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EXPERIMENTAL STUDY ON COMPRESSIVE STRENGTH AND SHEAR STRENGTH OF MASONRY UNIT WITH FIBER GLASS AND POLYPROPYLENE FIBER PAINT COATING

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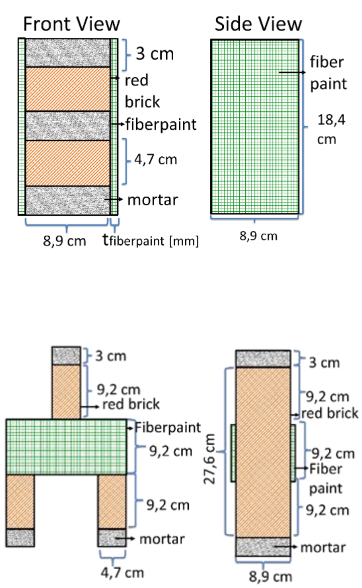
Graphical abstract



Abstract

In this study, the effects of fiber layers on the compressive and shear strength properties of masonry are investigated. The aim is to improve the mechanical properties of masonry walls that are prone to earthquakes The experimental investigations provide information on the mechanical properties of Indonesian masonry blocks under two conditions: without and with fiber coating. Two different types of fibers were used in this study: Fibreglass and Polypropylene fiber. The fiber content is 8% for 1 kg of paint with 5% water. The thickness of the coating applied to the masonry ranges from 1 mm to 3 mm. The compressive strength of the samples with a layer of polypropylene fibers with a thickness of 1 mm and 3 mm is 30.32 kg/cm², 31.16 kg/cm² and 47.16 kg/cm², respectively. The compressive strength of the samples with a layer of glass fiber paint with a thickness of 1 mm, 2 mm, and 3 mm is 30.1 kg/cm², 31.22 kg/cm², 53.31 kg/cm² and the value of the control sample is 25.89 kg/cm². The shear strength of masonry with polypropylene-coated fiber with a layer thickness of 1 mm, 2 mm, and 3 mm is 3.93 kg/cm², 4.64 kg/cm², and 5.89 kg/cm². The bricks reinforced with glass fiber paint with a layer thickness of 1 mm, 2 mm, and 3 mm have 3.77 kg/cm², 5.31 kg/cm², and 5.05 kg/cm². The addition of a 3 mm-thick glass fiber layer led to a significant increase in the maximum compressive strength of 51.44% compared to the control sample. The addition of a 3 mm-thick polypropylene layer led to the most significant increase in shear strength, with a percentage increase of 36.84% compared to the brick without reinforcement.

Keywords: Fiber Paint, Polypropylene, Fiberglass, Compressive Strength, Shear Strength

1.0 INTRODUCTION

A masonry wall is a construction component that serves to separate one area from another, primarily by its non-structural attributes, rather than bearing any significant load. Walls serve as physical partitions that demarcate the boundary between the external environment and the internal space. They function as protective barriers, preventing the ingress of light, wind, rainwater, dust, and other natural elements. Additionally, walls fulfill the role of spatial dividers within a dwelling, segregating areas of natural space and demarcating private rooms and secluded zones. In both a general and specialized context, artistic function plays a significant role [1]. The utilization of brick walls as a construction component dates back to 9000 BC and continues to persist in contemporary building practices. Brick walls are renowned for their affordability and ease of construction, as well as their notable thermal insulation and soundproofing characteristics.

Buildings with brick walls have historically led to significant loss of life, injuries, and economic damage. Earthquake data from around the world highlights the rapid collapse of brick structures during seismic events, resulting in numerous casualties. Recent earthquakes in Indonesia, such as the 6.1 Mw earthquake in West Pasaman in 2022, saw 6627 collapsed or severely damaged houses, leading to 27 fatalities and thousands injured [2], [3], [4]. Similarly, the Cianjur earthquake in November 2022, registering a magnitude of 5.6, caused 6570 houses to collapse or sustain severe damage, resulting in 310 deaths and displacing 58,000 individuals from their homes [5], [6]. The majority of these casualties were attributed to collapsed brick walls, underscoring their susceptibility to seismic forces [7]

The brittleness of red brick walls, coupled with the poor mortar-brick bond and substandard material quality, contribute to cracks forming at brick joints and wall-column/beam interfaces, compromising structural integrity [8]. These cracks can lead to the collapse of wall elements, posing a significant risk of severe injuries, particularly to vital areas like the head, which can be fatal.

