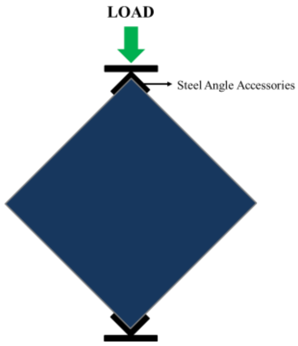

Figure 12. Shear Sample Testing Setup

2.3. Energy Dissipation

Dissipation energy is determined by calculating the area under the curve. The curve describes the relationship between the applied force and the deformation (Δ) in the structure or structural element. The area can be calculated using the multi-segment trapezoid method approach [36, 37], formulated in Equation 3.

$$A = \sum_{i=1}^{n} \Delta_i \frac{f(x_i)+f(x_{i-1})}{2} \tag{3}$$

Energy Dissipation (E) can be calculated using the following Equation 4.

$$E = \sum_{i=1}^{n} E_i \tag{4}$$

where, Ei is the total area of the curve formed.

3. Results and Discussion

3.1. Characteristics of Concrete Block

3.1.1. Visible Properties of Concrete Block

As per SNI 03-0349-1989, certified concrete blocks must possess a flawless surface, allow for various planned surface shapes, have ribs intersect at right angles, and include rib angles that cannot be easily straightened by manual force. The outcomes of the physical examination of concrete blocks are presented in Table 4.

Table 4. Visible Properties of Concrete Block

Concrete Block Code	Visible Properties of Concrete Block
	The first sample has no defects on the sides but has some damaged spots; the ribs are angled, and the edges are easy to smooth with hand strength.
	The second sample has a slight flaw on one side; the ribs are angled and easy to straighten with hand strength.
	The third sample has damage on the corners; the ribs are angled and can be easily straightened with hand strength.
	The fourth sample has no damage on the sides, the ribs are angled, and it is difficult to straighten with hand strength.
	The fifth sample has no damage on the sides, the ribs are angled, and it is difficult to straighten with hand strength.

3.1.2. Specific Gravity of Concrete Block

SNI 15-2094-2000 [30] specifies that the specific gravity of red brick masonry is 1700 kg/m³, as referenced in SNI 15-2094-2000 [30]. Table 5 presents the results of the Concrete Block testing, revealing that the specific gravity of the Concrete Block surpassed the conventional specific gravity of red brick masonry, recorded at 1890 kg/m³. This resulted in the concrete blocks meeting the specific gravity criteria outlined in SNI 15-2094-2000 [30].

Table 5. Specific Gravity of Concrete Block

Batako Sample Number	Dry Weight (gr)	Dry Saturated Weight Surface (gr)	Saturated Weight (gr)	Specific gravity (g/cm³)
1	2575	2810	1413	1.84
2	2825	3090	1572	1.86
3	3035	3200	1672	1.98
4	2900	3225	1648	1.83
5	2995	3165	1651	1.97
		Average		1.89

3.2. Concrete Block Strength

3.2.1. Flexural Strength of Concrete Block

The flexural strength test results are presented in Table 6 and Figure 13. The data show that applying fiberglass paint to concrete blocks enhances their ability to withstand flexural loads, indicating the coating's positive role in strengthening the block structure. Using fiberglass paint in concrete blocks enhances their strength in resisting flexural stresses. The percentage enhancement in the flexural strength of the concrete blocks is illustrated in Table 7 and Figure 14. Figure 15 compares concrete blocks with fiber paint coatings and without fiber paint coatings. According to Table 7 and Figure 14, the incorporation of fiberglass paint into blocks with thicknesses of 1 mm, 2 mm, and 3 mm yielded increases in flexural strength of 16.97%, 31.52%, and 66.06%, respectively

Table 6. Average Flexural Strength of Concrete Block

No.	Sample	Code	Average Flexural Strength (kN/cm²)
1	Normal	LN	1.65
2	Fiberglass 1 mm	LFG 1	1.93
3	Fiberglass 2 mm	LFG 2	2.17
4	Fiberglass 3 mm	LFG 3	2.74

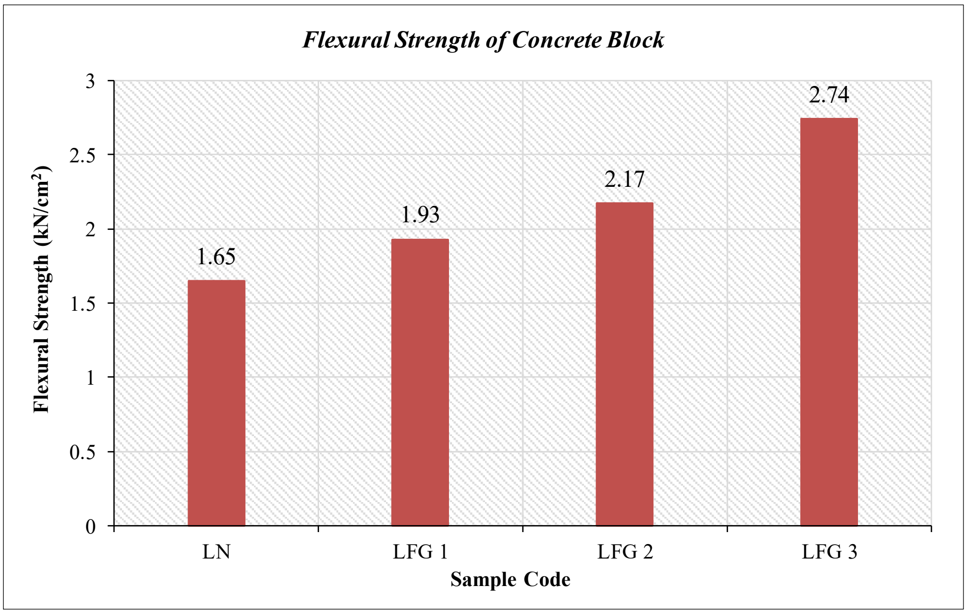

Figure 13. Average Flexural Strength of Concrete Blocks

Table 7. Percentage Increase in Flexural Strength of Concrete Block

Sample	Code	Flexural Strength Control Value	Flexural Strength Results of Concrete Blocks Testing	Percentage Increase
		(A)	(B)	(B-A)/A × 100%
Control	LN	1.65	1.65	0
Fiberglass 1 mm	LFG 1	1.65	1.93	16.97
Fiberglass 2 mm	LFG 2	1.65	2.17	31.52
Fiberglass 3 mm	LFG 3	1.65	2.74	66.06

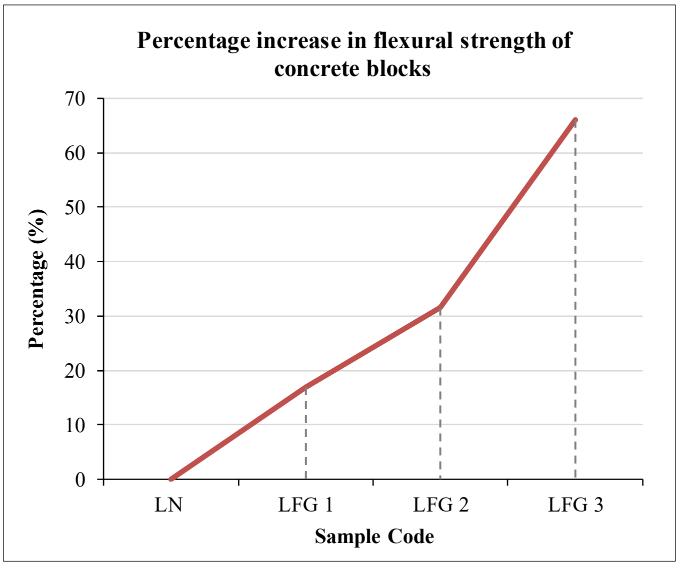

Figure 14. Increase in Flexural Strength of Concrete Block

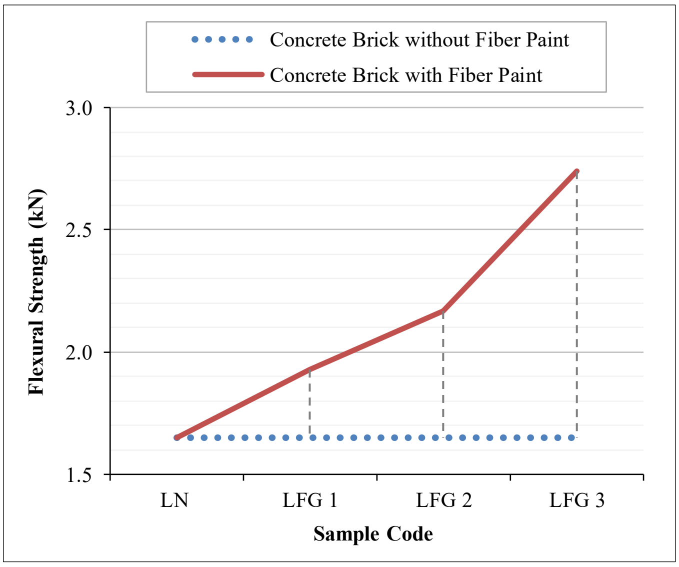

Figure 15. Comparison of Flexural Strength Test of Concrete Block with and without Coating

