A Comparative Study on the Influence of Banana and Coconut Fibre on Stabilized Soil Blocks

Kirupairaja Thanushan
University of Jaffna
Sathiparan Navaratnarajah (sakthi@eng.jfn.ac.lk)
University of Jaffna

Research

Keywords: Mortars, Recycling & reuse of materials, Fibre-reinforcement

Posted Date: December 9th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-122119/v1

Abstract

Agricultural waste disposal is among the environmental concerns in many countries. Finding economical uses for this waste by incorporating it in a product is the approach often used to overcome the environmental issue. Banana fibre and coconut coir are major agricultural waste products in Sri Lanka and fewer amounts of these are converted into usable products. Manufacturing cement-stabilized soil blocks incorporating these waste materials can reduce the environmental impact. The present research studied the post-peak behavior and durability of banana fibre and coconut coir-strengthened cement-stabilized soil blocks. Banana fibre-reinforced and coconut coir-reinforced blocks were tested for compression, flexural bending, water absorption, sorptivity and resistance against chemicals, wet-dry weathering and freeze-thaw weathering. The banana fibre showed better post-peak behavior in compression and coconut coir showed better post-peak behavior in flexural. Both fibre reinforcements improved the block's durability against the acid attack, alkaline attack, wet-dry weathering and freeze-thaw weathering. Moreover, the specimen reinforced with coconut fibres was found to exhibit better durability compared to the specimen reinforced with banana fibres.

1. Introduction

Agricultural waste disposal is an environmental concern in several countries. Incorporating this waste into a product is one approach used to overcome the environmental issue. One of the by-products of agricultural waste is natural fibres. Natural fibres extracted from coconut, banana, sugarcane, jute, sisal, oil palm and flex have been used in cementitious material. The purpose of incorporating fibres in cementitious material is to improve ductility, toughness and flexibility. The literature review indicates that both natural fibres and synthetic fibres have been incorporated in the production of cementitious material [1–7]. Even though synthetic fibres showed better performance, using natural fibres is beneficial as it is readily available, inexpensive, low density, biodegradable, energy-efficient and eco-friendly [8].

Another issue that the construction industry has faced in recent years is the scarcity of river sand. This is a fine aggregate used in the production of concrete and cement-sand blocks. The demand for the sand has led to illegal sand mining from the river bed and this has resulted in environmental issues [9]. The possible solution to this is focused on environmentally-friendly construction materials such as compressed earth cement blocks or cement-stabilized soil blocks. The raw material of the stabilized earth block is lateritic soil. This can be obtained from many places and therefore less transportation is required. However, there are major issues concerned with the use of cement-stabilized soil blocks for construction including the brittle behavior of the blocks and their lack of durability [10]. This issue may be overcome by incorporating fibres in the production process of the cement-stabilized soil blocks.

Several research studies have been carried out with fibre-reinforced concrete. In the context of the research work carried out on masonry blocks, the majority of the research has been done with cement-sand blocks [11–14] and adobe [15–17]. Investigations into the suitability of fibre-reinforced and cement-stabilized soil blocks is scarce. Of this, most of the work is focused on determination of its strength

capacity and a few works have reported on the post-peak behavior of cement-stabilized soil blocks [11, 18].

In view of the aforementioned review of the literature, the present study aims to evaluate the characteristics of cement-stabilized soil blocks using locally available natural fibres, specifically banana fibres and coconut fibres. Both fibres are major agricultural waste in Sri Lanka and fewer amounts of these are converted into usable products. The use of this waste as part of stabilizing the earth block's production may reduce the associated environmental concerns. The influence of fibres on the post-peak behavior and durability properties of the stabilized earth block has therefore been studied in the present investigation.

2. Materials And Methodology

2.1 Materials used

The following raw materials were used in the preparation of the mortar mixture:

- Cement: Ordinary Portland cement was used. The specific gravity and bulk density was 3.15 and 1362 kg/m^3 respectively.
- Soil: Locally available soil from the University premises in Kilinochchi, Sri Lanka was used. The specific gravity and apparent density was 2.37 and 1348 kg/m^3 respectively. The soil consisted of 45.8%, 50.2% and 4% of clay and silt, sand and gravel respectively.
- Banana fibre: The fibre was obtained from processing banana stem using a banana fibre extracting machine. It was cut into shorter pieces at an estimated length of 25 mm.
- Coconut coir: Locally available untreated coir was used. It was cut into shorter pieces at a length of length of 25 mm.

Figure 1 illustrates the distribution of the particle size of the materials used in the mortar mix preparation. The material used in the mortar mix is illustrated in Fig. 2(a).

2.2 Mix design

For the casting of the blocks and beams, a cement-sand mortar mix at a ratio of 1: 6 (by volume) was considered. The mortar mixing was done manually with a dry mixture of soil and cement. The fibre was added gradually by scattering it randomly. Then water was added during the mixing process until it became homogeneous. The water to cement ratio was kept at 0.9. The sequence of the specimen preparation is illustrated in Fig. 2(b). The mix design used for the mortar preparation is summarized in Table 1.

Table 1
Mix design of the mortar

Mortar	Cement (kg)	Soil (kg)	Banana fibre (g)	Coconut coir (g)	Water (kg)
Control	1.0	7.1	-	-	0.9
Banana fibre	1.0	7.1	32.4	-	0.9
Coconut coir	1.0	7.1	-	32.4	0.9

2.3 Preparation of the specimen

The cube size was 150 × 150 × 150 mm for the uniaxial compression tests, the beam size was 100 × 100 × 400 mm for the three-point bending tests and the block size was 100 × 100 × 60 mm for the durability tests. For each mortar type, five cubes and five beams were used for the uniaxial compression test and three-point bending test respectively.

2.4 Testing

The mortar cubes, beams and blocks were left to complete moisture curing for 28 days. To determine the physical, mechanical, and durability characteristics of the cement-stabilized soil blocks, tests were carried out according to specific standards.

- Density (ASTM C140 [19])
- Compressive strength (EN 772-1 [20])
- Flexural strength (BS EN 1015-11 [21])
- Saturated water content (ASTM C140 [19])
- Resistance against water, salt water and acid (ASTM C1152M-04 [22])
- Alkaline resistance (ASTM C289-07 [23])
- Wetting and drying resistance (ASTM-D6611 [24])
- Freezing and thawing resistance (ASTM-D560 [25])

To measure the sorptivity, the cubes were oven-dried at 50ºC for 24 hours and then allowed to cool in a normal environmental condition for 24 hours. The cubes were placed in water to the point of being partially submerged at a depth of 5 mm. At regular time intervals (t = 0, 5, 10, 15, 30, 60 and 90 min), the mass of the cubes was measured after the removal of the surface water. Sorptivity was calculated using Eq. (1) [26];

$$\Delta m/\rho A = s\sqrt{t} + I_0 \quad (1)$$

Where t is the measured time (min), ρ is the density of the water (kg/m^3), A is the bed area exposed to the water (m^2), Δm is an increase in weight due to capillary (g), I_0 is initial sorption (mm) and s is the sorption

coefficient (mm/min½).

3. Results And Discussion

Table 2 summarizes the density and saturated water content of both the control blocks and fibre-reinforced blocks. The blocks with banana fibre and coconut coir had a lesser dry density and higher wet density than that of the control blocks. It was observed that with the addition of fibre in the mortar, both the saturated water content and porosity were found to increase. The absorbent nature of banana fibre and coconut fibre was compared to the water absorption of the fine aggregates and the volume of pores in the mortar mix. It allowed more water to be absorbed by the mortar. Both the banana fibre and coconut coir reinforced blocks showed a similar dry density, wet density, water absorption rate and porosity.

