# Ferrocement Roof Reinforced with Fiberglass

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**Abstract**

This study aimed to produce fiberglass-reinforced ferrocement roof tiles to investigate their physical and mechanical properties. The production process involved manufacturing flat using a cement-to-sand ratio of 1:2.75 and a water-to-cement ratio (W/C) of 0.50. The fiberglass used in the research was a chopped strand mat with a density of 450 grams per square meter. The results of the study show that the average density of the 1-layer, 2-layer, and 5-layer fiberglass-reinforced ferrocement roof tiles is $2.13 \times 10^4$, $2.10 \times 10^4$, and $2.08 \times 10^4$ kilograms per cubic meter, respectively. The average water absorption values were found to be 5.05%, 5.44%, and 5.98% for the respective layers, indicating an increase in water absorption with decreasing density. The average breaking strength values were 3.140237, 3.897697, and 4.986658 kilonewtons per meter, respectively. The water penetration testing showed no water droplets under the surface, and they met the heat resistance standards specified in the industrial product standards, namely TIS 535-2556 for concrete roof tiles. The 5-layer fiberglass-reinforced ferrocement roof tiles exhibited the highest heat resistance and strength compared to the 1-layer and 2-layer fiberglass-reinforced tiles. These findings indicate that fiberglass-reinforced ferrocement, which incorporates composite polymer (FRP) materials, significantly impacts the strength of the material, enabling the production of innovative roofing options as a practical alternative for the construction industry.

**Keywords**: Roof Tile, Ferrocement, Fiberglass

## Introduction

Over the past decade, there has been a notable increase in residential construction, making the selection of construction materials crucial for factors such as aesthetics, durability, and cost-effectiveness. It is essential for both buildings and residential houses to have visually striking features that catch the eye, and roof tiles play a significant role as a prominent element of the house. They must be resilient, capable of withstanding external weather conditions, and provide effective thermal insulation to prevent heat from penetrating the structure. A weak and vulnerable roof structure can have detrimental effects on the inhabitants, particularly during natural disasters such as earthquakes, heavy rainstorms, or snow accumulation. In some areas, roof tiles are an essential component that requires careful selection or improvement to ensure their durability over time due to deterioration with age or environmental factors. Roof tiles can be categorized based on the materials used in their production; for example, concrete roof tiles have gained significant popularity due to their strength and durability. However, they do have certain limitations, such as being prone to cracking and occasional leaks. On the other hand, asbestos roof tiles are mixtures; therefore, prolonged exposure to the particles emitted by these tiles can pose health risks when inhaled. An alternative option that has garnered favor is ferrocement roof tiles, which offer versatility in terms of shape and form, allowing for customized designs. They require fewer materials, resulting in cost and transportation savings. Additionally, they offer strength comparable to that of other composite materials. The strength of concrete structures can be increased by incorporating steel and high-density composite materials and reinforcement using composite materials. The literature review suggests that the use of fiber-reinforced polymer (FRP) to enhance strength comes with increased costs and reduced performance at high temperatures. Additionally, achieving satisfactory homogeneity with the substrate (such as concrete or limestone) has proven challenging. As a result, composite materials have emerged as a promising solution, with industry leaders in the textile sector leading the way (Li & Lam, 2018). Textile-reinforced concrete (TRC), which is commonly utilized for small-scale structures, cannot withstand comparable forces.The researchers are interested in utilizing fiber-reinforced polymer (FRP), a composite polymer material that contains tensile and compressive strength properties in cement compared to other fiber types (Isikdag, 2015), to manufacture fiberglass ferrocement roof tiles and to explore the possibility of producing these tiles. This involves incorporating fiberglass as a strong reinforcing material into the cement through an alternating layering technique and increasing the number of layers of FRP materials to create roof tiles that are resilient and resistant to weather changes during different seasons.

**Research Purpose**

To produce fiberglass-reinforced ferrocement roof tiles and to study their physical and mechanical properties that are suitable for roof tiles

**Research Methodology**

The research study was divided into two parts. Part 1 focused on the production of ferrocement roof tiles reinforced with fiberglass chopped strand mat, which had a density of 450 grams per square meter in a flat tile design measuring 33 × 42 × 3 $cm^3$. Part 2 examined the physical and mechanical properties of the fiberglassreinforced ferrocement roof tiles, TIS 535-2556.

