Mechanical performance of mortars reinforced with steel fibers

Matías Renato Castro Castillo[(a)], Jaime Xavier Nieto-Cardenas[(a)], Paúl Illescas-Cárdenas[(a)], Pilar Roxana Naspud Uruchima[(a)]
[(a)]Academic Unit of Engineering, Industry, and Construction, Universidad Católica de Cuenca. Cuenca, Ecuador, 010101.
Corresponding author: jxnietoc@ucacue.edu.ec

Vol. 04, Issue 01 (2025): July
DOI: 10.53591/easi.v4i1.2410
ISSN-e 2953-6634
ISSN Print: 3073-1526
Submitted: June 17, 2025
Revised: June 26, 2025
Accepted: July 12, 2025

Engineering and Applied Sciences in Industry
University of Guayaquil. Ecuador
Frequency/Year: 2
Web:
revistas.ug.edu.ec/index.php/easi
Email:
easi-publication.industrial@ug.edu.ec

How to cite this article:
Castro Castillo, M. R.et al.(2025). Mechanical performance of mortars reinforced with steel fibers. *EASI: Engineering and Applied Sciences in Industry*, 4(1), 42–51. https://doi.org/10.53591/easi.v4i1.2410

Abstract. This article focuses on the evaluation of the resistance of mortars to indirect tension and compression, simple and reinforced, with different percentages of steel fiber. The aim is to find resistant and economical solutions to reinforce informal housing, through the use of plaster that improves the general characteristics of a masonry. Masonry constructed in an informal or artisanal manner has a high degree of structural vulnerability. First, the indirect tensile strength and displacements supported by simple and reinforced mortars are compared, where it is observed that reinforced mortars offer greater strength and deformation capacity as a function of the percentage of fiber. Then, the compressive strength is compared, where the reinforced mortars also show adequate results. In terms of economics, the reinforced mortar presents disadvantages due to the cost of the fibers; in the percentages studied in this article (10, 15, 20 and 25%), the use of reinforced mortars for informal housing is not so attractive; it is recommended to develop similar investigations with different percentages of fiber.

Keywords: Reinforced mortar, steel fiber, strength-deformation curve, compression test, informal housing.

Resumen: Este artículo se centra en la evaluación de la resistencia a la tracción y compresión indirectas de morteros, simples y reforzados, con diferentes porcentajes de fibra de acero. El objetivo es encontrar soluciones resistentes y económicas para reforzar viviendas informales, mediante el uso de revoque que mejore las características generales de la mampostería. La mampostería construida de manera informal o artesanal presenta un alto grado de vulnerabilidad estructural. En primer lugar, se compara la resistencia a la tracción indirecta y los desplazamientos soportados por morteros simples y reforzados, donde se observa que los morteros reforzados ofrecen mayor resistencia y capacidad de deformación en función del porcentaje de fibra. Posteriormente, se compara la resistencia a la compresión, donde los morteros reforzados también muestran resultados adecuados. En términos económicos, el mortero reforzado presenta desventajas debido al costo de las fibras; en los porcentajes estudiados en este artículo (10, 15, 20 y 25%), el uso de morteros reforzados para viviendas informales no resulta tan atractivo; se recomienda desarrollar investigaciones similares con diferentes porcentajes de fibra.

Palabras claves: Mortero reforzado, fibra de acero, curva derza-desplazamiento, ensayo de compresión, vivienda informal.

1. INTRODUCTION

Construction is a widespread activity globally. In Latin America, approximately 50% of construction is carried out informally, without the supervision of a qualified professional (El Comercio / IG-EPN, 2011). One of the main characteristics of this type of practice is the limited adherence to building codes and minimum construction standards (Vergara-Perucich et al., 2022). These structures often exhibit significant deficiencies, especially in the face of seismic events or extreme weather conditions (Samaniego, 2020). One potential solution involves reinforcing existing masonry to effectively increase the strength, durability, and stability of such structures, thereby ensuring the safety of occupants (Gonzalez, 2015).

A key component of non-structural masonry is mortar, which consists of a mixture of cement, fine aggregate, water, and additives. Due to its versatility, mortar is commonly used for block bonding, coating, and plastering walls (Quirós, 2018). In an effort to improve the physical and mechanical properties of this material, researchers have explored the incorporation of fibers and additives into mortar mixes. Among the different types of fibers, steel fibers stand out due to their excellent mechanical properties (Aguirre, 2021).