Table 7 and Figure 14 display the percentage increase in the flexural strength of the concrete blocks. Meanwhile, Figure 15 compares concrete blocks with and without a layer of fiber paint. Based on Table 7 and Figure 14, it can be concluded that the addition of fiberglass paint to concrete blocks with a thickness of 1 mm, 2 mm, and 3 mm experienced a percentage increase in flexural strength of 16.97%, 31.52%, and 66.06%, respectively.

Figure 16 illustrates the correlation between load and displacement, while Figure 17 presents the relationship between stress and strain. Based on the load-displacement curve in Figure 14, it is observed that the control specimen failed at a load of 1.68 kN. In contrast, specimens coated with fiber paint layers of 1 mm, 2 mm, and 3 mm thickness failed at progressively higher loads of 2.160 kN, 2.580 kN, and 3.120 kN, respectively. The results indicate increased maximum load-bearing capacity with greater coating thickness.

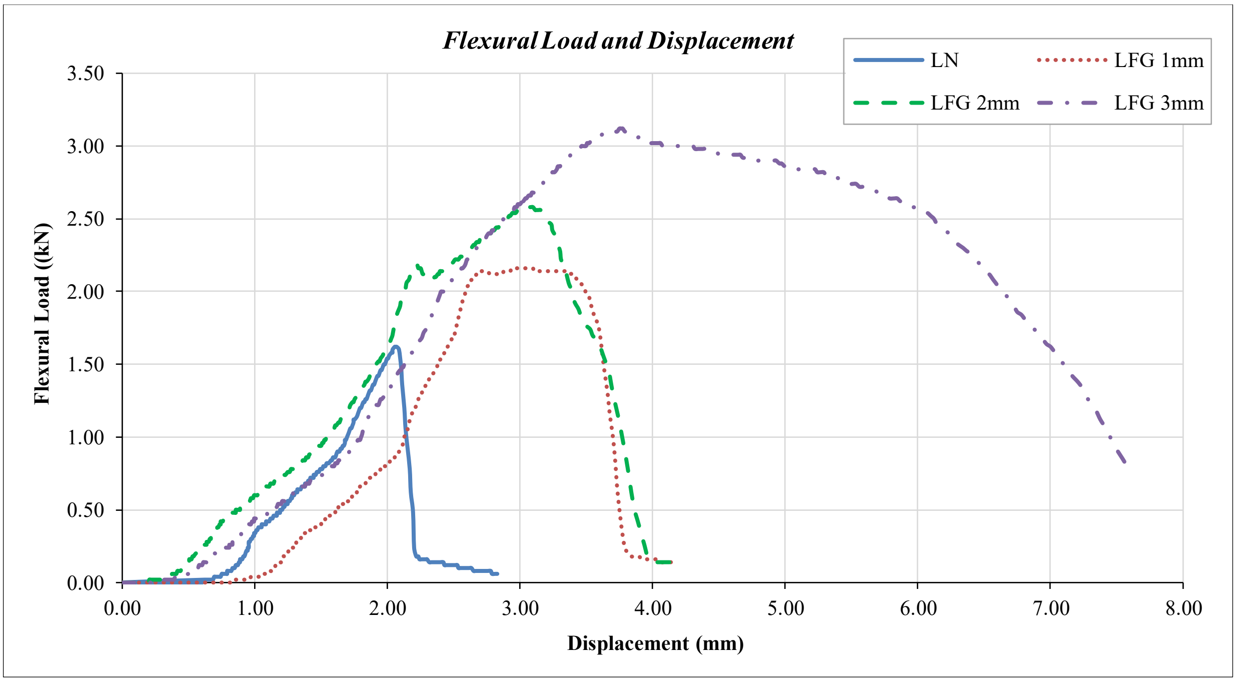

Figure 16. Load and Displacement of Flexural Strength of Concrete Block

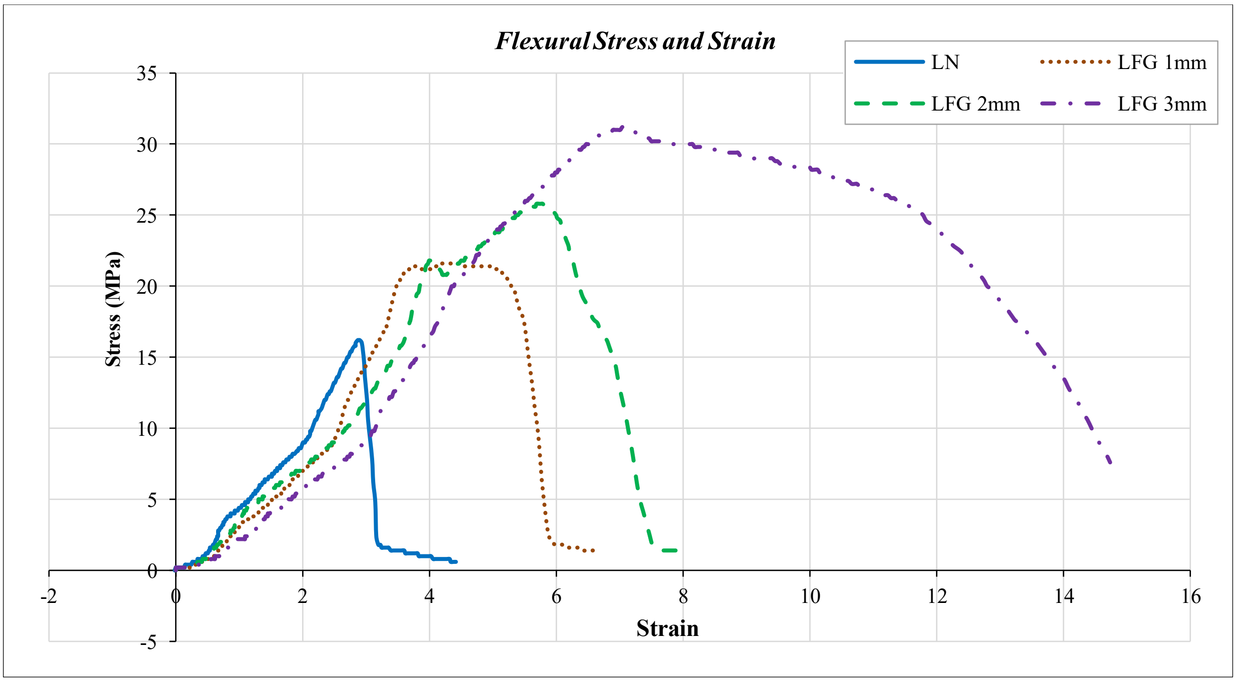

Figure 17. Stress and Strain of Flexural Strength of Concrete Block

In this study, the control specimen exhibited a peak flexural load of 1.68 kN with a deformation of 2.83 mm. After being coated with a 3 mm fiber-paint layer, the capacity increased to 3.12 kN with a deformation of 7.6 mm. This indicates that fiber paint is effective in enhancing maximum flexural strength while also providing additional deformation, although its strengthening effect is more dominant in improving peak capacity. In contrast, Multazam et al. [17] flexural test on hollow blocks with reinforcement bars showed an ultimate capacity averaging 3.9 kN, which is higher than that achieved with fiber paint. After reaching the peak load, the capacity decreased and fluctuated within the range of 1.5–2 kN, yet the reinforcement bars continued to support the structure. Even after significant cracking occurred at the mortar joints, the reinforcement bars were able to sustain the entire load until deformation exceeded 20 mm. This behavior confirms that reinforcement bars not only increase load capacity but also provide superior ductility. Overall, fiber paint is more advantageous for improving maximum capacity with a simple application method, whereas reinforcement bars contribute more significantly to deformation resistance and structural functionality after cracking. Thus, each strengthening method offers distinct advantages: fiber paint for practical enhancement of initial strength, and reinforcement bars for long-term performance and structural ductility.