**The production and mix ratio of fiberglass-reinforced ferrocement roof tiles**

The study focused on the production of fiberglass-reinforced ferrocement roof tiles in a flat tile design, with dimensions of 33 × 42 × 3 $cm^3$. The mixture ratio for the ferrocement roof tiles reinforced with fiberglass was as follows (by weight): cement-to-sand ratio of 1:2.75.
water-cement ratio (W/C) of 0.50, water: waterproofing admixture (100:0.5) (W/C), and the inclusion of 1, 2, and 5 layers of fiberglass.

**The production process of ferrocement roof tiles**

The production of fiberglass-reinforced ferrocement roof tiles was conducted to study their physical and mechanical properties according to the standard specification TIS 535-2556.

**The preparation of materials and components**

Fiberglass preparation: the fiberglass was cut into sizes of 38 × 2 $cm^2$ and 29 × 2 $cm^2$, then woven by placing the alternating strands of 38 × 2 $cm^2$ size first, with a spacing of 2 centimeters between each strand along the length. Subsequently, the strands of 29 × 2 $cm^2$ size were placed with a spacing of 2 centimeters between each strand along the width, as illustrated in Figure 1.

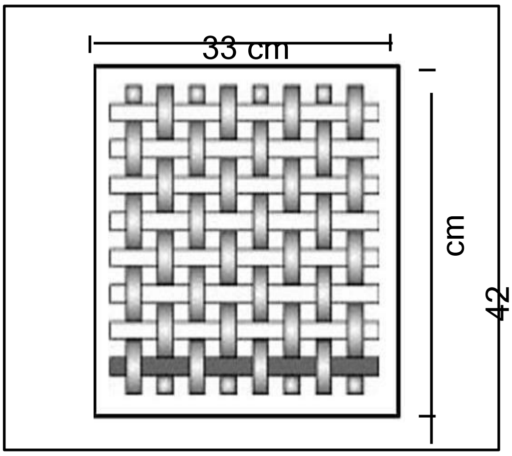



**Figure 1.** Alternating Fiberglass Placement in Each Layer

The sand was sieved through a mesh size of 16, then retained by using a sieve size of 30. The process of casting fiberglass-reinforced cement roof tiles involved mixing cement and sand in a ratio of 1:2.75 with a water-to-cement ratio (W/C) of 0.50 by weight. The mixture was blended until a consistent mixture was obtained. The mixed mortar was then poured into a mold with a thickness of 1.5 centimeters and smoothed using a trowel.
Then, it was compacted evenly and firmly. The prepared fiberglass was placed on the mortar, following the illustration in Figure 1 (1 layer of fiberglass, 1.5 cm thick mortar layer). Another mortar layer was placed on top of the fiberglass laid in the mold, and a trowel was used to smooth the surface, followed by the use of a compacting bar. It was left in the mold for 24 hours, and then the mold was removed, and the piece was cured in water for 28 days. The same process was repeated, but this time, the number of fiberglass layers was increased to 2 (1.0 cm thick mortar layer) and 5 layers (0.5 cm thick mortar layer), respectively, as shown in Figure 2.

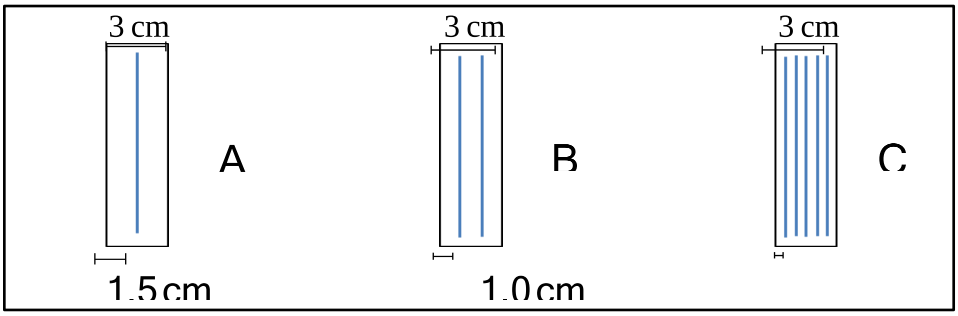



**Figure 2.** The thickness of Mortar in Fiber Glass Placement, Cases A, B, and C

**Testing and Data Analysis**

Testing and data analysis of fiber-reinforced ferrocement roof tiles were conducted to study their physical and mechanical properties according to the TIS 5352556 standard.

**Physical Properties Testing**

1. After a curing period of 28 days, the density testing of manufactured roof tiles was conducted. Measurements were taken at both edges and the center to determine the average values for the thickness, width, and length of the tiles on all sides, three times on each side. The density value of the test samples was obtained by measuring the average value, as demonstrated in Figure 3.