The use of fibers in masonry mortars has been documented since the 20th century. Graham introduced them to enhance strength and durability, and in 1920, Griffith published the first scientific study on the use of steel fibers in mortars (Bustos García, 2018). Steel fibers act as reinforcement within the cementitious matrix, improving tensile and flexural performance and thereby reducing cracks and fissures under load (Marcalíková et al., 2019). These fibers are known to increase both load-bearing capacity and durability, making them an optimal option for constructions with low initial strength (Nam, J.W.; Kim, S.M.; Park, S.H.; Han, 2018).

Recent studies on non-structural masonry reinforced with metallic fibers have shown promising results. For instance, Dawood & Ramli (2010), Guo et al. (2024), and Nian et al. (2024) investigated improvements in impact resistance and crack control in cementitious materials through the incorporation of steel fibers at various scales. He (2023) characterized the uniaxial tensile behavior of high-performance concrete enhanced with nano-concrete fibers. Another example is the reported increase in stiffness—2.4 times higher than mortars reinforced with welded wire mesh and 3.8 times higher than unreinforced walls. Furthermore, mortars reinforced with steel fibers exhibited a 67% increase in strength compared to unreinforced ones, and a 6.5% improvement over mortars reinforced only with welded mesh (Nieto-Cárdenas et al., 2023).

Other studies, such as those by Hidayat et al. (2021) and Li et al. (2011), analyzed variations in compressive and flexural behavior in fiber-reinforced mortars. At early ages, fibers also help control cracking during the hardening process, as demonstrated by Kang et al. (2024). Similarly, Nian et al. (2024) examined the influence of fibers in asphalt mixtures. Shen et al. (2022) and collaborators developed a mathematical model to predict crack formation in beams reinforced with steel fibers and BFRP bars. In addition, Pan & Ma (2017) and Younis et al. (2021) analyzed the impact resistance of concrete with metallic fibers. In the context of fatigue performance in high-strength concrete beams, Zhang et al. (2025) observed superior behavior in elements reinforced with steel fibers.

In general, whether in concrete, asphalt, or mortar (Carrillo et al., 2020; Hidayat et al., 2021b; Li et al., 2011b; Shi et al., 2021), the incorporation of fibers demonstrates considerable potential to enhance mechanical properties. This makes fiber reinforcement a viable solution for structurally improving informal housing.

This study presents two comparative analyses: first, it examines the mechanical properties (force–displacement behavior) of plain mortar and mortar reinforced with metallic fiber (DRAMIX 3D) at four different fiber contents by weight of cement: 10%, 15%, 20%, and 25% in indirect tension, and 10%, 15%, and 20% in compression. Second, it compares the strength and cost between plain mortar and fiber-reinforced mortars. The objective is to determine the optimal steel fiber content for application in the plastering of informal housing, where walls typically lack protective coatings. This reinforcement aims to prevent masonry block detachment during seismic events, thereby improving the structural integrity of dwellings and the safety of their occupants.

In summary, the use of steel fibers in masonry mortar—particularly for informal housing—offers an accessible solution for enhancing structural strength, reducing cracking, and increasing durability. This contributes to improved safety for residents in the face of seismic and other adverse events.

2. EXPERIMENTAL METHODOLOGY

The experimental study involved testing a commonly used mortar with a sand-to-cement ratio of 3:1. This mortar was evaluated both in its plain state and with steel fiber reinforcement at 10%, 15%, 20%, and 25% by weight of cement in the mix.

The preparation process, applicable standards, and theoretical foundations are outlined as follows:

- Prior to mortar mixing, tests were conducted to determine the granulometry, density, and moisture content of the fine aggregate, as well as the density of the cement.
- The granulometric analysis of fine aggregate was performed according to ASTM C136 (ASTM International, 2015).
- The density of the fine aggregate was determined following ASTM C128 (ASTM International, 2023).
- The density of the cement was calculated in accordance with ASTM C188 (ASTM International, 2023).
- The 3:1 mortar mix design is based on Sánchez (2000), using a volumetric proportioning method, which closely replicates mixing practices in informal construction.
- The mixing of mortar for cylindrical and cubic specimens was carried out manually to emulate methods used in informal housing construction.
- A total of 7 cylinders and 6 cubes were prepared for each mortar type to perform indirect tensile and axial compression tests.
- Indirect tensile tests were conducted according to ASTM C496 (ASTM International, 2016). Cylindrical specimens with a diameter of 10 cm and a height of 20 cm were tested using a loading rate of 0.234 kgf/cm²/s (ASTM International, 2016).
- Compression tests were performed following ASTM C109 (ASTM International, 2015). Cubic specimens with 50 mm edge length were tested using a loading rate of 2.5 kgf/cm²/s (ASTM International, 2015).