It is essential to strengthen existing masonry houses/buildings with masonry walls to reduce earthquake damage to masonry building types for better compressive, shear, and flexural strength [9], [10], [11]. Finding appropriate strengthening methods is important due to the large population of red-brick buildings in earthquake-prone areas, which continues to increase along with the increase in population.

Brick wall reinforcement methods for developing countries should be able to increase the strength and deformation capacity of buildings by considering several characteristics such as guaranteed availability of materials, ease of implementation in the sense that it is easy to implement by the community, acceptable and adaptable to the culture of the community, and economical (affordable price)[12].

Conventionally, various methods were used to reinforce red brick walls such as using fiber-reinforced polymer tape, steel plates, and geotextile [13]. However, the methods installed generally require a high level of expertise in implementation and some of the materials are difficult to obtain and cost considerable money. Methods such as using chicken wire (ferrocement) and elastoplastic tape are somewhat challenging to install and still need to be coated with mortar for the appearance of the wall and to increase its durability from environmental influences such as heat and rain [12].

Boen *et al*. (2019) studied reinforcing masonry walls with ferrocement wrapping, a thin composite layer of cement mortar matrix with woven wire. They found that adding this layer increased earthquake resistance. Juliafad & Melinda (2020) and Juliafad (2021) investigated using polypropylene fibers to enhance mortar and masonry compressive strength, showing increased flexural strength of masonry walls [14], [15]. However, these methods still present challenges in implementation due to the complexity and cost of materials.

A seismic retrofitting method for red brick walls is proposed using fiber-reinforced paint to achieve earthquake-safe houses, meeting strengthening criteria with readily available, affordable materials that can be quickly implemented, even by the general public. This approach is chosen for its simplicity, as it combines the familiar practice of painting buildings with the added benefit of strengthening them.

The objective of this study is to enhance the strength of red brick masonry by incorporating Polypropylene and Fiberglass fibers into waterproof paint. Polypropylene fiber, a fundamental material widely utilized in plastic manufacturing, constitutes one of the primary components. Polypropylene fiber enhances concrete strength and durability, as evidenced by its proven ability to improve properties such as ductility, shock resistance, wear resistance, and shrinkage resistance [14], [16], [17].

Fiberglass, a lightweight and durable material made from processed liquid glass fibers, is resistant to impacts and corrosion, boasting a moderate strength-to-weight ratio. Waterproof paint is applied to prevent water absorption by brick surfaces, as moisture promotes mold growth and accelerates weathering, affecting the brick's compressive and shear strength. Given the potential of Polypropylene and fiberglass fibers to enhance these properties in concrete, trials are necessary to evaluate the impact of paint containing these fibers on red brick's strength.

2.0 METHODOLOGY

2.1 Material

The first step is to test the mechanical properties of the red brick, sand, and water used to make the pair of red bricks.

2.1.1 Sand

The analysis of testing data indicates that the average silt content in the sand used is 2.07%, meeting the maximum permissible limit of 5% set by SII.005 and ASTM C.33 standards. The actual sand moisture content is 2.95%. According to SNI 03-1737-1989 and ASTM C566 standards, the permissible moisture content range for sand is 3% - 5%. Therefore, the fine aggregate meets the requirements for aggregate moisture content testing. The average loose bulk density and compacted bulk density are 1.235 kg/l and 1.46 kg/l, respectively. According to SNI 03-4804-

1998, both loose and compacted bulk densities meet the minimum requirement of 1.20 kg/l.

2.1.2 Red Brick

The visible qualities of red bricks include color, sound, shape, and right-angled edges. According to SNI 15-2094-2000, red bricks should produce a clear sound when tapped, have flat surfaces, be free from cracks, and have right-angled edges. Five red bricks were sampled for testing. The results show that the bricks used have flat surfaces, produce a clear sound when tapped, have right-angled edges, and are free from cracks.