Figure 16 shows that the flexural strength increases with the thickness of the fiber paint layer applied to the surface of the specimen. This enhancement indicates a significant contribution of the coating layer in resisting the flexure forces acting during the test. Mechanically, a thicker fiber paint layer tends to possess higher tensile capacity, strengthening the concrete surface against initial cracking and crack propagation during loading. Table 8 and Figure 18 demonstrated that the flexural test results indicate that applying fiber paint enhances the ductility and stiffness of concrete blocks, with the most significant improvements observed at 2 mm and 3 mm thicknesses. Specifically, 2 mm and 3 mm fiber paint layers increased ductility by 16% and 32%, respectively, while 1mm reduced it slightly by 4%. Stiffness improved across all fiberpaint thicknesses, with increases of 10%, 12%, and 9% for 1 mm, 2 mm, and 3 mm, respectively.

Table 8. Ductility and Stiffness of Flexural Test

Sample	Ductility	Ductility Percentage	Stiffness (kN/mm)	Stiffness Percentage
LN	1.11	0%	0.59	0%
LFG 1 mm	1.06	-4%	0.70	10%
LFG 2 mm	1.28	16%	0.72	12%
LFG 3 mm	1.46	32%	0.69	9%

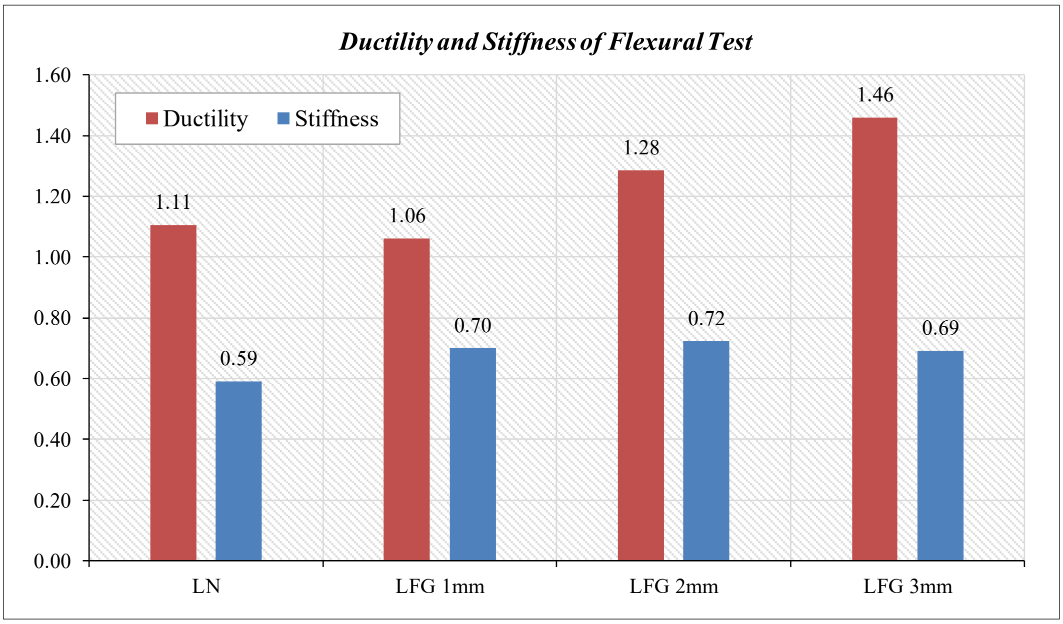

Figure 18. Load and Strain of Flexural Strength of Concrete Block

3.2.2. Shear Strength of Concrete Block

The shear strength data are presented in Table 9 and Figure 19. Using fiberglass paint in concrete blocks enhances their strength in resisting shear forces. The percentage enhancement in the shear strength of the concrete blocks is illustrated in Table 10 and Figure 20. Incorporating fiberglass fiber paint into concrete blocks with thicknesses of 1 mm, 2 mm, and 3 mm yielded increases in shear strength of 1.56%, 25.20%, and 47.36%, respectively. Figure 21 contrasts the shear strength values of concrete blocks with and without a layer of fiber paint.

Table 9. Average Shear Strength of Concrete Block

No.	Sample	Code	Average Shear Strength (kN/cm^2)
1	Normal	GN	10.71
2	Fiberglass 1 mm	GFG 1	10.88
3	Fiberglass 2 mm	GFG 2	13.41
4	Fiberglass 3 mm	GFG 3	15.79

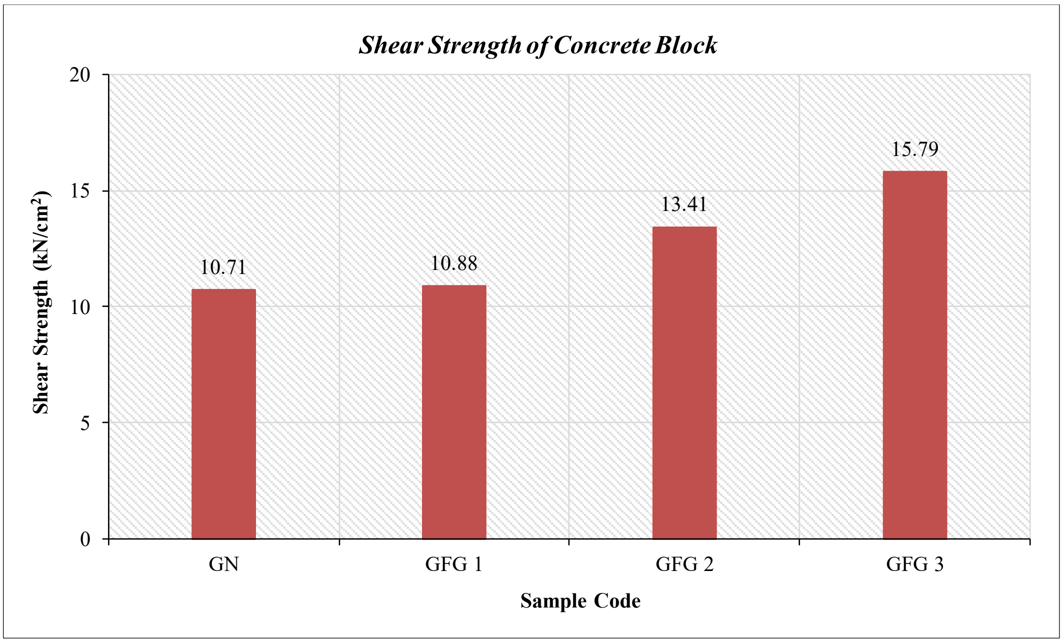

Figure 19. Average Shear Strength of Concrete Block

Table 10. Percentage Increase in Concrete Block Shear Strength

Sample	Code	Shear Strength Control Value	Shear Strength Results of Concrete Block Testing	Percentage Increase
		(A)	(B)	(B-A)/A × 100%
Control	GN	10.42	10.71	0.00
Fiberglass 1 mm	GFG 1	10.42	10.88	1.56
Fiberglass 2 mm	GFG 2	10.42	13.41	25.20
Fiberglass 3 mm	GFG 3	10.42	15.79	47.36

The percentage increase in the shear strength of the concrete blocks is illustrated in Table 10 and Figure 20. It shows that using fiberglass-reinforced paint on concrete block surfaces significantly improves shear strength performance. Specifically, for thicknesses of 1 mm, 2 mm, and 3 mm, the shear strength increased by 1.56%, 25.20%, and 47.36%. These results indicate that a thicker fiberglass coating enhances the material's ability to withstand shear forces. This improvement is likely due to increased bonding and surface integrity from the fiberglass particles, which act as reinforcement against crack initiation and propagation. Figure 21 shows how uncoated concrete block and concrete blocks with various thicknesses of fiberglass paint perform better under shear load. The results demonstrate the effectiveness of fiber paint in enhancing mechanical performance under shear load.