The materials and equipment used in this research are listed below:

- Fine aggregate sourced from the canton of Santa Isabel, Azuay Province, Ecuador.
- Type GU cement (Guapán, n.d.).
- DRAMIX 3D steel fibers from the company Ideal Alambrec-Bekaert (Ltd., 2017).
- Cubic and cylindrical molds for casting mortar specimens.
- Shimadzu Concrete 2000x series hydraulic press for indirect tensile and compression tests.
- Minor tools such as scales, shovels, wheelbarrows, compaction rods, rubber hammers, and other general tools.
- Le Chatelier flask and Abrams cone.

Figure 1. Materials used in mortar production. Source: Authors' own work.

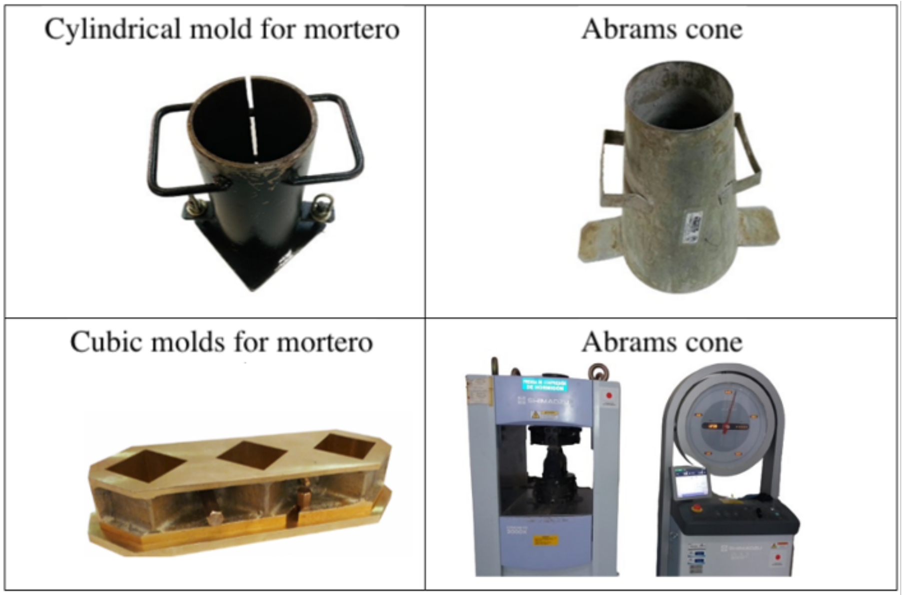


Figure 2. Tools used for the experimental tests. Source: Authors' own work.

Table 1. Designation and Coding of the Specimens.

Code	Description
TI.MS	Cylindrical specimen of plain mortar
TI.M-10	Cylindrical specimen of mortar with 10% fiber
TI.M-15	Cylindrical specimen of mortar with 15% fiber
TI.M-20	Cylindrical specimen of mortar with 20% fiber
TI.M-25	Cylindrical specimen of mortar with 25% fiber
MS	Cubic specimen of plain mortar
M-10	Cubic specimen of mortar with 10% fiber
M-15	Cubic specimen of mortar with 15% fiber
M-20	Cubic specimen of mortar with 20% fiber

Figure 3. Manual mixing process of the mortar.

Figure 4. Casting and demolding of mortar specimens.

3. RESULTS

The results of the experimental investigation are presented as follows:

The fineness modulus of the sand was determined to be 2.79, which complies with the ASTM C136 standard [12], falling within the acceptable range of 2.30 to 3.10.