According to the Indonesian Standard for red brick material, SNI 15-2094-2000, red brick is a building material in the form of a long rectangular prism, solid or hollow. It is used to construct building walls, made from clay with or without additives, and burned at 800^{0}C so as not to disintegrate when immersed in water. Following SNI 15-2094-2000 [18] (19). The size and tolerance of solid red bricks for wall pairs can be seen in Table 1. Compressive strength and coefficient of variation for red brick can be seen in Table 2.

Table 1 Sizes and Tolerances of Red Bricks

Modul	Size and tolerance		
	Height (mm)	Width (mm)	Length (mm)
M-5a	65 ± 2	92 ± 2	190 ± 4
M-5b	65 ± 2	100 ± 2	190 ± 4
M-6a	52 ± 3	110 ± 2	230 ± 5
M-6b	55 ± 3	110 ± 2	230 ± 5
M-6c	70 ± 3	110 ± 2	230 ± 5
M-6c	80 ± 3	110 ± 2	230 ± 5

(Source: SNI 15-2094-2000 (19))

Table 2 Compressive Strength Value and Coefficient of Variation of Red Brick

Class	Minimum Average Compressive Strength of 30 Bricks Tested Kg/cm² (MPa)	Coefficient of Variation of the Tested Average Compressive Strength (%)
50	50 (5)	22
100	100 (10)	15
150	150 (15)	15

(Source: SNI 15-2094-2000 (19))

2.2 Fabricated Masonry Unit

This research conducts compressive and shear strength tests of brick blocks. Compressive strength test consists of brick block without fiber paint coating as controlled sample, brick block with fiberglass fiber paint coating, and with polypropylene fiber paint.

2.2.1 Fiber paint Coating Production

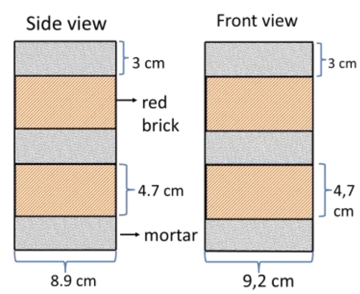
In this study, two types of fiber paint were utilized: a waterproof paint blended with polypropylene fibers and another type mixed with fiberglass. To produce the polypropylene fiber paint, 8% polypropylene was combined with 1 kg of paint, while the fiberglass fiber-paint mixture was created by blending 8% fiberglass fibers with 1 kg of paint (Figure 1).

(a). fiber glass (b) fiberglass Paint

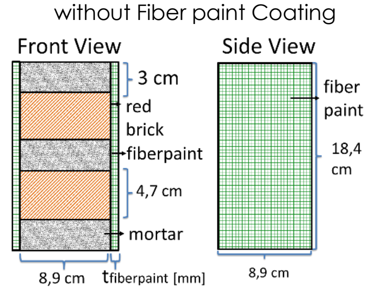
Figure 1 Fiber Paint Mixing Process

2.2.2 Compressive Test Unit

The design of the brick unit with fiber paint coating (Figure 2) consists of red brick cut in half, each of which is united with mortar. We used 1 part of Portland Cement and 3 fine aggregates for the mix proportion for mortar (Figure 2(a)). For the compressive block unit, we applied fiber paint coating to two sides of the masonry unit with different thicknesses: 1 mm, 2 mm, and 3 mm (Figure 2 (b)).



(a). Design of Compression Test Sample of Redbrick without Fiber paint Coating



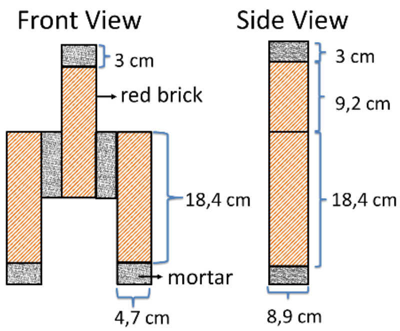
(b) Design of red brick with Fiber paint Coating

Figure 2 Brick Compression Test Sample

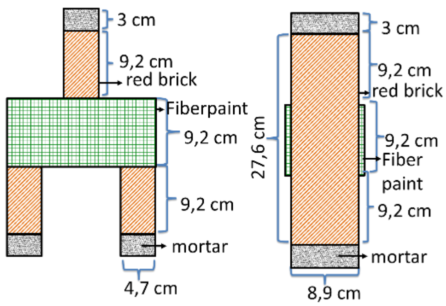
2.2.3 Shear Test Unit

The shear strength test of red brick masonry is a test on bricks that is carried out to determine the mortar's capacity against the shear force on the wall when it receives earthquake loads or forces that act longitudinally or in the long direction on the wall (Figure 3 (a)). Figure 4 show the manufacture of compression test (a) and shear test Specimen (Figure

4 (b)). The shear brick sample consists of 3 red bricks united with 3cm mortar, then each side with the area indicated black shaded area in Figure 3 (b) is coated with fiber paint.