Table 2
Physical properties of the blocks

	Control	Banana fibre r/f	Coconut coir r/f
Dry density (kg/m^3)	1792	1776	1778
Wet density (kg/m^3)	2007	2050	2055
Saturated water content (kg/m^3)	215.2	274.7	277.0
Porosity (%)	21.5	27.5	27.7

3.1 Compression behavior

Figure 3 illustrates the compression test results of the control blocks and fibre-reinforced blocks. For the control mortar, due to shear, cracks occurred and the blocks separated into several parts as shown in Fig. 3(a). In the case of the banana and coconut coir reinforced blocks, they showed more ductile behavior. As shown in Fig. 3(b) and (c), even for the larger deformations, the fibres maintained the integrity of the blocks and did not show any brittle failures. For the visuals, both fibre reinforced blocks showed similar behavior.

Figure 4 illustrates the stress-strain behavior of the control block and fibre-reinforced blocks. The results showed that the compressive strength of the banana fibre and coconut coir reinforced blocks was less than the control mortar. The calcium silicate hydrate gel generated from the cement reacts with water and this is responsible for holding the aggregates together. When the fibres were added to the cement-stabilized soil mortar, it reduces the cement content percentage of the overall mix. This leads to a reduction in the compressive strength of the cement-stabilized soil mortar. In all cases, the stress-strain looked similar until it reached peak stress. The post-peak behavior showed substantial variations. Due to the fibres, there was the establishment the tensile resistance at the crack openings and the stress was distributed throughout the mortar. The existence of fibre reduces unstable crack opening and introduces

better-distributed cracking. Hence the cement-stabilized soil blocks with both banana fibre and coconut coir showed better post-peak behavior than the control mortar.

Table 3 summarizes the strain at first crack, compressive strength, compressive stress at the axial strain of 0.06 and the compressive toughness index. The compressive toughness index (CTI) refers to the deformation energy under uniaxial compression for a particular amount of strain [27]. The area inside the stress-strain curve shown in Fig. 4(a) was calculated and the strain was limited to 0.06 in the present study. The higher CTI value for both banana fibre and coconut coir reinforced blocks indicate that the fibre addition improves post-peak behavior and ductility.

Table 3
Compression characteristic of fibre reinforced blocks (standard deviation shown in brackets)

Mix	Δ_P (%)	σ_P (MPa)	$\sigma_{0.06}$ (MPa)	$\sigma_{0.06}/\sigma_P$	$CTI_{0.06}$ (10^{-3})
Control	1.51 (0.09)	3.44 (0.11)	0.51 (0.19)	0.15	83 (12)
Banana fibre r/f	1.50 (0.11)	3.16 (0.08)	1.76 (0.43)	0.56	121 (16)
Coconut coir r/f	1.53 (0.07)	3.11 (0.08)	1.52 (0.21)	0.49	120 (8)

Δ_P - strain at peak load, σ_P - compressive strength, $\sigma_{0.06}$ - compressive stress at the strain of 0.06, $CTI_{0.06}$ - compressive toughness index

3.2 Flexural behavior

Figure 5 illustrates the specimen after the flexural tensile test. It is shown that the fibre addition improved the ductility of the beams. The control mortar beam showed a brittle failure while there was a gradual failure for both the banana fibre and coconut coir reinforced mortar beams. The gradual failure of the fibre mortar may be a consequence of the inclusion of fibres distributing the crack before failure. As observed in Fig. 6, the flexural tensile strength is slightly reduced with the addition of fibres. The lower flexural tensile strength observed for the coconut coir reinforced beams was 0.92 MPa, which is 13.2% less than the control beams. The corresponding value for the banana fibre reinforced beams was 1.01 MPa and 4.7% respectively.

Flexural toughness index is an important parameter involved when studying the post-peak characteristics of the blocks. Toughness is determined according to ASTM C1018 [28] by measuring the area under the load versus the deflection curve up to a specific level of deflection. The toughness index is calculated by dividing the toughness at a particular deflection by the first-crack toughness. Three deflections at 3, 5.5 and 10 times the first-crack deflection were considered in this study and the corresponding toughness

index was defined as I_5, I_{10} and I_{20} respectively. Table 4 summarizes the first crack deflection, the modulus of the rupture and the toughness indices. From the results, it can be seen that the value of the toughness indices for the coconut coir reinforced beams is larger than that for the banana fibre reinforced beams. However, both fibre beams had higher toughness indices than the control mortar beam.

Table 4
Test results of mortar beams in flexural (standard deviation shown in brackets)

Mix	Modulus of rupture	First-crack deflection	Toughness indices		
	(MPa)	(mm)	I_5	I_{10}	I_{20}
Control	1.06 (0.05)	0.87 (0.05)	1.21	1.23	1.24
Banana fibre r/f	1.01 (0.03)	0.86 (0.02)	2.09	2.45	2.59
Coconut coir r/f	0.92 (0.02)	0.84 (0.02)	2.16	3.04	3.76

3.3 Sorptivity

Figure 7 illustrates the sorption rate of the cement-stabilized soil blocks. The sorptivity coefficients were calculated from the gradient of the sorption rate versus the square root of the time curve shown in Fig. 7. The sorptivity coefficients in the initial stage were 0.68, 0.98 and 1.00 mm/min^{½} for the control, banana fibre and coconut coir reinforced blocks respectively. These results reveal that the fibre addition to blocks resulted in the water being absorbed at a faster rate. The main factor that affects the capillary rise is the porous nature of the fibre reinforced blocks.

3.4 Chemical resistance

Figure 8 illustrates the reduction of compressive strength of the cement-stabilized soil blocks which were kept in an outside environment, submerged in water, submerged in saltwater, submerged in a 3% NaOH solution and submerged in a 3% H_2SO_4 acid solution. The test results showed that:

- The compressive strength reduction of all three types of blocks which were kept outside in the environment, submerged in water and submerged in saltwater varied between 1 and 2%. These conditions therefore do not affect the compressive strength of the blocks.
- Both the control and fibre-reinforced blocks showed that they were the most vulnerable against alkaline and acid attacks. The compressive strength reduction was 6.6%, 6.1% and 4.8% for the control, banana fibre and coconut coir reinforced blocks respectively.
- In the study of their resistance to acid attacks, the compressive strength reduction was 14.7%, 9.4% and 7.9% for the control, banana fibre and coconut coir reinforced blocks respectively.

This demonstrates that the inclusion of fibres, especially coconut coir, within cement-stabilized soil blocks offers an improvement in durability against alkaline and acid attacks.

3.5 Freeze and thaw resistance

Figure 9 illustrates the compressive strength reduction after the particular number of freeze-thaw cycles. It was observed that the compressive strength reduction was increased as the freeze-thaw cycles increases. However, the inclusion of fibres, especially coconut coir, in the blocks resulted in less of a strength reduction. After 12 freeze-thaw cycles, the strength reduction of the control, banana fibre and coconut coir reinforced blocks was 33%, 25% and 19% respectively. This revealed that the mortar reinforced with banana fibre and coconut coir improved the durability of the blocks against freeze-thaw cycles.