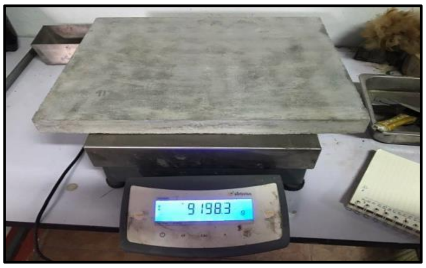


**Figure 3.** Density Testing of Test Samples

2. The width of each tile was measured using a measuring tool with a precision of 0.1 cm. The average value was calculated, and the results of the tiles were reported.
3. The water absorption test was performed using six test pieces from the tiles that were tested for breaking strength, with each piece weighing no less than 1,000 g. The test was conducted for 24 hours at room temperature. The results of the test were reported, as illustrated in Figure 4.

**Figure 4.** Water Absorption Test

4. The water penetration test was conducted according to the standards specified in TIS 535-2556. Each sample tile was placed in a frame made of nonabsorbent material and sealed using a sealing compound. The frame was filled with water, and the water level was maintained above

the highest point on the upper surface of the tile by 50 mm or above the maximum height of the upper surface of the tile by 12 mm, depending on which level was higher, for a duration of 2 hours. Subsequently, the underside of the sample tile was inspected for the presence of water droplets, and the test results were recorded.

5. The heat resistance test was conducted by subjecting the test tiles to a burning process in an external furnace at a temperature of 600°C for a duration of 2 hours. The test involved observing the degree of bending, surface texture, odor, and color changes of the test tiles that occurred after the burning process. The test results were recorded, as shown in Figure 5.

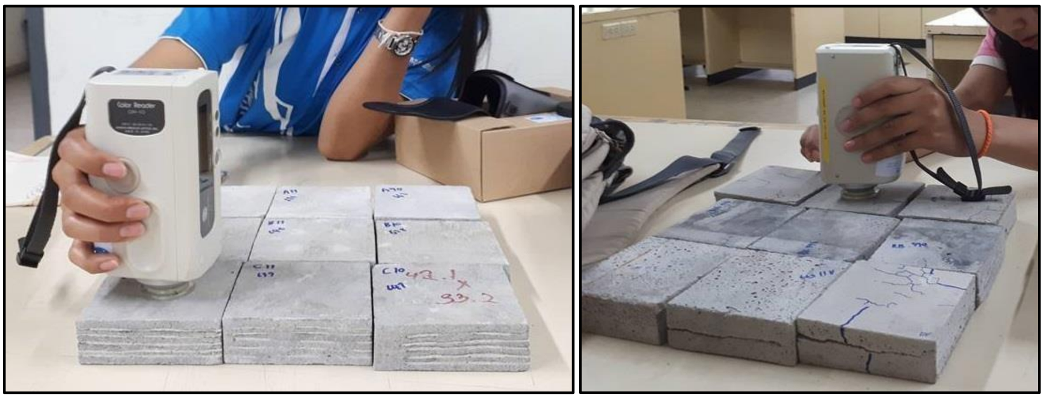


**Figure 5.** The Heat Resistance Test

**Mechanical Properties Testing**

The tile-breaking strength test was conducted as follows: A total of six sample tiles were taken for testing. The force was incrementally applied uniformly until the tiles were broken. The applied force was recorded as the tile breaking strength for each tile, and the minimum required breaking strength for each tile was calculated as shown in Figure 6.