(a). Design of Shear Test Sample of Redbrick without Fiber paint Coating



(a). Design of Shear Test Sample of Redbrick with Fiber paint Coating

Figure 3 Brick Shear Test Sample

(a) The casting of brick pair sample

(b) The casting of shear specimens

Figure 4 The brick pair specimen production

conducted as well to brick unit with 3mm mortar pilaster thickness and specimen of brick unit with 3mm waterproof paint.

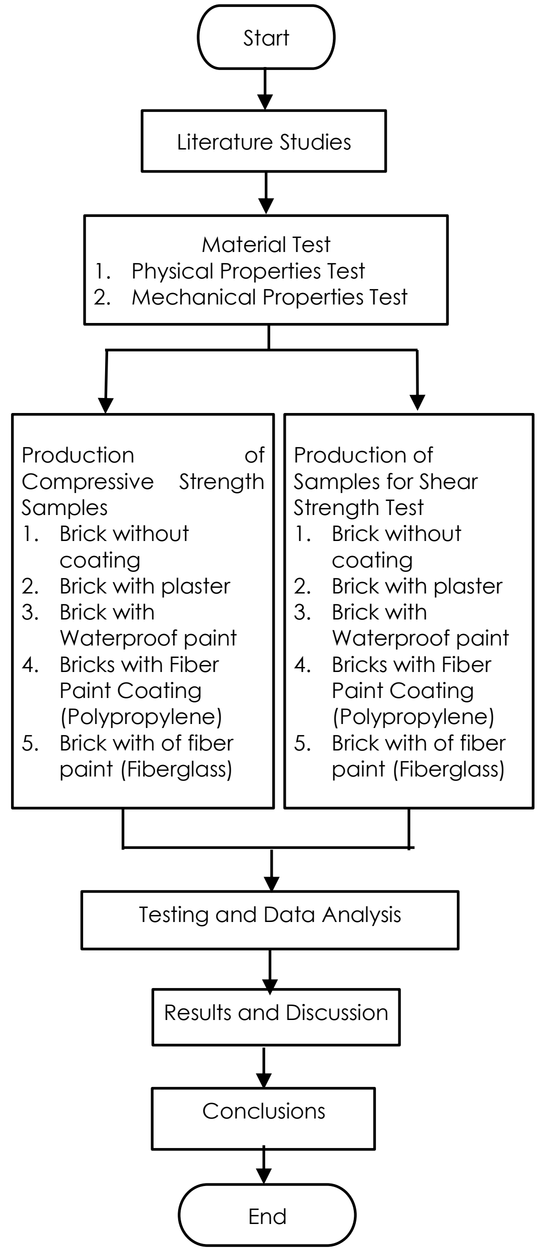


Figure 5 Flowchart of the research

2.3 Method

This research is conducted using experimental methods, namely by conducting experiments in person to obtain a result related to the variable being investigated. Experiments will be shown on the test object pair of red bricks (Figure 5). The specimen will be divided into 3 types; control, polypropylene fiber paint, and fiberglass fiber paint red brick block sample. The control sample did not have a coating while the pair of red bricks will be coated with a layer of fiber paint. Compression and shear test procedure

Any variation of the fiber is tested to determine the strengths of the compression and shear strength. The test objects produced were brick pairs coated with polypropylene fiber paint with percentages of each type of object 8% and variations in the thickness of each percentage variation of the fiber, 1mm, 2mm, and 3mm, respectively—implementation of test guidelines to existing test standards. The procedure was applied as well for fiberglass fiber paint brick

After conducting testing, compiling, and analyzing data using equations 1 for compressive strength and equation 2 for shear strength, the results and discussion culminate in the conclusion regarding the study on the reinforcement of bricks through fiber paint coating.