3.6 Wet and dry resistance

Figure 10 illustrates the compressive strength reduction after wet and dry cycles. It was observed that the compressive strength reduction was increased as the wet and dry cycles increased. The blocks with the coconut coir addition had a better level of performance than the control and banana reinforced blocks. After 12 wet-dry cycles, the strength reduction for the control, banana fibre and coconut coir reinforced blocks was 25%, 24% and 22% respectively. It has been shown that mortar reinforced with coconut coir improved the durability against wet-dry cycles. However, the improvement was not as much as the freeze-thaw resistance.

4. Conclusion

This study has evaluated the post-peak performance and durability of cement-stabilized soil blocks after incorporating banana fibre and coconut fibre reinforcements. The major findings can be summarized as follows:

- Blocks with banana fibre and coconut coir showed a lesser dry density and higher wet density than the control blocks. Both banana fibre and coconut coir reinforced blocks showed a similar dry density, wet density, water absorption rate, porosity and sorptivity.
- The presence of fibres reduced the compressive and flexural tensile strength. The banana fibre reinforced blocks showed slightly better performance than the coconut coir blocks. However, the fibre addition enhanced the residual strength, ductility and toughness. Between the two fibres, banana fibres showed better post-peak behavior in compression and coconut coir showed better post-peak behavior in flexural.
- Both fibre reinforcements improved the resistance of the blocks against acid attacks, alkaline attacks, freeze-thaw cycles and wet-dry cycles. In all cases, the coconut coir reinforcement had a better level of performance than the banana fibre reinforcement.

These results indicate that the addition of banana fibre and coconut fibre offer post-peak compressive and flexural behavior and durability improvements. These benefits come as a trade-off in the form of a reduction in the initial compressive and flexural strengths.

This study focused on how banana fibre and coconut fibre influence the mechanical properties and durability characteristics of cement-stabilized soil blocks. Further tests such as a micro-structural analysis and the examination of the porous characteristics, fire resistance and thermal conductivity are needed to assess the feasibility of the fibre-reinforced cement-stabilized soil blocks for the purpose of house unit construction. It is recommended to conduct further feasibility studies on the use of these fibre-based cement-stabilized soil blocks in their intended actual application.

Declarations

Availability of data and materials

Data and materials are available on request.

Competing interests

The authors declare that they have no competing interests.

Funding

No funding to report.

Authors' contributions

Thanushan carried out the experimental works. Sathiparan coordinated the research work and wrote the paper. All authors read and approved the final manuscript.

Acknowledgements

The authors express their sincere gratitude for the support given by Concrete Lab, Department of Civil Engineering, Faculty of Engineering, University of Jaffna.

References

1. De Pellegrin MZ, Acordi J and Montedo ORK. Influence of the length and the content of cellulose fibres obtained from sugarcane bagasse on the mechanical properties of fibre-reinforced mortar composites. *Journal of Natural Fibres* 2019; https://doi.org/10.1080/15440478.2019.1612311.
2. Fujiyama R, Darwish F and Pereira MV. Mechanical characterization of sisal reinforced cement mortar. *Theoretical and Applied Mechanics Letters* 2014; 4(6): 061002.
3. Gil L, Bernat-Masó E and Cañavate FJ. Changes in properties of cement and lime mortars when incorporating fibres from end-of-life tires. *Fibres* 2016; 4(1): 7.
4. Mansur MA and Aziz MA. A study of jute fibre reinforced cement composites. *International Journal of Cement Composites and Lightweight Concrete* 1982; 4(2): 75-82.

5. Mostafa M and Uddin N. Effect of banana fibres on the compressive and flexural strength of compressed earth blocks. *Buildings* 2015; 5: 282-296.
6. Ozerkan NG, Ahsan B, Mansour S and Iyengar SR. Mechanical performance and durability of treated palm fibre reinforced mortars. *International Journal of Sustainable Built Environment* 2013; 2(2): 131-142.
7. Sathiparan N, Rupasinghe MN, Bhasura HMP. Performance of coconut coir reinforced hydraulic cement mortar for surface plastering application. *Construction and Building Materials* 2017; 142: 23-30.
8. Hwang C, Tran V, Hong J and Hsieh Y. Effects of short coconut fibre on the mechanical properties, plastic cracking behavior, and impact resistance of cementitious composites. *Construction and Building Materials* 2016; 127: 984–992.
9. Sathiparan N and De Zoysa HTSM. The effects of using agricultural waste as partial substitute for sand in cement blocks. *Journal of Building Engineering* 2018; 19: 216-227.
10. Yogananth Y, Thanushan K, Sangeeth P, Gracian J and Sathiparan N. Comparison of strength and durability properties between earth-cement blocks and cement-sand blocks. *Innovative Infrastructure Solutions* 2019; 4:50.
11. Aymerich F, Fenu L and Meloni P. Effect of reinforcing wool fibres on fracture and energy absorption properties of an earthen material. *Construction and Building Materials 2012;* 27: 66–72.
12. Galán-Marín C, Rivera-Gómez C and Petric J. Clay-based composite stabilized with natural polymer and fibre. *Construction and Building Materials* 2010; 24: 1462–1468.
13. Taallah B, Guettala A, Guettala S and Kriker A. Mechanical properties and hygroscopicity behavior of compressed earth block filled by date palm fibres. *Construction and Building Materials* 2014; 59: 161–168.
14. Mostafa M and Uddin N. Experimental analysis of compressed earth block (CEB) with banana fibres resisting flexural and compression forces. *Case Studies in Construction Materials* 2016; 5:53–63.
15. Danso H, Martinson DB, Ali M and Williams JB. Mechanisms by which the inclusion of natural fibres enhance the properties of soil blocks for construction. *Journal of Composite Materials 2017;* 51: 3835-3845.
16. Millogo Y, Morel J, Aubert J and Ghavami K. Experimental analysis of pressed adobe blocks reinforced with hibiscus cannabinus fibres. *Construction and Building Materials* 2014; 52: 71–78.
17. Quagliarini E and Lenci S. The influence of natural stabilizers and natural fibres on the mechanical properties of ancient Roman adobe bricks. *Journal of Cultural Heritage* 2010; 11: 309–314.
18. Thanushan K, Yogananth Y, Sangeeth P, Gracian J and Sathiparan N. Strength and durability characteristics of coconut fibre reinforced earth cement blocks. *Journal of Natural Fibres* 2019; https://doi:10.1080/15440478.2019.1652220.
19. ASTM C140/C140M: Standard test methods for sampling and testing concrete masonry units and related units. ASTM International, West Conshohocken, PA, USA; 2017.