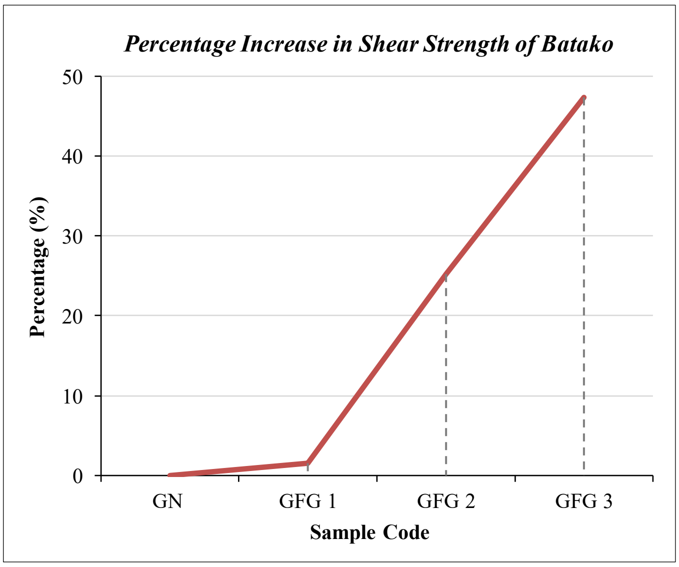

Figure 20. Increase in Shear Strength of Concrete Block

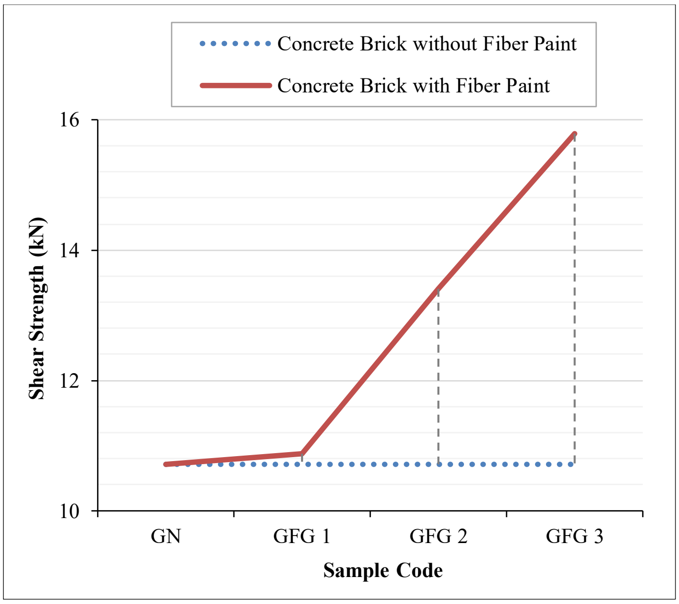

Figure 21. Comparison of Shear Strength Test of Concrete Block with and without Coating

The relationship between load and displacement is illustrated in Figure 22, while Figure 23 depicts the relationship between stress and strain. Referring to the load-displacement curve in Figure 22, the control specimen failed at a maximum load of 10.60 kN. In comparison, the specimens coated with fiber paint with thicknesses of 1 mm, 2 mm, and 3 mm failed at maximum loads of 11.34 kN, 14.44 kN, and 22.90 kN, respectively. These results indicate that the increase in fiber paint thickness corresponds to an increase in maximum shear strength. This trend shows that the additional material not only enhances the structural integrity of the specimen but also plays a crucial role in increasing the load-bearing capacity.

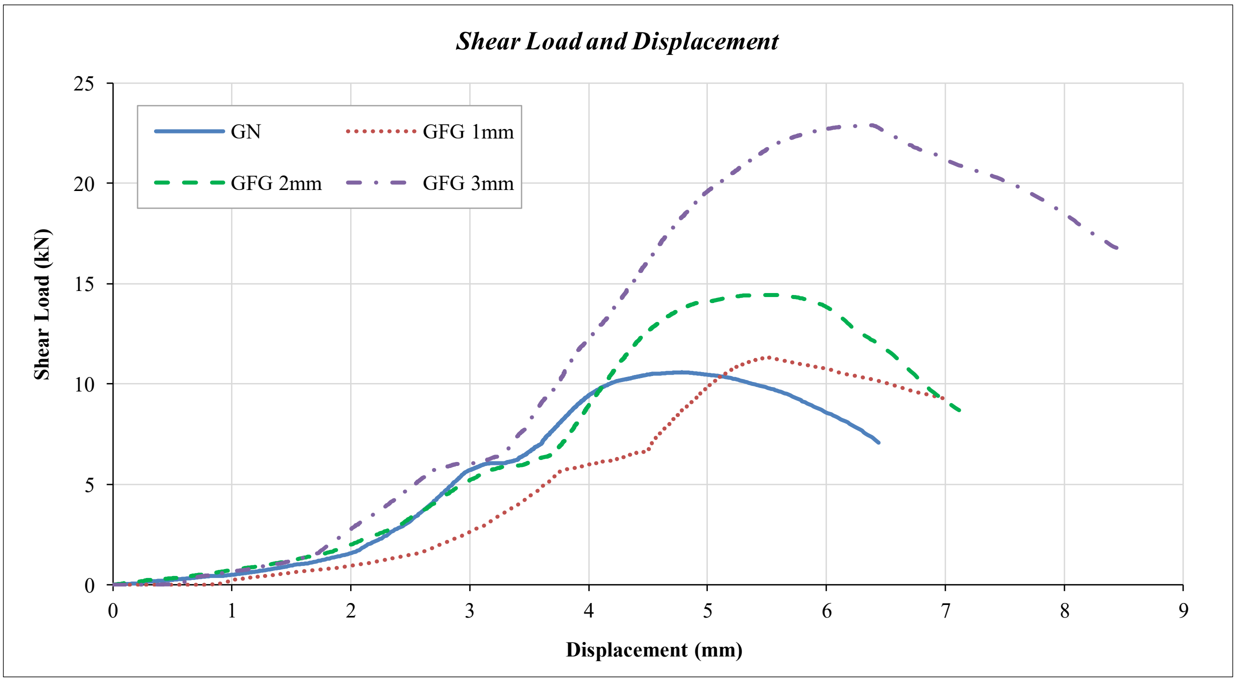

Figure 22. Shear Test Load and Displacement of Concrete Block

This study demonstrated that the control concrete blocks specimen maximum shear load of 10.60 kN with a deformation of 6.44 mm, whereas the specimen coated with a 3 mm fiber-paint layer achieved a significantly higher shear capacity of 22.90 kN with a deformation of 8.485 mm. This indicates that the fiber-paint layer provides substantial improvement in shear strength while maintaining deformation capacity. In contrast, Multazam et al. [38] reported that unreinforced hollow blocks exhibited an average peak shear load of 7.68 kN with a deformation of 5.8–7.6 mm. The application of fiber paint increased the shear load to 8.62 kN but resulted in a markedly larger deformation exceeding 35 mm. These findings suggest that the fiber paint in Multazam's study was more effective in enhancing ductility than in improving peak strength. Similarly, Juliafad et al. [10] investigation on red brick masonry unit showed an increase in shear strength from 3.72 kg/cm² (control) to 5.05 kg/cm² with a 3 mm fiber-paint coating. Although the improvement was smaller compared to the present study, the overall trend was consistent: fiber-paint coating enhances the mechanical performance of masonry units, whether hollow blocks, red bricks, or concrete blocks. The variation in strength enhancement across studies can be attributed to differences in base material properties, the bond between the coating and the substrate, as well as fiber size and quality.