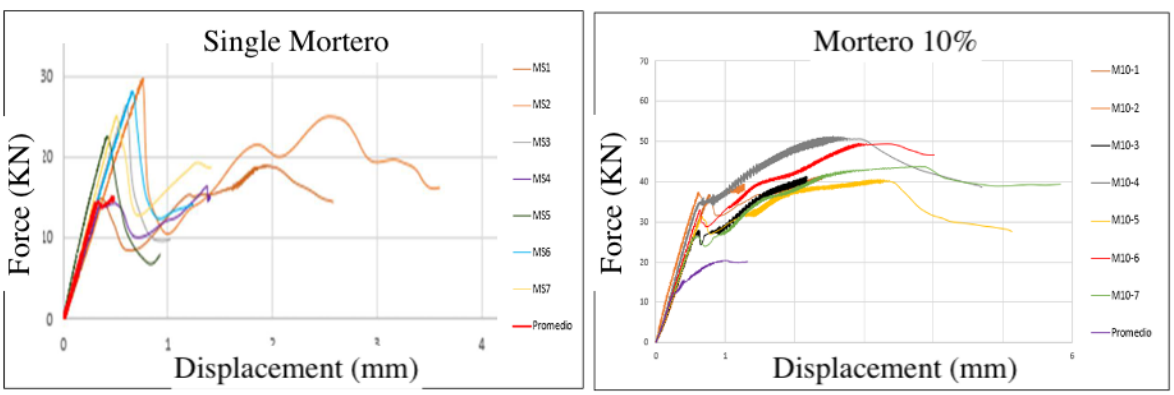
The density of the cement, obtained using the Le Chatelier flask in accordance with ASTM C188 [14], was 2.81 g/cm³.

The relative density of the sand was found to be 2.30, calculated using the pycnometer method in accordance with ASTM C128 [13].

The force–deformation curves and compressive strength results presented in the following graphs illustrate the mechanical response of the specimens after testing using a hydraulic press, through indirect tensile and compressive strength tests.

Indirect tensile strength results of mortars:

The graphs in Figure 5 show the results of the indirect tensile tests (force–displacement curves) for cylindrical specimens of each mortar mix design.



(A) (B)