20. BS EN 772-1: Methods of test for masonry units - Part 1: Determination of compressive strength. Brussels: Comité Européen de Normalisation, Brussels; 2011.
21. BS EN 1015-11: Methods of test for mortar for masonry - Part 11: determination of flexural and compressive strength of hardened mortar. Brussels: Comité Européen de Normalisation, Brussels; 1999.
22. ASTM C1152M-04: Standard test method for acid-soluble chloride in mortar and concrete. ASTM International, West Conshohocken, PA, USA; 2012.
23. ASTM C289-07: Standard test method for potential alkali-silica reactivity of aggregates (chemical method). ASTM International, West Conshohocken, PA, USA; 1996.
24. ASTM D6611-16: Standard test method for wet and dry yarn-on-yarn abrasion resistance. ASTM International, West Conshohocken, PA, USA; 2016.
25. ASTM D560/D560M: Standard test methods for freezing and thawing compacted soil-cement mixtures. ASTM International, West Conshohocken, PA, USA; 2016.
26. Sathiparan N, Anjalee WAV and Kandage KKS. The scale effect on small-scale modeling of cement block masonry. *Materials and Structures* 2016; 49(7): 2935-2946.
27. Rasheed MA and Suriya Prakash A. Mechanical behavior of sustainable hybrid-synthetic fibre reinforced cellular light weight concrete for structural applications of masonry. *Construction and Building Materials* 2015; 98: 631-640.
28. ASTM C1018: Flexural toughness and first-crack strength of fibre-reinforced concrete (using beam with third-point loading). ASTM International, West Conshohocken, PA, USA; 1997