2.2 Experimental Design

Masonry samples were tested using a Compression Testing Machine, Merk ELLE. The testing is located in the Material and Soil Mechanic Laboratory Universitas Negeri Padang Indonesia. The test object is pressed with a compression machine until it is crushed with a pressing speed of up to 2 Kg/cm²/sec (Figure 6).

The compressive strength of a test object is obtained from the highest compressive load and the smallest compressive area. The average compressive strength is the sum of the compressive strengths of all test objects divided by the number of samples. In calculating the compressive strength of red brick, the formula:

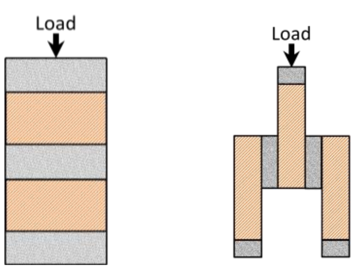
$$F = P/A \qquad \text{eq.1}$$

where F = compressive strength (kg/cm2), P = Maximum Load (kg), and A = Area of Pressure (cm²).

The shear strength test of red brick masonry was carried out based on ASTM 155207 (Standard Practice for Capping Concrete Masonry Units) (26). Calculating the shear strength of masonry can use the formula:

$$F_{vh} = \frac{p+w}{2(b \times h')} \qquad \text{eq.2}$$

Where: F_{vh} = Shear Strength [kg/cm²], P = Maximum Load (Kg), b: Brick Width (cm), h': shear plane length (cm) = ½ h, and w: Sample Weight (Kg)



(a) Load for compression test (b) Load for Shear test

Figure 6 Experimental design and loading

3.0 RESULTS AND DISCUSSION

This section discusses the results and observations from the compressive and shear strength of brick without fiber coating as well as the tests of sample with fiberglass paint and polypropylene paint coating.

3.1 Compressive Strength

The results of the brick compressive strength test are presented in Table 3. In Figure 7-9, it can be seen that adding a layer of fiber paint affects the compressive strength of the red brick masonry. From Table 3, it can be seen that the percentage of compressive strength of red brick has increased after being coated with Polypropylene and Fiberglass fiber paint with a thickness of 1 mm, 2 mm, and 3 mm, respectively, amounting to 17.11%, 16.26%, 20.36%, 20.59%, 82.16%, and 105,91%.

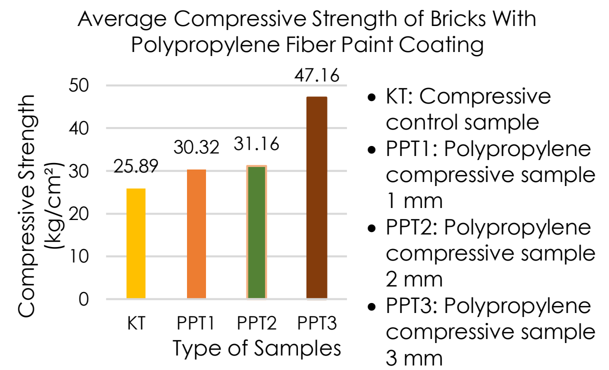


Figure 7 Average Compressive Strength of Bricks with Polypropylene Fiber Paint Coating