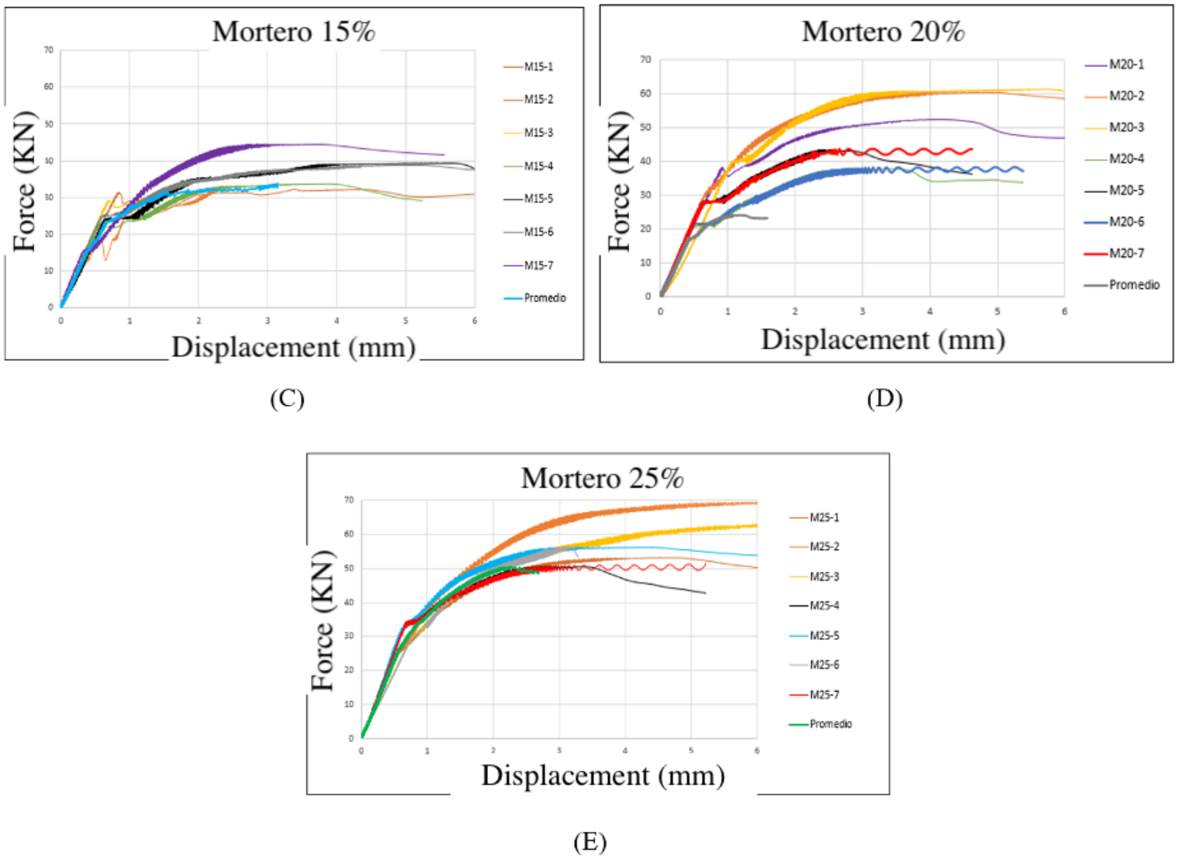
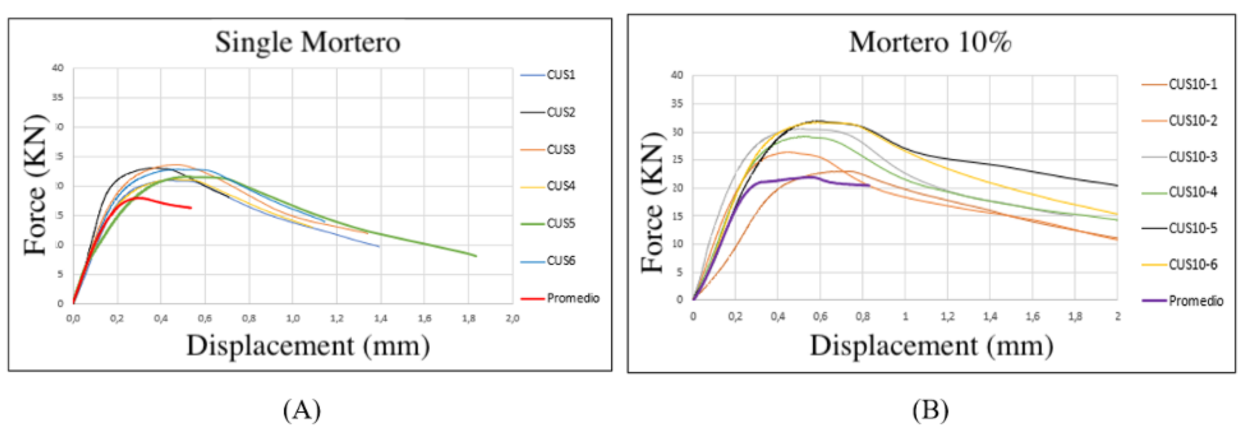
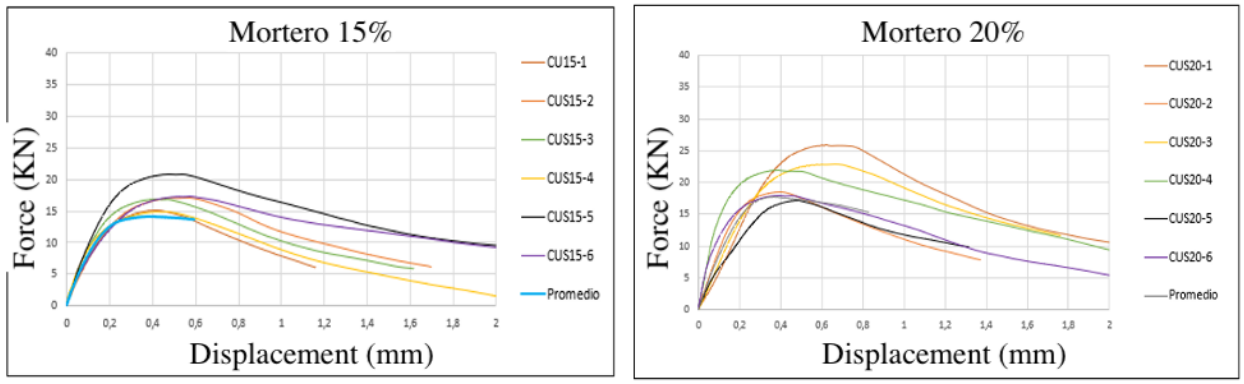


Figure 5. Force–displacement curves from indirect tensile tests.