Figures

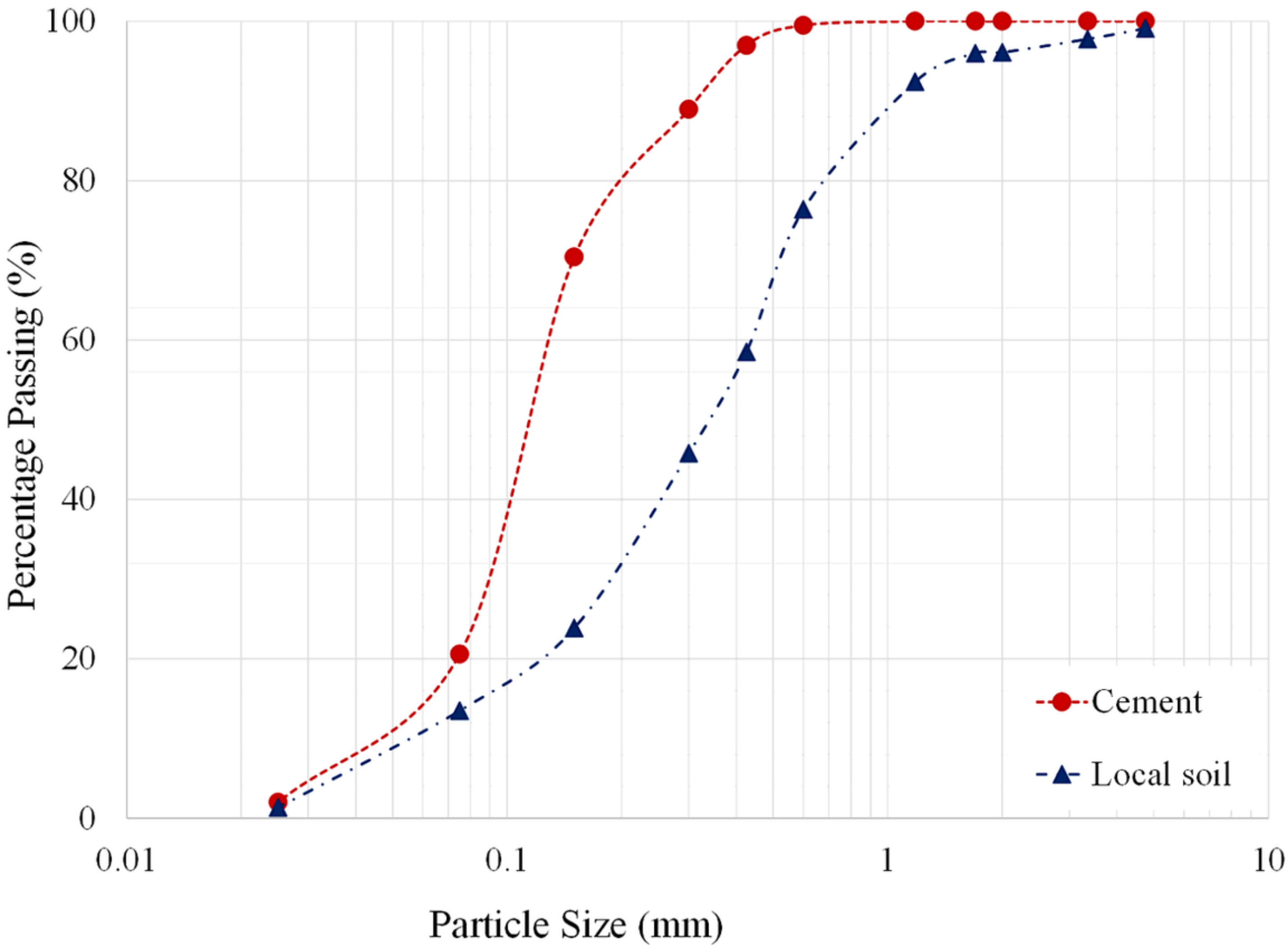

Figure 1

Particle size distribution of cement and local soil

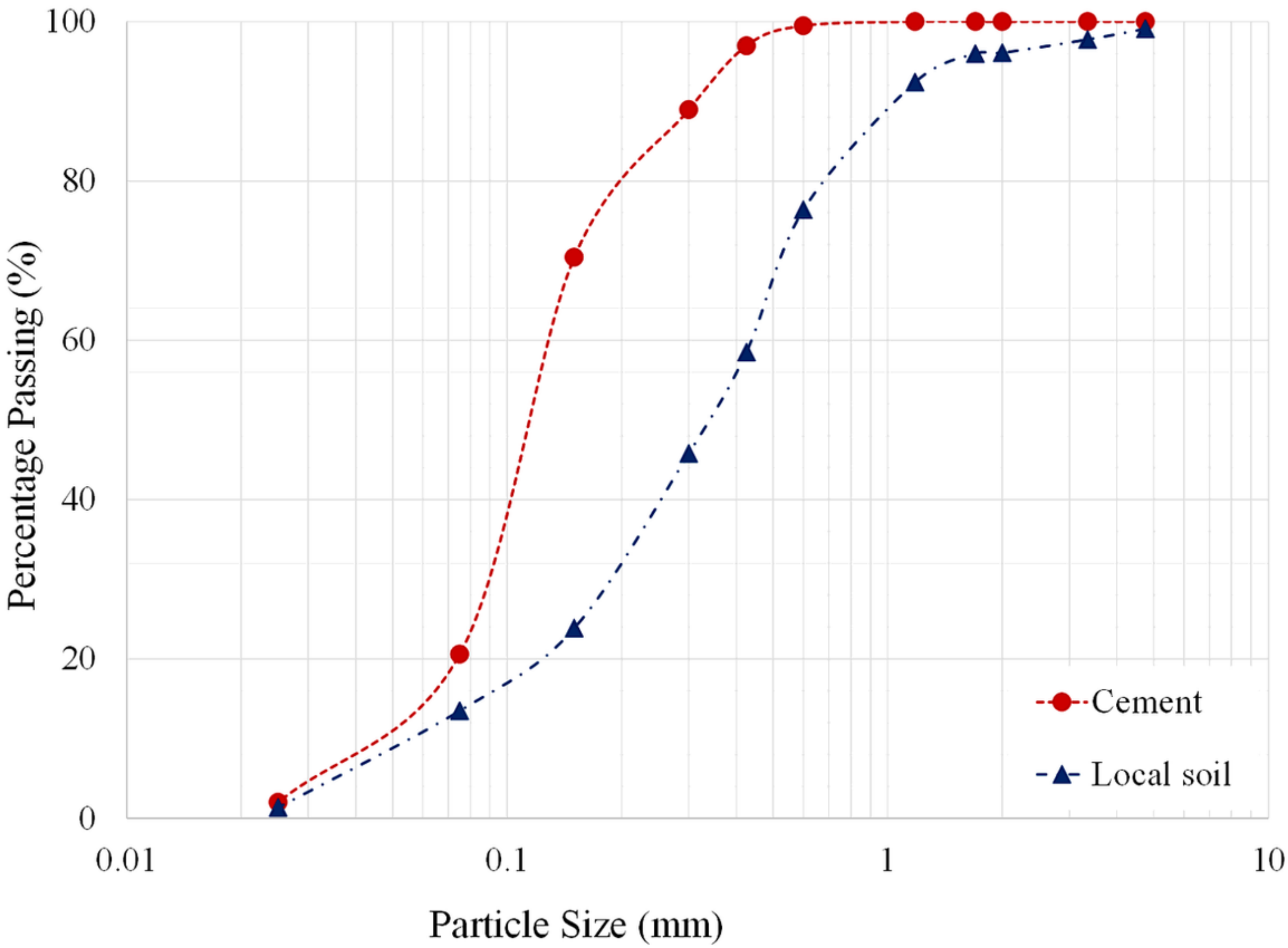

Figure 1

Particle size distribution of cement and local soil

Figure 2

(a) Materials used for mortar and (b) Specimen preparation sequence

Figure 2

(a) Materials used for mortar and (b) Specimen preparation sequence

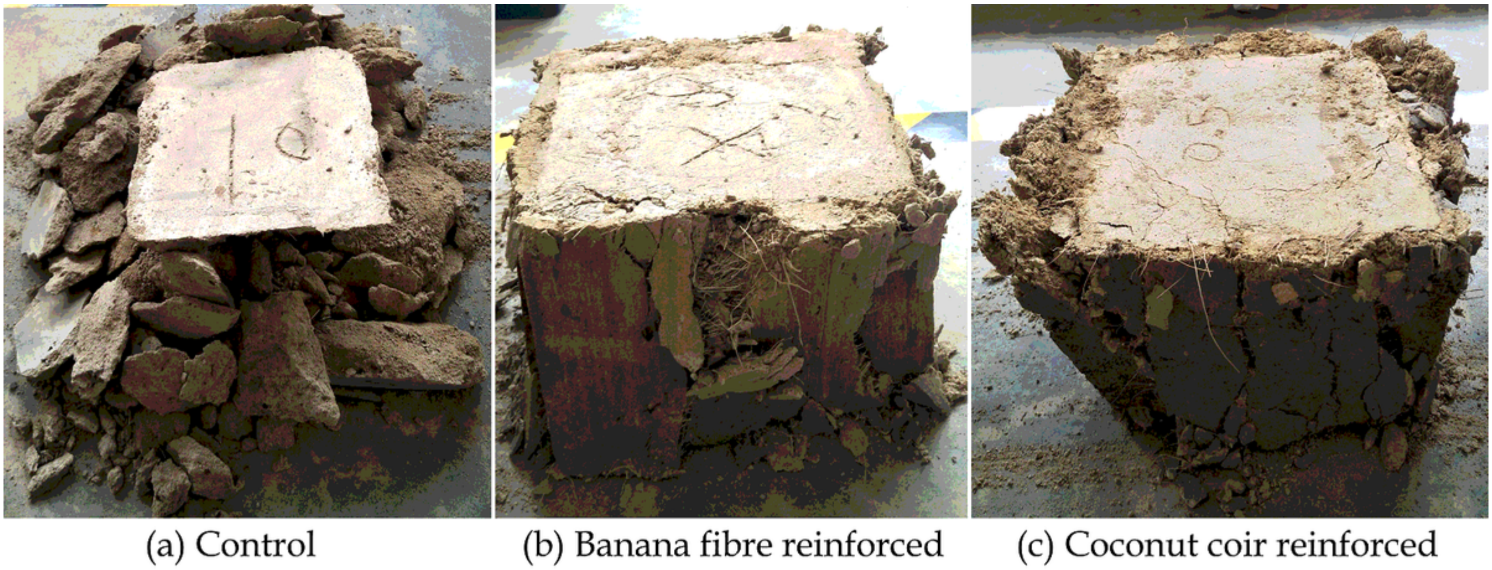

Figure 3

Failure pattern of the mortar cubes in compression