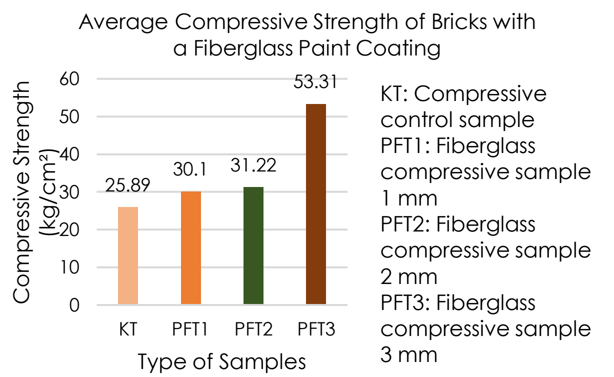


Figure 8 Average Compressive Strength of Bricks with a Fiberglass Paint Coating

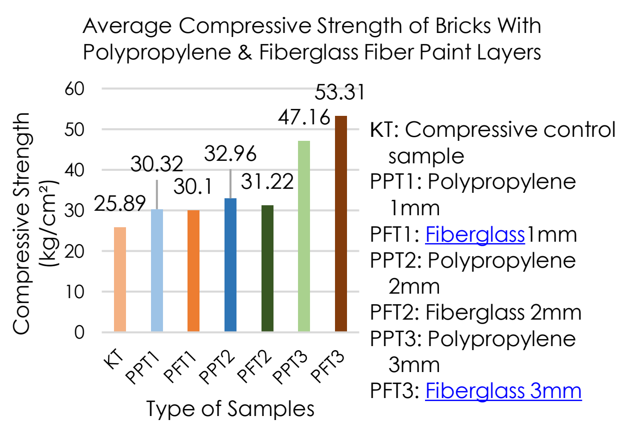


Figure 9 Average Compressive Strength of Bricks With Polypropylene and Fiberglass Fiber Paint Layers

Figure 10 shows that the 3 mm thickness of fiber paint coating gives the highest strength increment on the brick pairs for polypropylene and fiberglass fiber paint. In this study, the fiberglass fiber paint at 3 mm thickness has a higher compressive strength than Polypropylene. When we compare the 3 mm coating of fiber pain with the 3 mm coating of ordinary mortar (BT3) and 3 mm thickness of paint only (BPT3), the fiber-reinforced paint can show the improvement of compressive strength (Figure 8). In Table 3, Fiberglass paint brick offers superior value over polypropylene due to its higher tensile strength of 1300 MPa, surpassing polypropylene fiber's 486 MPa [18].

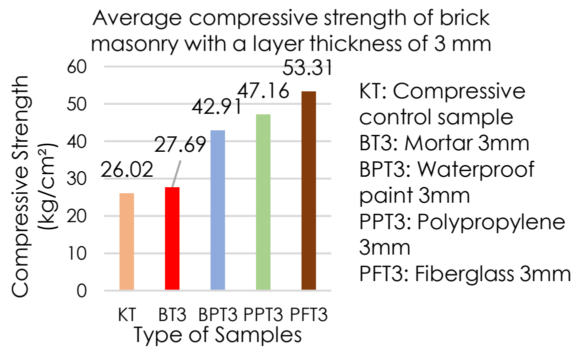


Figure 10 Average compressive strength of brick masonry with a layer thickness of 3 mm

Table 3 Percentage Increase in Compressive Strength of Red Brick

Samples	Code	Normal Brick Compressive Strength (A) (kg/cm²)	Compressive Strength of Brick Testing (B) (kg/cm²)	Percentage ($\frac{B-A}{B} x\ 100\%$)
Compression without paint	CC	25,89	25,89	0
Shear without paint	SC	25,89	25,89	0.00%
Mortar 3 mm	BT_3	25,89	27,69	6.95%
Waterproof paint 3 mm	BPT_3	25,89	42,91	65.74%
Polypropylene 1 mm	PPT_1	25,89	30,32	17.11%
Fiberglass 1 mm	PFT_1	25,89	30,1	16.26%
Polypropylene 2 mm	PPT_2	25,89	31,16	20.36%
Fiberglass 2 mm	PFT_2	25,89	31,22	20.59%
Polypropylene 3 mm	PPT_3	25,89	47,16	82.16%
Fiberglass 3 mm	PFT_3	25,89	53,31	105.91%

3.2 Shear Strength

Brick masonry samples are tested in the Testing Laboratory using a Compression Testing Machine. The results of the brick shear strength test are presented in Table 4. Figure 11-14 shows that adding a layer of fiber paint significantly affects the shear strength of the red brick masonry without paint.

From Table 4, it can be seen that the shear strength of red brick masonry using a layer of Polypropylene fiber paint and a layer of Fiberglass Fiber paint with a layer thickness of 1 mm, 2 mm and 3 mm has increased compared to red brick masonry without a layer of fiber paint, masonry with a layer of plaster, and waterproof paint layer, with percentage increases of 5.65%, 1.34%, 24.73%, 43.82%, 58.33% and 35.75%. After testing brick masonry with fiber paint layers, adding 3 mm of Polypropylene increases compressive strength by 82.16% and Fiberglass by 105.91% (Figure 12). Shear strength increases by 58.33% with 3 mm of Polypropylene and 43.82% with 2 mm of Fiberglass (Table 4). Polypropylene exhibits higher shear strength due to its modulus elasticity of 4800 MPa compared to Fiberglass's 4286 MPa [18].