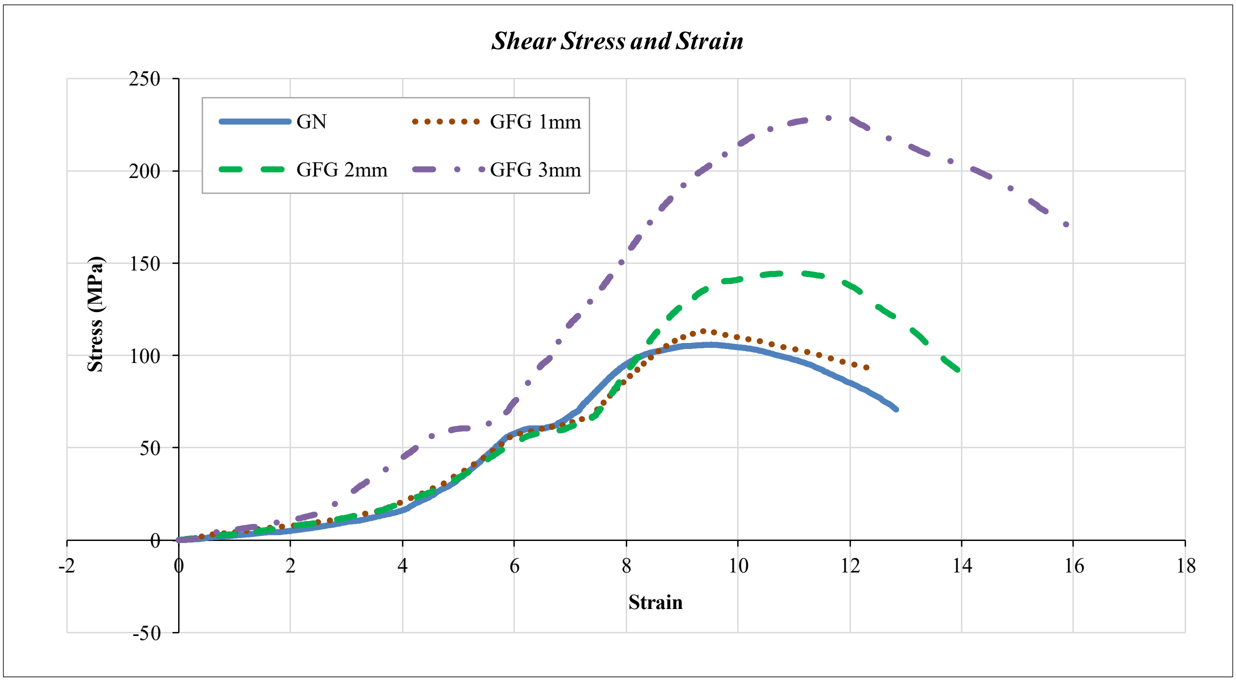

Figure 23. Stress and Strain of Shear Strength of Concrete Block

The ductility and stiffness results obtained from the shear tests are summarized in Table 11 and illustrated in Figure 24. Adding fiberglass paint to the concrete block's surface affected both mechanical properties. Specifically, the ductility of the specimens decreased by 6%, 25%, and 29% for fiber layer thicknesses of 1 mm, 2 mm, and 3 mm, respectively. This decrease indicates that although the material becomes more resistant to deformation, its capacity to undergo significant strain before failure decreases with increasing layer thickness. A decrease in stiffness was recorded for specimens with 1 mm and 2 mm fiberglass layers, which showed a 21% and 2% decrease, respectively. However, at a layer thickness of 3 mm, the stiffness increased by 13%, indicating that the fiberglass layer contributes positively to the structural stiffness at a specific thickness.

Table 11. Ductility and Stiffness of Shear Test

Sample	Ductility	Ductility Percentage	Stiffness (kN/mm)	Stiffness Percentage
GN	1.57	0%	2.54	0%
GFG 1 mm	1.48	-6%	2.22	-21%
GFG 2 mm	1.18	-25%	2.51	-2%
GFG 3 mm	1.12	-29%	2.75	13%

The ductility and stiffness values acquired from the shear test are illustrated in Table 11 and Figure 24, encompassing fiberglass in concrete blocks with thicknesses of 1 mm, 2 mm, and 3 mm, which resulted in reductions in ductility of 6%, 25%, and 29%, respectively. Regarding stiffness, concrete blocks coated with 1 mm and 2 mm of fiber paint demonstrated 21% and 2% reductions, respectively. Conversely, a 13% increase in stiffness was reported in blocks containing 3 mm fiber.

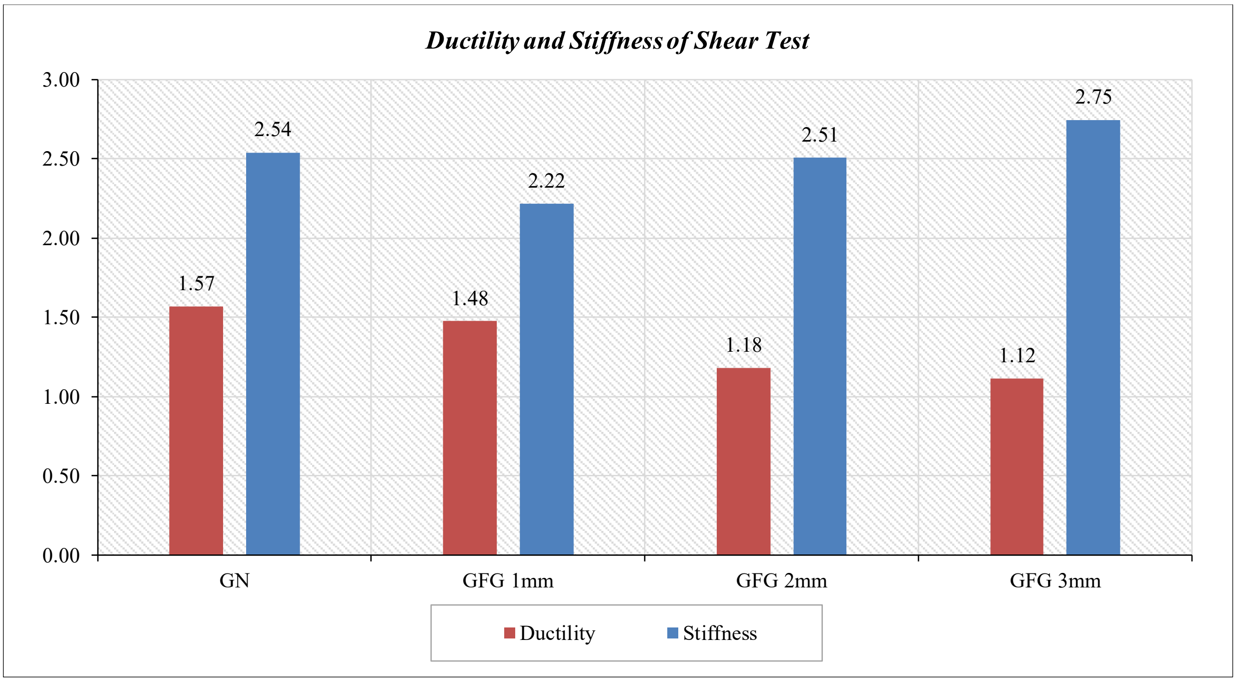

Figure 24. Load and Strain of Shear Strength of Concrete Block

3.3. Energy Dissipation

The dissipation energy in flexural and shear tests can be seen in Tables 12 and 13. The values shown are the total energy dissipated by the concrete block behavior and the amount of energy up to the maximum load.

Table 12. Energy Dissipation of Flexural Test

No.	Sample	Code	Total Energy (kNmm)	Energy Up To the Maximum Load (kNmm)
1	Normal	LN	1.38	1.12
2	Fiberglass 1 mm	LFG 1	2.80	1.65
3	Fiberglass 2 mm	LFG 2	5.37	3.27
4	Fiberglass 3 mm	LFG 3	10.76	4.22

Table 13. Energy Dissipation of Shear Test

No.	Sample	Code	Total Energy (kNmm)	Energy Up to the Maximum Load (kNmm)
1	Normal	GN	38.37	18.39
2	Fiberglass 1 mm	GFG 1	39.30	23.12
3	Fiberglass 2 mm	GFG 2	47.63	30.48
4	Fiberglass 3 mm	GFG 3	50.72	32.81

In Figure 25, the energy dissipation generated from the flexure test shows an increasing trend with adding the fiber paint layer thickness to the sample surface. The total energy in the sample without the fiber paint coating is 1.38 kNmm. Adding a 1 mm thick fiber paint layer increases the dissipated energy to 2.80 kNmm. This increase continues significantly at 2 mm and 3 mm thicknesses, with dissipation values of 5.37 kNmm and 10.76 kNmm, respectively. Furthermore, the energy dissipation up to the maximum load in the test specimen without the fiber paint coating is 1.12 kNmm, and the increasing trend continues with the addition of the fiber paint layer thickness, which at 1 mm, 2 mm, and 3 mm thicknesses are 1.65 kNmm, 3.27 kNmm, and 4.22 kNmm, respectively. The analysis indicates that the fiber coating strengthens the inter-material bond and enhances the material's ability to absorb energy when subjected to flexure loads.