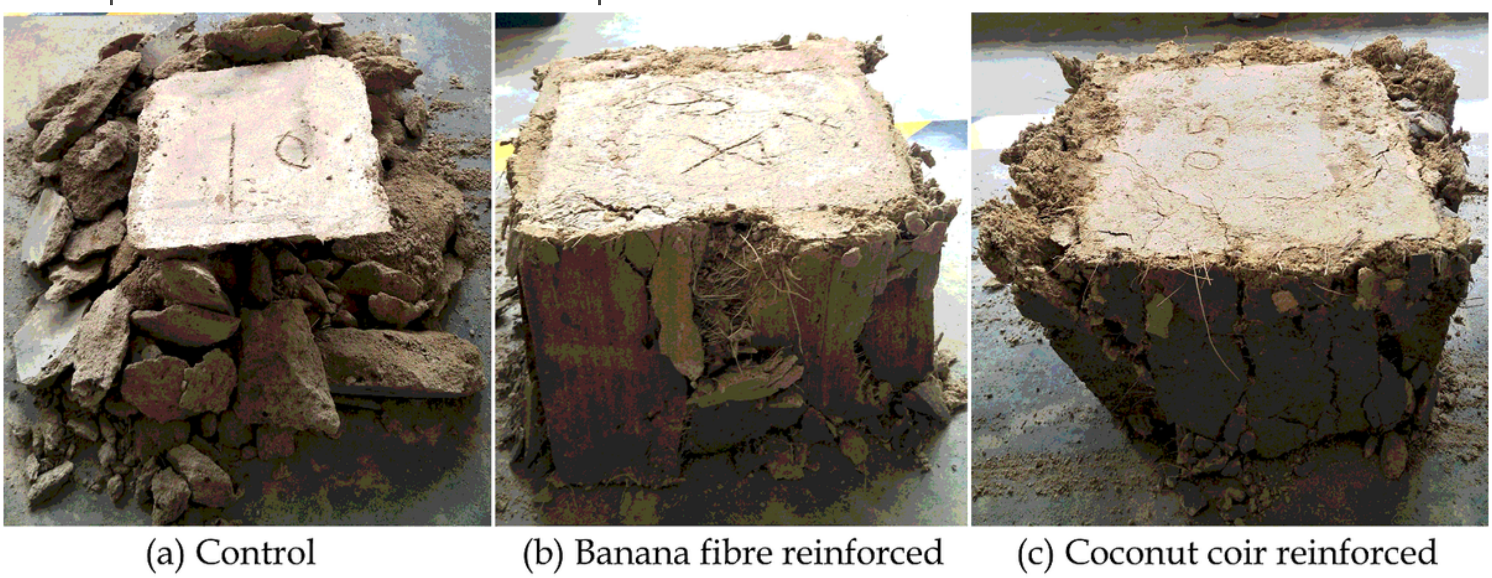

Figure 3

Failure pattern of the mortar cubes in compression

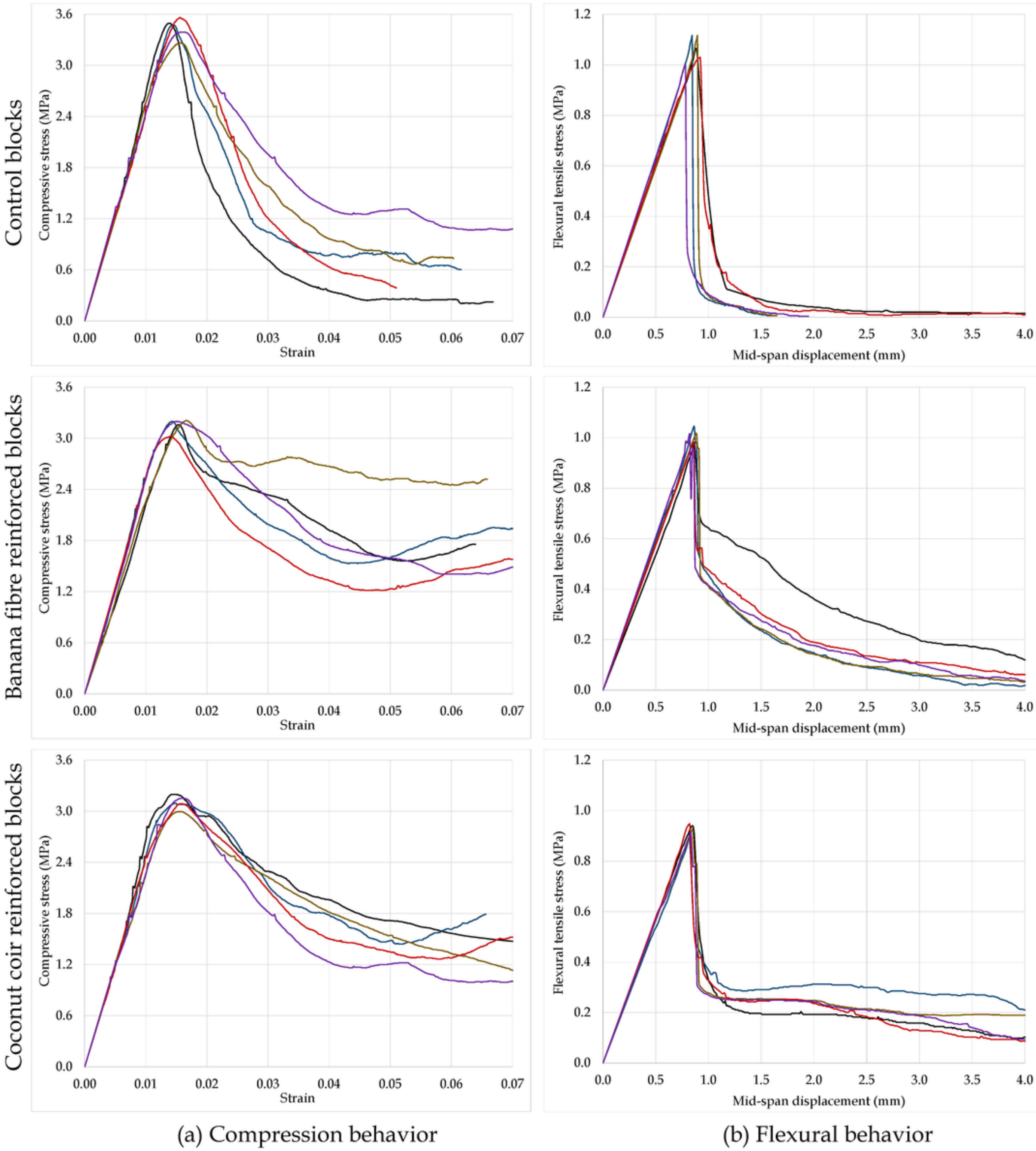

Figure 4

Test results (a) stress−strain curves from compression test and (b) flexural tensile stress vs. mid-span displacement from three-point test

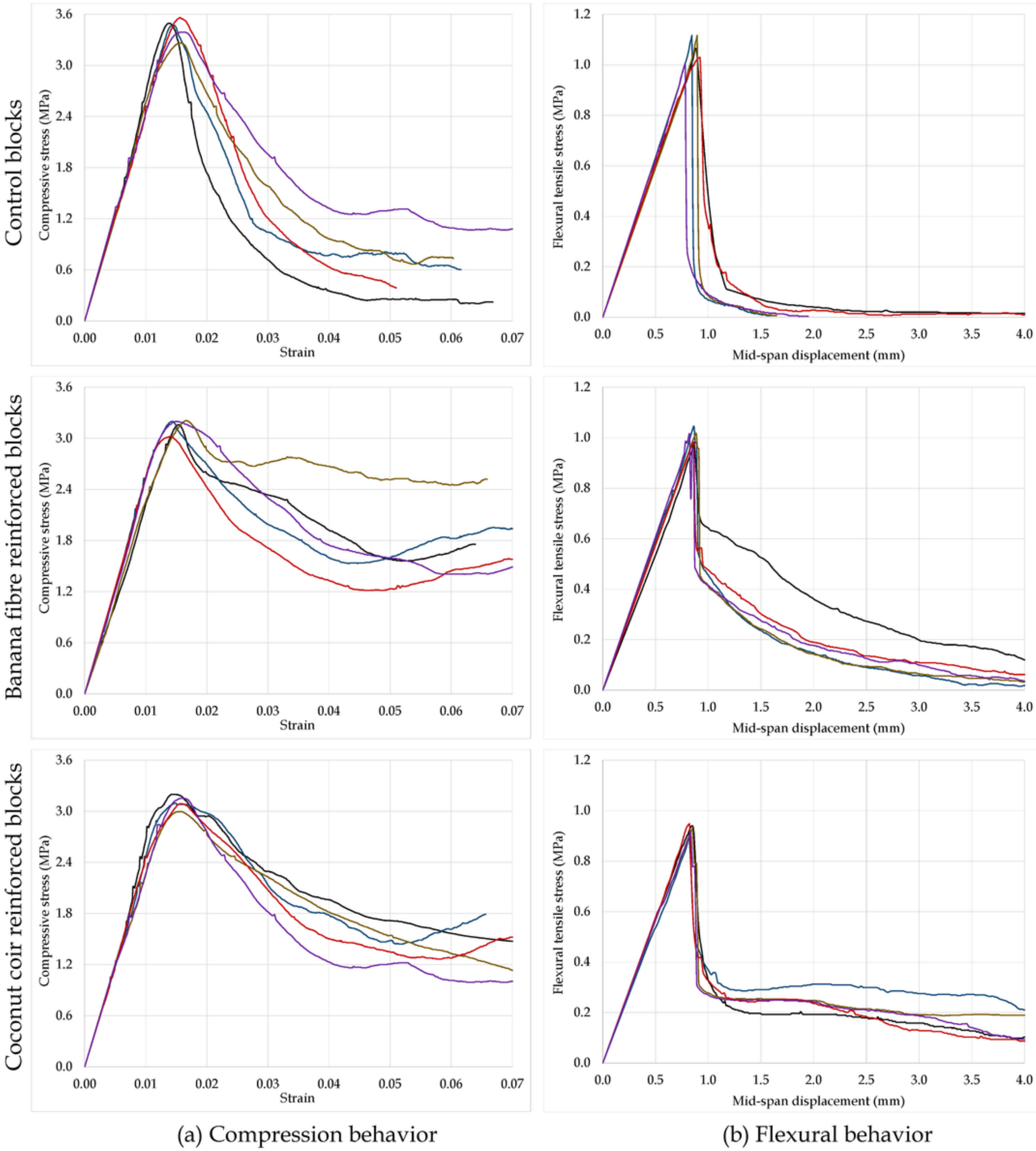

Figure 4

Test results (a) stress−strain curves from compression test and (b) flexural tensile stress vs. mid-span displacement from three-point test