The graphs in Figure 6 present the results of the compression tests (force–displacement curves) for cubic specimens of each mortar mix.

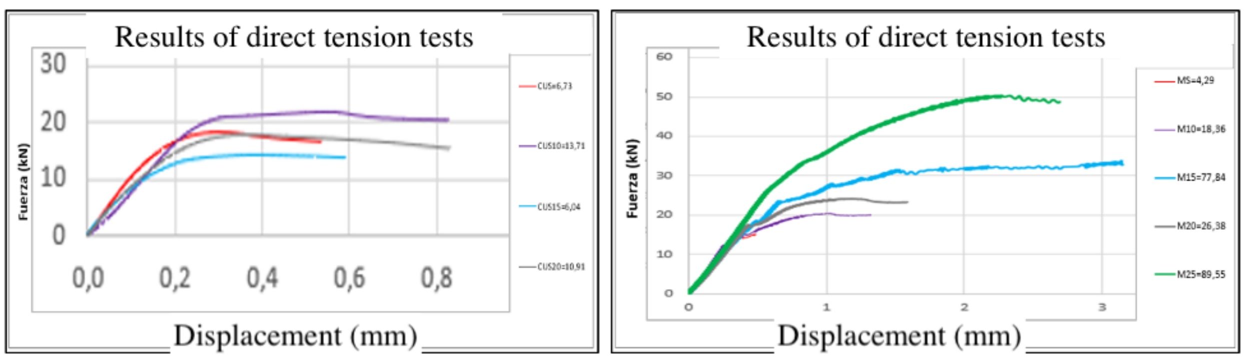




(C) (D)

Figure 6. Force–displacement curves from uniaxial compression tests.

Figure 7A displays the summary curves for each fiber dosage under indirect tensile testing using cylindrical molds, along with the area under each curve; the corresponding data are shown in the legend. Similarly, Figure 7B presents the summary curves and areas under the curve for the compression tests conducted on mortar cubes.



(A) (B)

Figure 7. Summary force–displacement curves from indirect tensile and uniaxial compression tests.

After analyzing the compression and indirect tensile test curves for the different mortar types, the following observations can be made:

- The mortar specimen that withstood the highest indirect tensile load was the one with 25% fiber content, supporting a load of 50.36 kN.
- The specimen with the highest compressive strength corresponded to the mortar with 20% fiber content, reaching 7 MPa.
- The greatest maximum displacement in the indirect tensile test was recorded in the 15% fiber specimen, with a displacement of 3.14 mm before failure.
- In the compression tests, the plain mortar showed a very similar response to the mortars reinforced with 10% and 15% fiber, indicating that adding these percentages of fiber does not significantly improve compressive strength.
- In the indirect tensile tests, the plain mortar displayed a clearly different response compared to any fiber-reinforced mortar, exhibiting an almost entirely elastic behavior, whereas fiber-reinforced mortars demonstrated post-peak resistance and increased energy absorption.
- Strength vs. Cost Analysis per Cubic Meter of Mortar (Uninstalled):
- A unit price analysis was performed considering current market costs of the materials in the local context:
  - Cement: $0.16 per kg
  - Steel fiber: $4.00 per kg
  - Sand: $0.01 per kg

- Water: $0.57 per m³
- Labor: $3.50 per hour

Table 2. Summary Table of Strength–Cost Comparison.

Mortar	Compressive Strength (MPa)	Indirect Tensile Strength (kN)	Cost per m³ (USD)
Simple	7,20	15,01	110,90
10% fiber	8,70	20.46	335,54
15%fiber	5,60	43,55	447,86
20% fiber	7,00	24,11	560,18
25% fiber	N/A	50,36	672

The difference in cost per cubic meter of mortar is mainly attributed to the amount of fiber used, as the unit price of steel fibers is relatively high and they are currently not easily available in the local market.