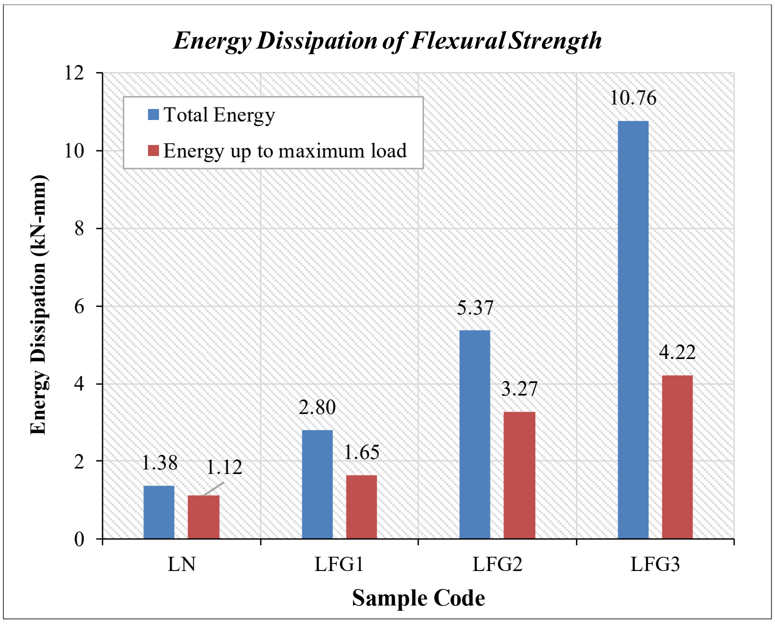

Figure 25. Energy Dissipation of Flexural Strength

A similar trend was also observed in the shear test, as shown in Figure 26. The total energy dissipation of the sample without fiber paint is 38.47 kNmm. When the fiber paint is applied with a thickness of 1 mm, the energy increases to 39.30 kNmm. A more significant increase occurs at 2 mm and 3 mm thicknesses, with energy dissipation recorded at 47.63 kNmm and 50.72 kNmm, respectively. The energy dissipation until reaching the maximum load on the sample without the fiber paint layer is recorded at 18.39 kNmm. As the thickness of the fiber paint layer increases, the energy dissipation value shows an increase, namely 23.12 kNmm at 1 mm thickness, 30.48 kNmm at 2 mm, and 32.81 kNmm at 3 mm. These findings reinforce that fiber paint is crucial in enhancing the structural toughness in resisting shear forces. Thus, increasing the thickness of the fiber paint layer can be considered one of the effective strategies in material engineering to enhance mechanical resistance to deformation and damage due to dynamic loads.

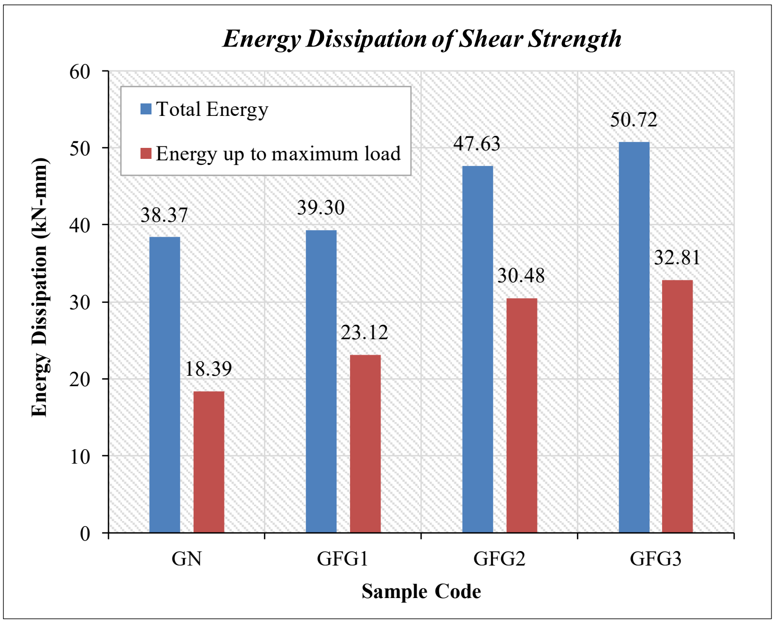

Figure 26. Energy Dissipation of Shear Strength

The results reveal that the fiberpaint coating makes the concrete blocks much better at dissipated energy. This improvement is crucial from a structural safety perspective, as elements with greater energy dissipation are able to absorb seismic input energy and reduce the risk of brittle failure. Structures with a greater energy dissipation capacity typically demonstrate improved ductility, improved crack control, and a greater capacity to maintain load-bearing capacity after peak loads during seismic events [39]. The findings of Chen & Chung (2013) demonstrated that the incorporation of admixtures such as silane-treated silica fume and graphite significantly enhanced the energy dissipation capacity of cement-based materials, with the energy dissipation fraction (EDF) reaching 0.26 in paste, 0.58 in mortar, and 0.22 in concrete [40]. These values indicate that the modified mortar, in particular, exhibits superior damping performance compared to conventional mixtures, due to the synergistic interaction between silica fume and graphite network in the microstructure. In comparison, the present study on fiber paint-coated concrete blocks also revealed a notable increase in energy dissipation capacity. The flexural test showed that energy dissipation increasing from 1.38 kNmm in the control specimen to 10.76 kNmm at 3 mm thickness, and shear energy rising from 38.47 kNmm to 50.72 kNmm. Compared with control specimens, the reinforced specimens showed up to 680% higher total energy dissipation in flexural samples and up to 32% higher in shear samples, implying a significant improvement in seismic resistance. Similar findings have been reported by Multazam (2022), where the addition of a fiber-based reinforcing layer increased the ductility and energy absorption capacity of masonry structures [38]. Another study by Multazam et al. (2025) highlighted that embedding rebar reinforcement in concrete hollow block (CHB) masonry notably enhanced seismic resilience by improving ductility and load-carrying capacity, thus validating the role of reinforcement in strengthening weak masonry units [17]. In addition, the use of basalt fiber mortar on the URM surface slows down stiffness degradation and improves energy dissipation [18]. Furthermore, a study in Indonesia on concrete columns filled with Autoclaved Aerated Concrete (AAC) masonry showed that the combination met the energy dissipation criteria of international standards and exhibited high ductility, indicating that the system could withstand further seismic deformation before failure [19]. When comparing these studies, it is clear that both internal and external retrofitting approaches serve as effective mechanisms for improving energy dissipation and the overall resilience of masonry and concrete systems. Overall, the increased energy dissipation capacity observed in these studies can be interpreted as a positive contribution to structural safety, as it allows these elements to withstand greater seismic loads before failure.

3.4. Damage Pattern

3.4.1. Flexural Damage Pattern

Following the flexural strength testing of concrete blocks incorporating an 8% fiberglass paint layer, the results indicated a flexural strength of 1.93 kN/cm² for a 1 mm thick fiber paint, 2.17 kN/cm² for a 2 mm thickness, and 2.74 kN/cm² for a 3 mm thickness. Upon examining the damage pattern on the blocks, a layer of fiberglass paint comprising 8% was applied, which had undergone testing for flexural strength (Figure 27). The test results indicate that the thickness of the fiberpaint layer has a significant influence on the crack patterns of concrete blocks under flexural testing. In uncoated specimen Figure 27-a, experienced a vertical tensile crack that initiated at the mid-span on the tension side and propagated upward, leading to flexural failure of the concrete block specimen. The application of a 1 mm fiberpaint layer (Figure 27-b) began to show improvements, where cracks became finer and more controlled, although still clearly visible. With a thickness of 2 mm in Figure 27-c, the cracks were fewer, thinner, and did not propagate completely, indicating enhanced flexural resistance and better ductility. Meanwhile, the 3 mm fiberpaint layer (Figure 27-d) provided the best performance, as evidenced by the presence of very fine tensile cracks limited to the mid-span area without extensive propagation. This demonstrates that fiberpaint is capable of restraining crack propagation and distributing tensile stresses more evenly, thereby improving the flexural performance and crack resistance of concrete blocks.