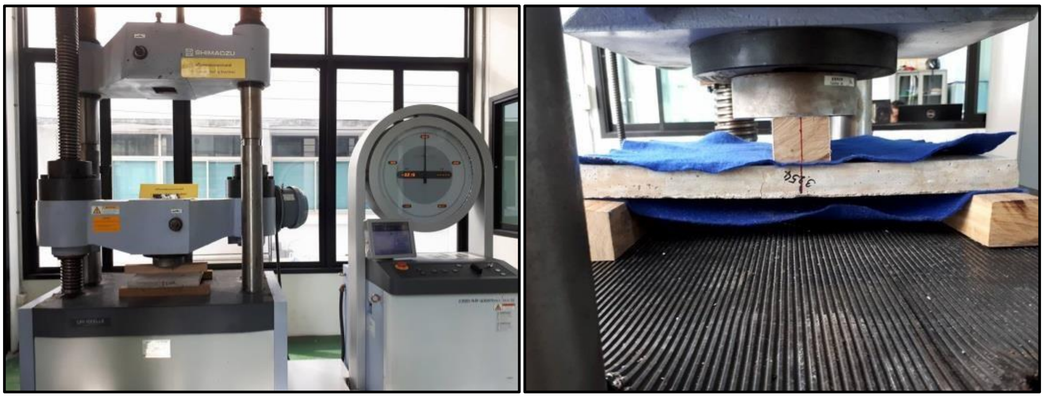


**Figure 6.** The Tile Breaking Strength Test

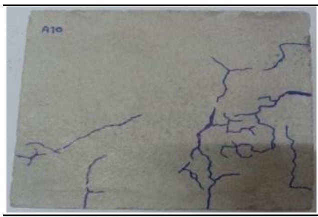
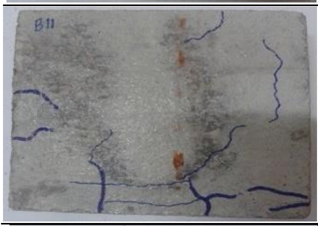
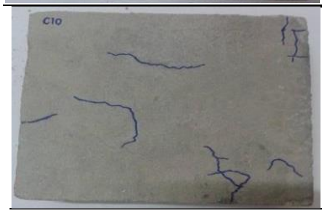
**Results**

**1. Physical Properties Testing**

A study of the density properties of fiberglass-reinforced ferrocement roof tiles revealed that the roof tiles reinforced with 1 layer of fiberglass had the highest average density of 2.13 × $10^4$ kg/cm$^3$, while the roof tiles reinforced with 5 layers of fiberglass had the lowest average density of 2.08 × $10^4$ kg/cm$^3$. A study on the width and length usability of roof tiles revealed that roof tiles reinforced with 5 layers of fiberglass had an average width usability of 33.2 cm with the highest tolerance, while roof tiles reinforced with 2 layers of fiberglass had an average width usability of 33.1 cm with the lowest tolerance. The tolerance was measured at 0.58% and 0.43%, respectively.

A study on the water absorption of fiberglass-reinforced ferrocement roof tiles found that roof tiles reinforced with 1 layer of fiberglass had the lowest water absorption, with an average water absorption of 5.32%. On the other hand, roof tiles reinforced with 5 layers of fiberglass had the highest water absorption, with an average water absorption of 6.37%.

**Table 1** *The heat resistance and physical characteristics of fiber-reinforced ferrocement roof tiles*

| Test samples | | Physical characteristics | | |
|---|---|---|---|---|
| | | Bending properties | Surface texture | Color (before : after) |
|  | A10 | Not bending | Visible cracks with a width of approximately < 3 mm | L : (75.43 : 66.37) a : (+0.20 : +0.57) b : (+4.80 : +2.90) |
|  | B11 | Not bending | Small cracks that are difficult to observe unless thoroughly inspected with a width of approximately < 1 mm. | L : (70.70 : 56.76) a : (+0.27 : +0.44) b : (+6.43 :+2.50) |
|  | C10 | Not bending | Hairline cracks with a width of approximately < 0.1 mm | L : (65.37 : 63.27) a : ( -0.36 : +1.00) b : (+5.37 :+4.20) |

A study on the heat resistance properties of fiberglass-reinforced ferrocement roof tiles during combustion revealed that the tiles reinforced with 5 layers of fiberglass experienced the least amount of cracking (small cracks that are difficult to observe unless thoroughly inspected, with a width of approximately < 1 mm and a length of 120 mm). The tiles reinforced with 3 layers of fiberglass exhibited slightly more cracking (small cracks that were difficult to observe unless thoroughly inspected, with a width of approximately < 1 mm and a length of 180 mm). However, the tiles reinforced with 1 layer of fiberglass showed the most significant cracking (visible cracks with a width of approximately < 3 mm and a length of 250 mm). The occurrence of cracking in the concrete was influenced by the rate of load application and temperature. When the temperature of the concrete increased, it expanded, and when it cooled down, it contracted, leading to the formation of cracks.

## 2. Mechanical Properties Testing

The mechanical properties testing was conducted to study the strength characteristics of the manufactured tiles, following the standard TIS 535-2556.