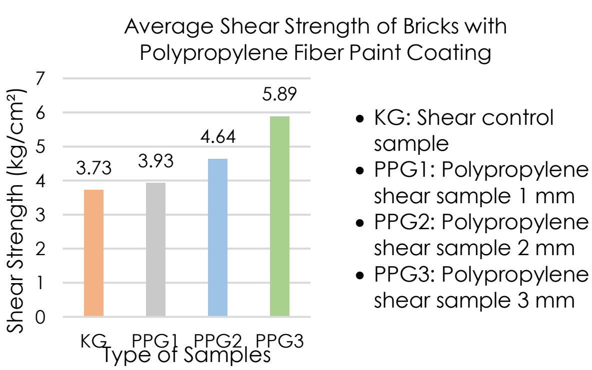


Figure 11 Average Shear Strength of Bricks with Polypropylene Fiber Paint Coating

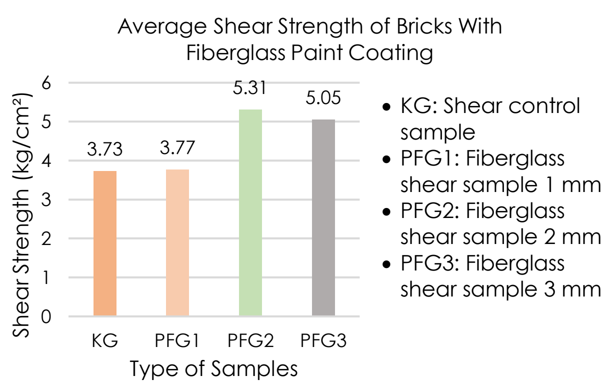


Figure 12 Average Shear Strength of Bricks with Fiberglass Paint Coating

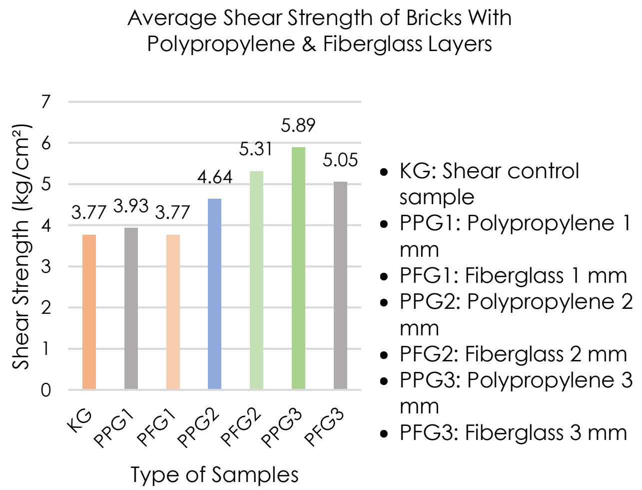


Figure 13 Average Shear Strength of Bricks with Polypropylene and Fiberglass Layers