(a) The control sample can be seen as collapsed in the middle of the image.

(b) The sample of 1 mm thick fiberglass painted Concrete Block cracked in the middle.

(c) The sample of 2 mm-thick fiberglass-painted Concrete Block cracked in the middle.

(d) A sample of 3 mm thick fiberglass painted Concrete Block appears to have cracks in the middle.

Figure 27. Samples Flexural Damage Pattern

3.4.2. Shear Damage Pattern

Shear strength tests on concrete blocks with an 8% fiberglass paint layer yielded results of 10.88 kN/cm² for a 1 mm thickness, 13.42 kN/cm² for a 2 mm thickness, and 15.79 kN/cm² for a 3 mm thickness. The damage pattern observed on concrete blocks, resulting from applying a fiberglass paint layer mixed at 8%, which was evaluated for shear strength, is illustrated in Figure 28. In the shear test, the application of fiberpaint coatings was found to significantly influence the crack patterns of the concrete blocks. In the control specimen without fiberpaint coating (Figure 28-a), the concrete block experienced complete failure after being subjected to shear loading, characterized by major cracks leading to overall collapse. In contrast, the concrete block coated with 1 mm fiberpaint (Figure 28-b) exhibited cracks only along the sides of the specimen, while the fiberpaint layer effectively restrained the formation of larger cracks. For the specimen with a 2 mm coating (Figure 28-c), the damage was primarily observed in the uncoated areas, whereas the coated regions showed only fine cracks. A similar trend was observed in the specimen with a 3 mm coating (Figure 28-d), where no cracks appeared in the fiberpaint layer, and the damage was confined to the uncoated portions of the block. These findings indicate that the application of fiberpaint enhances the shear resistance of concrete blocks by restricting crack propagation and reducing the extent of structural damage.

(a) The control shear sample is seen in the image to have collapsed when given a load.

(b) Concrete Block with 1mm thick fiberglass paint experienced cracks on the right side and shrinkage of the paint on the left side.

(c) The concrete block with 2 mm thick fiberglass paint did not experience cracks in the paint layer but experienced cracks on the inside of the block, and it was seen that the paint only experienced shrinkage.

(d) Concrete Block with 3 mm-thick fiberglass paint can be seen in the image. There were no cracks in the paint layer, but there were cracks on the inside of the block, and the paint can be seen to have only shrunk.

Figure 28. Samples Shear Damage Pattern

4. Conclusions

The research on concrete blocks reinforced with a fiberglass paint layer indicates that the flexural strength of Concrete Block with fiberglass paint layers of 1 mm, 2 mm, and 3 mm thicknesses are 1.93 kN/cm², 2.17 kN/cm², and 2.74 kN/cm², respectively. Compared to the control sample, the fiber paint coating increased flexural strength by 16.97%, 31.52%, and 66.06%, respectively. The shear strength of concrete blocks coated with fiberglass paint at the same thicknesses is 10.88 kN/cm², 13.41 kN/cm², and 15.79 kN/cm², respectively, with percentage increases in shear strength of 1.56%, 25.20%, and 47.36%.

The flexural test of concrete block with 2mm and 3mm fiber paint had increased ductility at 16% and 32%, respectively. In contrast, ductility decreased by 4% in the 1 mm. The stiffness in samples with 1mm, 2mm, and 3mm fiber paint increased by 10%, 12% and 9%, respectively. These findings suggest that a fiberpaint thickness of 2mm provides the most balanced enhancement of both ductility and stiffness. In the shear test, ductility reduces as fiber thickness increases, with the most significant loss occurring at 3 mm. Only the 3 mm thickness exhibits a 13% increase in stiffness, while the 1 mm and 2 mm thicknesses experience a drop. This indicates that the 3 mm thickness improves stiffness, although it negatively impacts ductility.

The flexural test showed an increase in energy dissipation that was in line with the thickness of the fiber coating layer. The sample without fiber coating had total energy of 1.38 kNmm, while samples with 1 mm, 2 mm, and 3 mm fiberpaint coating had total energies of 2.80 kNmm, 5.37 kNmm, and 10.76 kNmm, respectively. Similarly, the shear test also demonstrated an increase in energy dissipation; the sample without fiber coating had total energy of 38.47 kNmm, whereas the samples with fiberpaint coating recorded total energies of 39.30 kNmm, 47.63 kNmm, and 50.72 kNmm, at 1 mm, 2 mm, and 3 mm, respectively. Therefore, increasing the thickness of the fiber coating consistently enhances energy dissipation in both flexural and shear tests. Samples with fiber coating demonstrate a better ability to absorb energy, which positively correlates with resistance to deformation and structural damage due to dynamic loads.

Future research should expand on these findings through large-scale testing, long-term durability assessments under environmental and fire exposure, and numerical modeling to validate the applicability of this strengthening method in real construction practices. In addition, dynamic and seismic loading tests, such as cyclic and shake-table experiments, are necessary to evaluate the performance of fiber paint coatings under earthquake-like conditions. These efforts will be essential before the technique can be considered for wider adoption in retrofitting strategies or integration into design codes.

5. Declarations

5.1. Author Contributions

Conceptualization, E.J.; methodology, E.J., F.Y., and L.J.R.; software, N.S.; validation, E.J.; formal analysis, E.J., F.Y., and L.J.R.; investigation, E.J., R.R.P., and L.J.R.; resources, E.J.; data curation, E.J.; writing—original draft preparation, A.R. and L.J.R.; writing—review and editing, E.J. and L.J.R.; visualization, E.J.; supervision, E.J.; project administration, E.J.; funding acquisition, E.J. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

5.3. Funding and Acknowledgments

The authors would like to thank Universitas Negeri Padang for financial support toward the APC of this article, funded by the EQUITY Kemdiktisaintek Program supported by LPDP, under contract number 4310/B3/DT.03.08/2025 and 2692/UN35/KS/2025.

5.4. Conflicts of Interest

The authors declare no conflict of interest.

6. References

[1] SNI 2847-2019. (2019). Structural Concrete Requirements for Building Construction. Badan Standardisasi Nasional (BSN), Jakarta, Indonesia. (In Indonesian).

[2] Melinda, A. P., & Juliafad, E. (2022). Experimental Study of Masonry Wall Strengthened by Polypropylene Fiber Mortar. International Journal on Advanced Science, Engineering and Information Technology, 12(3), 1066–1072. doi:10.18517/ijaseit.12.3.11198.

[3] Multazam, Z., Yamamoto, K., Timsina, K., Gadagamma, C. K., & Meguro, K. (2024). Shaking table tests of a one-quarter scale model of concrete hollow block masonry houses retrofitted with fiber-reinforced paint. Scientific Reports, 14(1), 8041. doi:10.1038/s41598-024-58365-4.

[4] Mayorca, P., & Meguro, K. (2010). Strengthening of masonry structures using polypropylene bands. Japan Society of Civil Engineers 58th Annual Academic Conference, 28 February 2010, 1077-1078.

[5] SNI 03-0349-1989. (1989). Concrete bricks for wall masonry. Badan Standardisasi Nasional (BSN), Jakarta, Indonesia. (In Indonesian).

[6] Zahra, T., Thamboo, J., & Asad, M. (2021). Compressive strength and deformation characteristics of concrete block masonry made with different mortars, blocks and mortar beddings types. Journal of Building Engineering, 38, 102213. doi:10.1016/j.jobe.2021.102213.

[7] Imai, H., Minowa, C., Lanuza, A. G., Penarubia, H. C., Narag, I. C., Soridum, R. U., Okazaki, K., Narafu, T., Hanazato, T., & Inoue, H. (2015). A full-scale shaking table test on philippine concrete hollow blocks (CHB) masonry houses. Journal of Disaster Research, 10(1), 113–120. doi:10.20965/jdr.2015.p0113.

[8] Juliafad, E., Arifin, A. S. R., & Putri, P. Y. (2019). Brick Making Training According to Indonesian National Standards for School Dropouts. Cived, 6(4), 1–6. doi:10.24036/cived.v6i4.107719.

[9] Juliafad, E., & Andayono, T. (2021). Study on building permit awareness in West Sumatra, Indonesia. IOP Conference Series: Earth and Environmental Science, 708(1), 12093. doi:10.1088/1755-1315/708/1/012093.