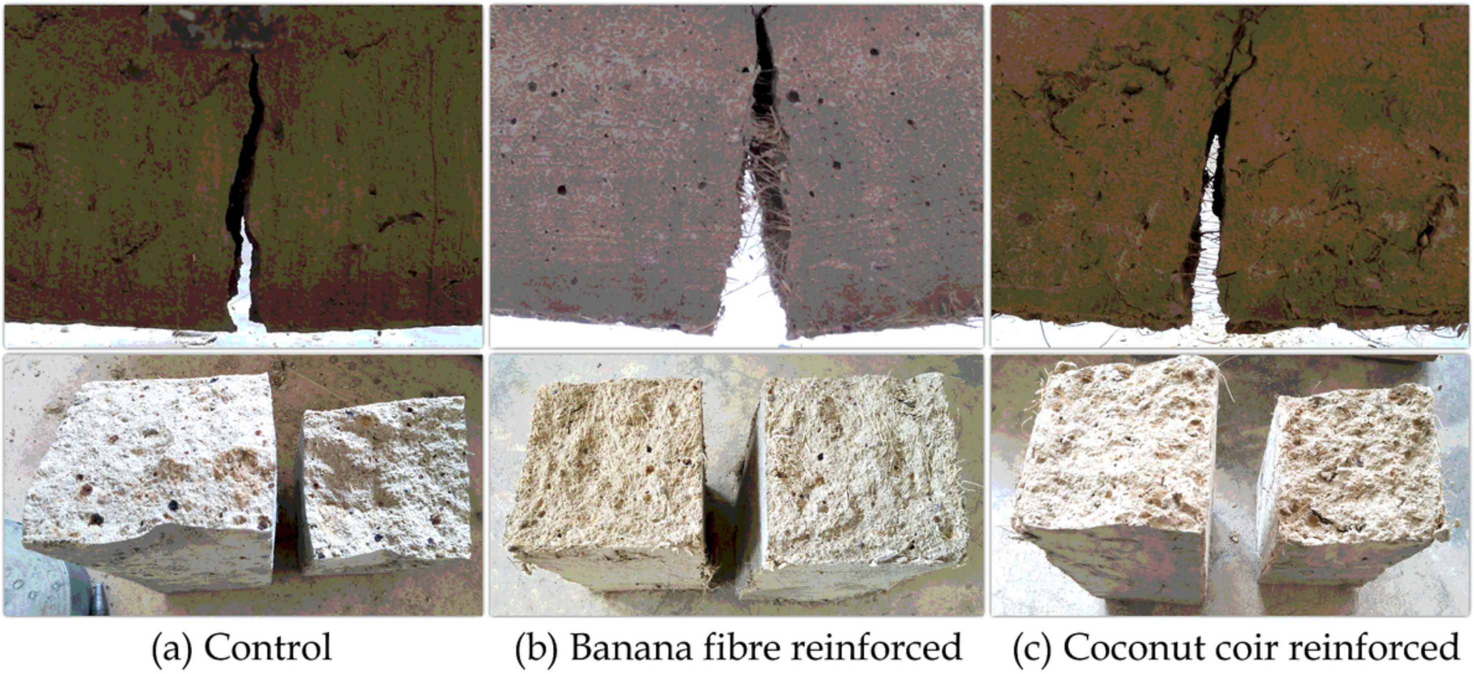

Figure 5

Failure pattern and cross-section of the mortar beams in flexural

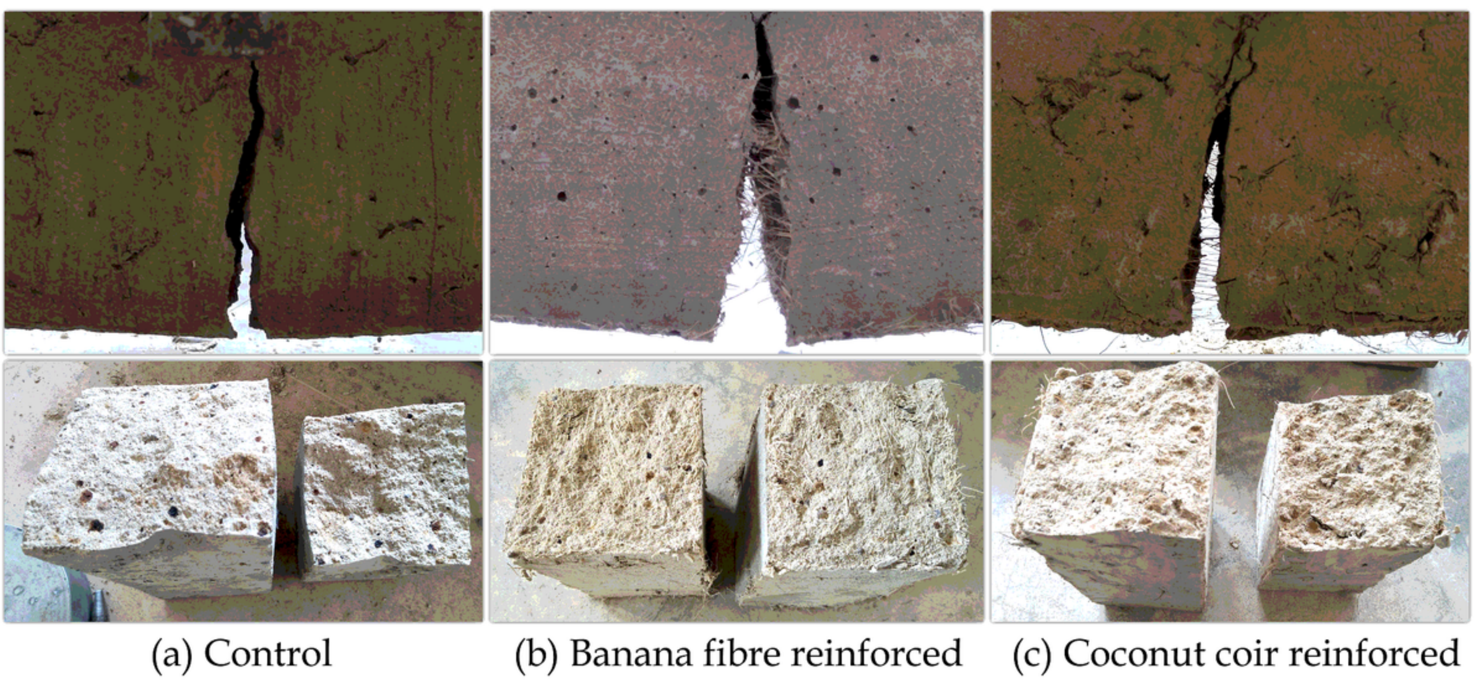

Figure 5

Failure pattern and cross-section of the mortar beams in flexural