4. CONCLUSIONS

This research demonstrates the increase in mortar strength resulting from the inclusion of steel fibers in the mix. The key findings from the results are summarized below:

- Regarding indirect tensile strength, it is evident that the more steel fiber is added, the better the performance. The mortar with 25% fiber content was 3.35 times stronger in indirect tension than the plain mortar.
- In terms of displacement, the mortar with 15% fiber content exhibited a capacity to deform 6.58 times more than the plain mortar before failure.
- For compressive strength, the specimen with 25% fiber also achieved the highest resistance, with a value 3.57 times greater than that of the plain mortar.
- In all reinforced cases (except for plain mortar), it was observed that the steel fibers continued to contribute structurally after the initial failure of the matrix, allowing the material to bear additional loads. This post-peak behavior resulted in the characteristic curves previously presented.
- Although the 25% fiber content significantly enhances the mechanical properties of the mortar, it presents two major drawbacks:
    - Workability is severely compromised, making the mixing and application process difficult.
    - Cost is substantially increased—this mortar is 6.02 times more expensive than plain mortar due to the high price of steel fiber, which is 21 times more costly than cement per kilogram.
    - Within the range of fiber contents studied, this type of mortar is not recommended for informal housing applications, mainly due to its high cost and poor workability. It is suggested that future studies evaluate lower fiber percentages than those tested in this article.

The authors recommend further research to develop a future line of knowledge, particularly exploring the application of fiber-reinforced mortars in compression-loaded masonry prisms, to better understand their potential contribution to masonry wall performance.

ACKNOWLEDGMENTS

The authors express their sincere gratitude to the family of Engineer Matías Castro, who kindly provided valuable information that made it possible to complete this work. Engineer Castro sadly passed away a few weeks after finishing his degree project. We also thank the laboratories of the Universidad Católica de Cuenca for their support and collaboration during the experimental phase of this research.

REFERENCES

Aguirre, J. (2021). Las fibras de vidrio, acero y polipropileno en forma de hilachas, aplicadas como fibras de refuerzo en la elaboración de morteros de cemento.

ASTM C128. (2023). Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate (Vols. CO128-22).

ASTM C188-17. (2023). Standard Test Method for Density of Hydraulic Cement (Vols. CO188-17).

ASTM International. (2015). Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates.

ASTM International. (2023). Standard Test Method for Density of Hydraulic Cement.

Bustos García, A. (2018). Morteros con propiedades mejoradas de ductilidad por adición de fibras de vidrio, carbono y basalto. 1–324.

Carrillo, J., Pincheira, J., & Flores, L. E. (2020). Quasi-static cyclic tests of confined masonry walls retrofitted with mortar overlays reinforced with either welded-wire mesh or steel fibers. Journal of Building Engineering, 27(October 2019), 10. https://doi.org/10.1016/j.jobe.2019.100975

Dawood, E. T., & Ramli, M. (2010). Flowable high-strength system as repair material. Structural Concrete, 11(4), 199–209. https://doi.org/10.1680/stco.2010.11.4.199

El Comercio / IG-EPN. (2011). La informalidad en la construcción es el mayor riesgo en un terremoto. Instituto Geofísico – Escuela Politécnica Nacional. https://www.igepn.edu.ec/servicios/noticias/381-la-informalidad-en-la-construcción-es-el-mayor-riesgo-en-un-terremoto

Gonzalez, G. (2015). Estudio de durabilidad de paredes de mamposteria reforzadas con mortero y fibras naturales y artificiales.

Guapán, U. C. N. (UCEM) – P. (n.d.). Ficha Técnica Cemento Hidráulico Guapán Tipo GU.

Guo, Y., Liu, X., Wang, X., Ye, Q., Xiang, K., & Wang, R. (2024). Multiscale Hybrid Steel Fiber Enhances the Impact Resistance and Crack Resistance of Cement-based Materials. Cailiao Daobao Materials Reports, 38(2). https://doi.org/10.11896/cldb.22030271

He, Y. (2023). Characterisation of unidirectional tensile failure performance of steel fibre nano high strength concrete. International Journal of Microstructure and Materials Properties, 16(6), 533–544. https://doi.org/10.1504/IJMMP.2023.134769

Hidayat, B. A., Sabdono, P., Indriyantho, B. R., & Hung, C.-C. (2021a). Compressive and flexural behavior of fiber-reinforced mortar: An experimental study. Aip Conference Proceedings, 2447. https://doi.org/10.1063/5.0072700

International, A. (2015). Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates.