[10] Juliafad, E., Restu, L. J., Yusmar, F., Putra, R. R., & Meguro, K. (2024). Experimental Study on Compressive Strength and Shear Strength of Masonry Unit with Fiber Glass and Polypropylene Fiber Paint Coating. Jurnal Teknologi, 86(6), 85–93. doi:10.11113/jurnalteknologi.v86.21658.

[11] Umair, S. M., Numada, M., Amin, M. N., & Meguro, K. (2015). Fiber reinforced polymer and polypropylene composite retrofitting technique for masonry structures. Polymers, 7(5), 963–984. doi:10.3390/polym7050963.

[12] Boen, T., Imai, H., Lenny, & Sarah, E. S. (2021). Masonry buildings strengthened with textile-fiber composite (TRC) layers and fiber-reinforced cementitious (FRC) layers. E3S Web of Conferences, 331, 05002. doi:10.1051/e3sconf/202133105002.

[13] Junior, R., & Juliafad, E. (2022). Interlocking Reinforcement Method of Red Brick Masonry Using 6mm Diameter Plain Reinforcement Steel. Journal Applied Science in Civil Engineering, 3(1), 33–37. doi:10.24036/asce.v3i1.321566. (In Indonesian).

[14] Rino, R., & Juliafad, E. (2023). Utilization of Petung Bamboo as Reinforcement on Red Brick Walls. Journal Applied Science in Civil Engineering, 4(1), 106-111. (In Indonesian).

[15] Chilton, K., Kadivar, M., & Hinkle, H. (2025). From Problems to Possibilities: Overcoming Commercialization Challenges to Scale Timber Bamboo in Buildings. Sustainability (Switzerland), 17(4), 1575. doi:10.3390/su17041575.

[16] Iroegbu, A. O. C., & Ray, S. S. (2021). Bamboos: From bioresource to sustainable materials and chemicals. Sustainability (Switzerland), 13(21), 12200. doi:10.3390/su132112200.

[17] Multazam, Z., Yamamoto, K., Timsina, K., Shanthanu, R., & Meguro, K. (2025). Enhancing seismic resilience in weak masonry units: the impact of rebar reinforcement in concrete hollow block masonry structures. Journal of Disaster Science and Management, 1(1). doi:10.1007/s44367-025-00004-4.

[18] Wang, Y., Li, B., Nong, Q., & Liu, X. (2025). Quasi-Static Testing of Unreinforced Masonry Walls Using Different Styles of Basalt Fiber Mortar Surface Reinforcements. Buildings, 15(7), 1074. doi:10.3390/buildings15071074.

[19] Yavartanoo, F., Kim, C. S., & Kang, T. H. K. (2025). Cost-Effective Retrofitting Method for Dry-Stack Masonry Walls Using Fiber-Reinforced Polymers. International Journal of Concrete Structures and Materials, 19(1), 48. doi:10.1186/s40069-025-00792-2.

[20] Tekeli, H., Yüksel, C., Anıl, Ö., & Mutlu, E. O. (2024). Experimental and numerical investigation of hysteretic earthquake behavior of masonry infilled RC frames with opening strengthened by adding rebar-reinforced stucco. Bulletin of Earthquake Engineering, 22(6), 3169–3207. doi:10.1007/s10518-024-01905-0.

[21] Sathiparan, N. (2020). State of art review on PP-band retrofitting for masonry structures. Innovative Infrastructure Solutions, 5(2), 62. doi:10.1007/s41062-020-00316-9.

[22] Thomason, J. L. (2019). Glass fibre sizing: A review. Composites Part A: Applied Science and Manufacturing, 127, 105619. doi:10.1016/j.compositesa.2019.105619.

[23] Li Li, H. (2021). Fiberglass Science and Technology. Springer International Publishing, Cham, Switzerland. doi:10.1007/978-3-030-72200-5.

[24] Yamamoto, K., Rajasekharan, S., & Meguro, K. (2020). Study on Moisture Effects on Masonry Retrofitted with Fiber Reinforced Paint. 17th World Conference on Earthquake Engineering, 13-18 September, 2020, Sendai, Japan.

[25] Juliafad, E., Ananda, R., Sulistyo, D., Suhendro, B., & Hidayat, R. (2019). Nonlinear Finite Element Method Analysis of after Fire Reinforced Concrete Beam Strengthened with Carbon Fiber Strip. Journal of Physics: Conference Series, 1175(1), 12019. doi:10.1088/1742-6596/1175/1/012019.

[26] Nofriadi, N., Dary, R. W., Sitompul, M., & Melinda, A. P. (2021). Experimental Study of Shear Capacity of Brick Walls with the Addition of Wire Mesh. Cived, 8(3), 185. doi:10.24036/cived.v8i3.114150. (In Indonesian).

[27] Acharya, A. (2020). Metal oxide glass fibers. Metal Oxide Glass Nanocomposites, 273–278. doi:10.1016/B978-0-12-817458-6.00016-0.

[28] Saleem, M. U., Numada, M., Amin, M. N., & Meguro, K. (2016). Seismic response of PP-band and FRP retrofitted house models under shake table testing. Construction and Building Materials, 111, 298–316. doi:10.1016/j.conbuildmat.2016.02.073.

[29] Yamamoto, K., Numada, M., & Meguro, K. (2015). Shake table tests on one-quarter scaled models of masonry houses retrofitted with fiber reinforced paint. 14th International Symposium on New Technologies for Urban Safety of Mega Cities in Asia, 29-31 October, 2015, Kathmandu, Nepal.

[30] SNI 15-2094-2000. (2000). Solid Red Brick for Wall Cladding. National Standardization Agency. Badan Standardisasi Nasional (BSN), Jakarta, Indonesia. (In Indonesian).

[31] ASTM C136/C136M-19. (2025). Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates. ASTM International, Pennsylvania, United States. doi:10.1520/C0136_C0136M-19.

[32] ASTM C33/C33M-18. (2023). Standard Specification for Concrete Aggregates. ASTM International, Pennsylvania, United States. doi:10.1520/C0033_C0033M-18.

[33] SNI 03-4165-1996. (1996). Testing Method for Flexural Strength of Red Brick Walls in the Laboratory. Badan Standardisasi Nasional (BSN), Jakarta, Indonesia. (In Indonesian).

[34] Rivai, F. W. (2018). Diagonal Shear Test on Hook-Cement Brick Walls Based on ASTM Standard E519-02-2002. Bachelor Thesis, Universitas Islam Indonesia, Sleman, Indonesia. (In Indonesian).

[35] ASTM E519-02. (2017). Standard Test Method for Diagonal Tension (Shear) in Masonry Assemblages. ASTM International, Pennsylvania, United States. doi:10.1520/E0519-02.

[36] Yadav, S., Damerji, H., Keco, R., Sieffert, Y., Crété, E., Vieux-Champagne, F., Garnier, P., & Malecot, Y. (2021). Effects of horizontal seismic band on seismic response in masonry structure: Application of DIC technique. Progress in Disaster Science, 10, 100149. doi:10.1016/j.pdisas.2021.100149.

[37] Wuaten, H. M. (2022). Energy Dissipation in Columns Jacketed with Wire Mesh and Self-Compacting Concrete Under Cyclic Loads. Cantilever: Jurnal Penelitian Dan Kajian Bidang Teknik Sipil, 11(1), 55–64. doi:10.35139/cantilever.v11i1.136.

[38] Multazam, Z., Yamamoto, K., & Meguro, K. (2022). Diagonal Tension (Shear) Test of Full-Scale Concrete Hollow Blocks Masonry Assemblages Retrofitted By Fiber-Reinforced Paint. MDPI in OHOW 2022 – The 1st International Symposium on One Health, One World. MDPI, Basel, Switzerland. doi:10.3390/ohow2022-13617.

[39] Bahmani, H., Mostafaei, H., & Mostofinejad, D. (2025). Review of Energy Dissipation Mechanisms in Concrete: Role of Advanced Materials, Mix Design, and Curing Conditions. Sustainability (Switzerland), 17(15), 6723. doi:10.3390/su17156723.

[40] Chen, P. H., & Chung, D. D. L. (2013). Mechanical energy dissipation using cement-based materials with admixtures. ACI Materials Journal, 110(3), 279–289. doi:10.14359/51685661.