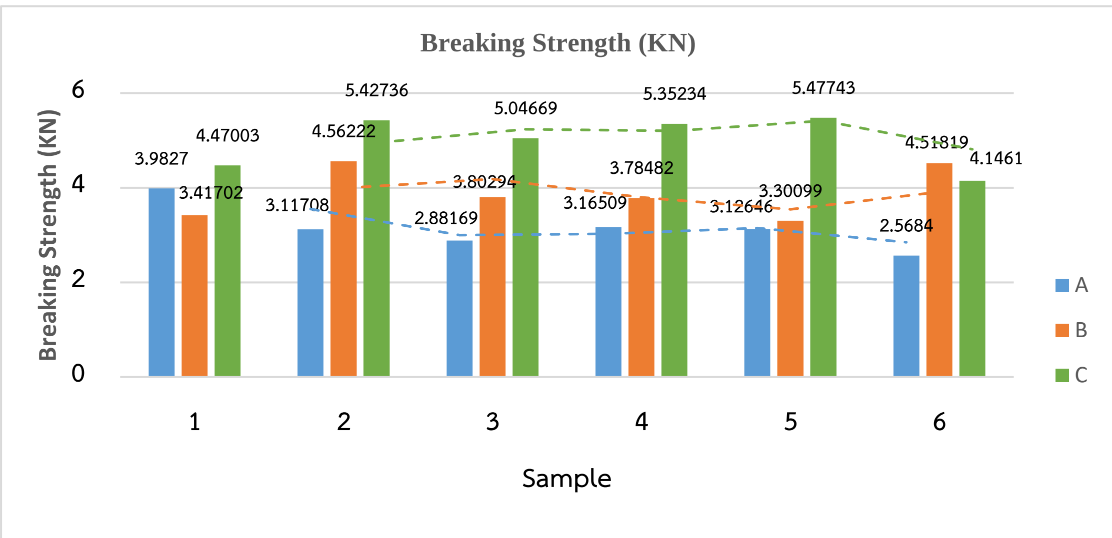



**Figure 7.** The Breaking Strength of Fiber-Reinforced Ferrocement Roof Tile

It was found that the ferrocement roof tiles reinforced with 5 layers of fiberglass had the highest average breaking strength compared to other variations. The tiles reinforced with 2 layers of fiberglass and 1 layer of fiberglass had the lowest breaking strength. The average breaking strengths in terms of perpendicular compression were 4.986658 kN, 3.897697 kN, and 3.140237 kN, respectively. All tested tiles exhibited breaking strengths higher than the industry standard specified in TIS 535-2556.

## Discussion

The fiberglass-reinforced ferrocement roof tiles, manufactured for the study, exhibit a consistent average density. This can be attributed to the fact that the primary mass of the test specimens is composed of mortar, while the supplementary fiberglass reinforcement has a relatively lower mass. These observations are in accordance with the research findings of Fahmy et al. (2012). The five-layered fiberglass-reinforced ferrocement roof tiles exhibit the highest water absorption. This leads to the formation of voids between the mortar matrix, which are then filled with infiltrating water. It is evident that increasing the number of fiberglass layers enhances water absorption. According to the load-bearing tests, the five-layered fiberglass-reinforced ferrocement roof tiles demonstrate excellent heat resistance and exhibit the highest breaking strength. This is attributed to the reinforcing properties of fiberglass, which significantly contribute to its overall strength. These findings are consistent with the research conducted by Amornpunyapat et al. (2021). The roof tiles also demonstrate high tensile strength and meet the industry product standards specified in TIS 535 - 2556.

## Conclusion

The ferrocement roof tiles, reinforced with one layer of fiberglass, had the highest average density of 2.13 × $10^4$ kg/cm$^3$, while the roof tiles reinforced with five layers of fiberglass had the lowest average density of 2.08 × $10^4$ kg/cm$^3$. The width and length usability of the ferrocement roof tiles were suitable for practical use, as they exhibited an average dimensional tolerance of only 0.22%. In the water absorption test, all tiles met the industry product standards specified in TIS 535 - 2556, and the water penetration test showed no water droplets beneath the tiles. In the heat resistance test, all the ferrocement roof tiles did not bend when exposed to burning heat. The surface texture of the tiles reinforced with 1 layer of fiberglass exhibited the highest cracks, while the tiles reinforced with 5 layers of fiberglass had the lowest cracks. The color of all test tiles slightly changed after firing, with a slight decrease in brightness, remaining within the gray color range but shifting towards red and blue hues. The compression test of the fiberglass-reinforced ferrocement roof tiles also passed the industry standards specified in TIS 535 - 2556.

## Suggestions

1. Recommendations for Applying Research Findings: It is suggested to utilize fiberglass-reinforced ferrocement roof tiles by adjusting the length of the fibers to suit the size of the tiles for application. This will ensure that the roof tiles possess the desired physical and mechanical properties according to the standard guidelines.
2. Suggestions for Future Research: It is recommended to explore the possibility of incorporating certain additives, such as polyester and nylon, to enhance the strength and reduce the weight of fiberglass-reinforced ferrocement roof tiles.

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