International, A. (2016). Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens.

International, A. (2023). Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate.

Kang, J., Shen, D., Shao, H., Huang, Q., & Liu, X. (2024). Experimental Study on Early-Age Cracking Behavior of Hooked-End Steel Fiber-Reinforced Concrete under Different Curing Temperatures. Journal of Materials in Civil Engineering, 36(10). https://doi.org/10.1061/JMCEE7.MTENG-17246

Li, C., Liu, J., Liu, J., Lv, J., & Yang, Z. (2011b). Quantitative evaluation and mechanism of crack resistance of steel fiber reinforced mortar. Kuei Suan Jen Hsueh Pao Journal of the Chinese Ceramic Society, 39(3), 531–536.

Marcalíková, Z., Procházka, L., Pešata, M., Boháčová, J., & Čajka, R. (2019). Comparison of material properties of steel fiber reinforced concrete with two types of steel fiber. IOP Conference Series: Materials Science and Engineering, 549(1). https://doi.org/10.1088/1757-899X/549/1/012039

Nam, J.W.; Kim, S.M.; Park, S.H.; Han, S. H. (2018). Performance of oxygen/argon plasma-treated steel fibres in cementitious composites. Construction and Building Materials, 189, 169–176. https://doi.org/10.1016/j.conbuildmat.2018.08.198

Nian, T., Wang, M., Li, P., Song, J., Ge, J., & Guo, R. (2024). Enhancing low-temperature crack resistance: A method for establishing meso-models and evaluating steel fiber-reinforced hot recycled asphalt mixtures. Construction and Building Materials, 438. https://doi.org/10.1016/j.conbuildmat.2024.137026

Nieto-Cárdenas, X., Takeuchi, C., Carrillo, J., & Cobos, C. (2023). Performance of non-structural masonry retrofitted with welded wire mesh and steel fibers under axial compression load. AIP Conference Proceedings, 2928(1). https://doi.org/10.1063/5.0170782

Pan, H., & Ma, Y. (2017). Impact Resistance of Steel Fiber Reinforced Concrete and Its Mechanism of Crack Resistance and Toughening. Jianzhu Cailiao Xuebao Journal of Building Materials, 20(6), 956–961. https://doi.org/10.3969/j.issn.1007-9629.2017.06.021

Quirós, L. (2018). Estudio del comportamiento mecánico del mortero reforzado con fibra de coco y modificado con óxido de hierro (Vol. 3, Issue 2). Universidad Pontificia Bolivariana.

Samaniego, V. (2020). En la construcción en Ecuador, la informalidad mata. Universidad Del Azuay. https://www.uazuay.edu.ec/noticias/en-la-construccion-en-ecuador-la-informalidad-mata

Sánchez, D. (2000). Tecnología del concreto y del mortero: Vol. Cuarta.

Shen, W., Chen, S., & Zhang, J. (2022). Calculation of Cracks in Partially Steel Fiber Reinforced Concrete Beams with BFRP Bars. Advances in Materials Science and Engineering, 2022. https://doi.org/10.1155/2022/9158379

Shi, K., Zhang, M., Zhang, T., Li, P., Zhu, J., & Li, L. (2021). Seismic performance of steel fiber reinforced high–strength concrete beam–column joints. Materials, 14(12). https://doi.org/10.3390/ma14123235

Vergara-Perucich, F., Fuster-Farfán, X., Rojas Rubio, I., Hidalgo Dattwyller, R., Rincón Quiroz, S., Álvarez, J. C., Alvarado Peterson, V., Meseguer Ruiz, O., & Lizana Vásquez, F. (2022). Vivienda informal y las organizaciones territoriales en América Latina. Revista de Geografía Norte Grande, 14(81), 5–14. https://doi.org/10.4067/s0718-34022022000100005

Younis, K. H., Jirjees, F. F., Yaba, H. K., & Maruf, S. M. (2021). Experimental study on impact resistance of concrete containing steel fibers. In Key Engineering Materials: Vol. 872 KEM. https://doi.org/10.4028/www.scientific.net/KEM.872.1

Zhang, M., Zhang, S., & Jing, J. (2025). Effect of steel fiber content on fatigue performance of high-strength concrete beams. Scientific Reports, 15(1). https://doi.org/10.1038/s41598-025-96217-x