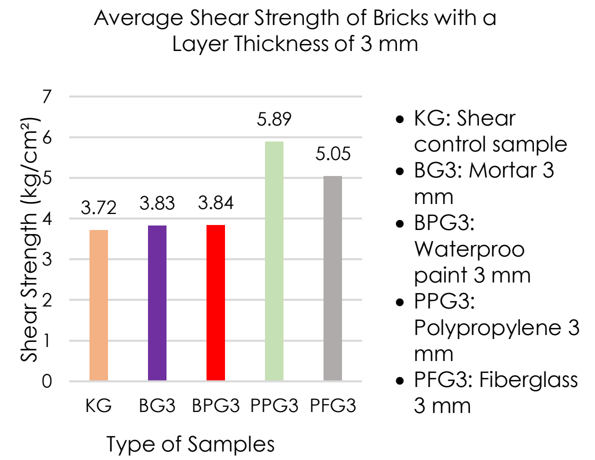


Figure 14 Average Shear Strength of Bricks with a Layer Thickness of 3 mm

Table 4 Percentage of Shear Strength of Red Brick Pair

Samples	Code	Normal Brick Shear Strength Value (A) (kg/cm²)	Shear Strength of Brick Testing (B) (kg/cm²)	Percentage $(\frac{B-A}{B} x\ 100\%)$
Control	KG	3,72	3,72	0
Mortar 3 mm	BG_3	3,72	3,83	2,87%
Waterproof paint 3 mm	BPG_3	3,72	3,84	3,12%
Polypropylene 1 mm	PPG_1	3,72	3,77	1,33%
Fiberglass 1 mm	PFG_1	3,72	4,64	19,83%
Polypropylene 2 mm	PPG_2	3,72	5,31	30,47%
Fiberglass 2 mm	PFG_2	3,72	5,89	36,84%
Polypropylene 3 mm	PPG_3	3,72	5,05	26,34%

3.3 Crack Pattern

Adding fiber paint coating increases the red brick masonry unit's compressive and shear strength, as mentioned in sections 3.1 and 3.2. This section enhances understanding of the effects of fiber paint coating addition to the brick unit through its crack or failure pattern under the compression and shear loads.

There are four types of shear failure: interface failure (type A), block failure (Type B), mortar failure (Type C), and partial block/mortal failure (Type D). Type A has a crack in the interface which propagates also in the brick, type B show debonding accompanied with shear mortar failure, type C show debonding accompanied with shear mortar failure and type D has a shear crack propagation through mortar [19], [20], [21].

Figure 15(a) shows the crack pattern that appeared on the control sample of the compression unit, wherein a small compressive strength happened in a brick unit on all sides of the sample (Figure 15(a)). Meanwhile, in Figure 15(b), the compressive unit shows no crack on the side, which is coated with fiber paint. The shear test shows that the fiber paint endured the shear plane between brick and mortar to collapse (Figure 15(d)) and is classified as type A. The shear failure was changed from type A to type B where the crack observed on the red block not in the interface of mortar and brick.

The elastic nature of fiber paint influences the failure and has a strong binding capacity. Judging from the brick masonry's damage pattern, the bricks did not immediately fail when they received the compressive load from the digital Compression Testing Machine. The coated parts were still perfectly attached because of the adhesive power of the paint mixed with Polypropylene fiber and Fiberglass fiber.

4.0 CONCLUSION

This study aims to strengthen red brick masonry by adding Polypropylene and Fiberglass fibers to waterproof paint, leveraging Polypropylene's known enhancement of concrete's strength and durability. The compressive strength of bricks coated with 1 mm, 2 mm, and 3 mm layers of Polypropylene fiber paint is 30.32 Kg/cm², 31.16 Kg/cm², and 47.16 kg/cm², respectively, exhibiting percentage increases of 17.11%, 20.36%, and 82.16% compared to normal samples. Similarly, bricks coated with Fiberglass fiber paint at the same thicknesses show compressive strengths of 30.1 Kg/cm², 31.22 Kg/cm², and 53.31

Kg/cm², with percentage increases of 16.26%, 20.59%, and 105.91% from normal samples.

Shear strength of brick masonry with 1 mm, 2 mm, and 3 mm layers of Polypropylene fiber paint is 3.93 Kg/cm², 4.64 Kg/cm², and 5.89 kg/cm², demonstrating increases of 5.65%, 24.73%, and 58.33% from the normal sample. Likewise, shear strength of brick masonry with Fiberglass fiber paint at the same thicknesses is 3.77 Kg/cm², 5.35 Kg/cm², and 5.05 kg/cm², with increases of 1.34%, 43.82%, and 35.75% from normal samples, particularly notable at the 2 mm thickness.

(a) Compressive brick without fiber paint

(b) Compressive brick with fiber paint

(c) Shear Brick without fiber paint

d. Shear Brick with fiber paint

Figure 15 Crack Pattern of Brick Specimen

This research is crucial for reinforcing brick walls in seismic-prone areas, offering a straightforward approach with accessible materials and methods. Further investigation is required to understand the impact on buildings already coated with mortar plaster.

Acknowledgment

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