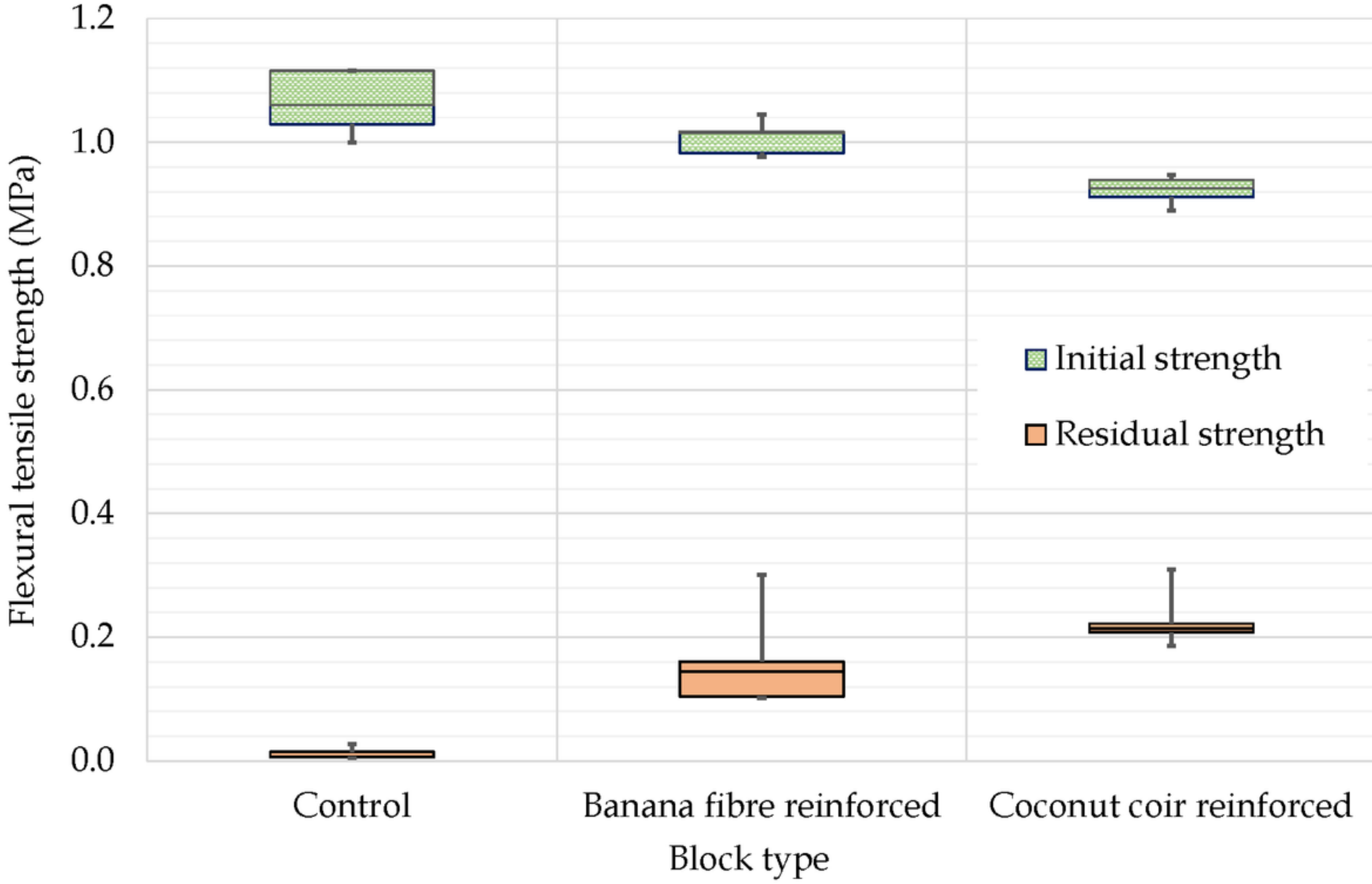

Figure 6

Initial and residual flexural tensile strengths of mortar beams

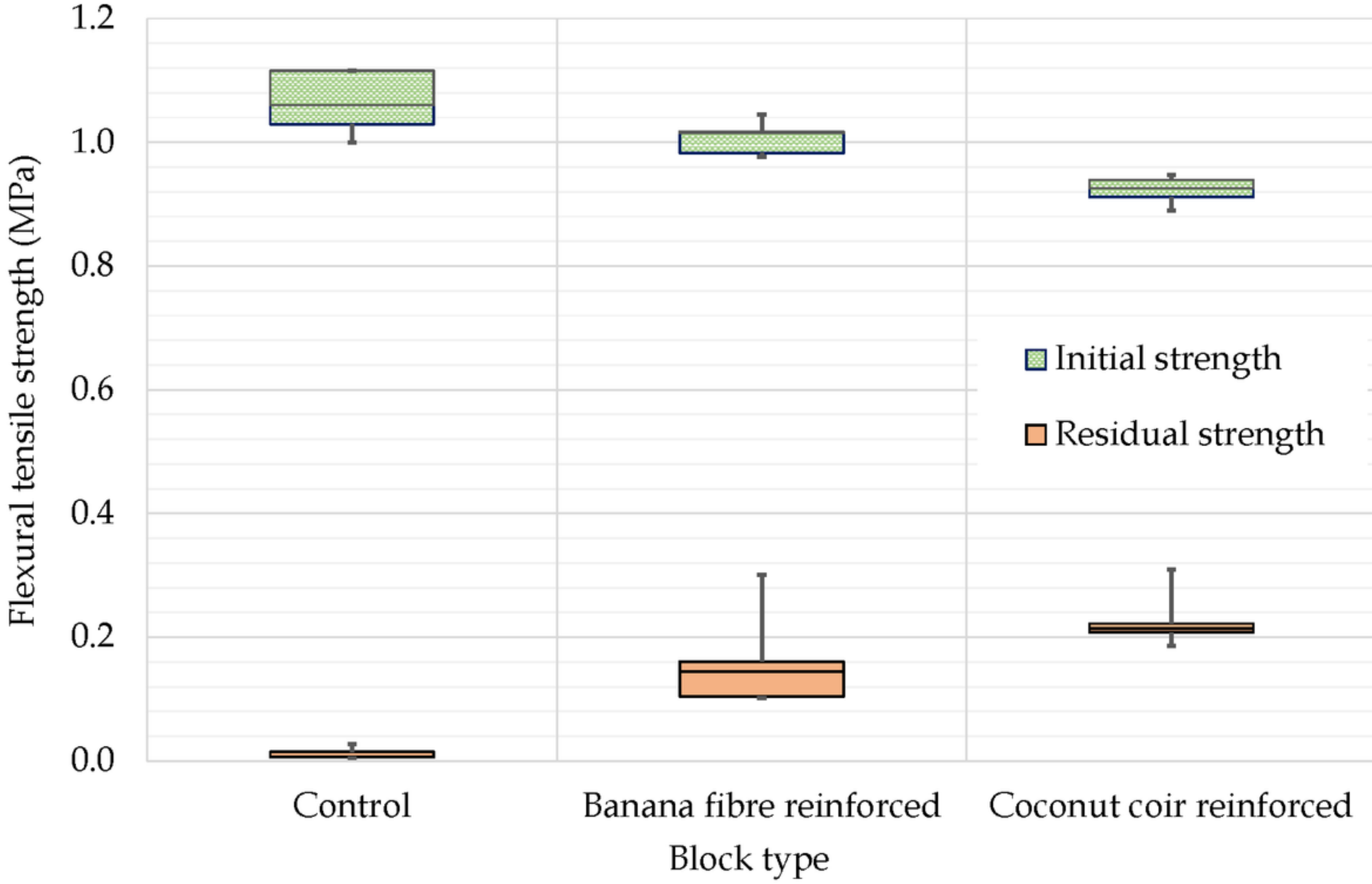

Figure 6

Initial and residual flexural tensile strengths of mortar beams

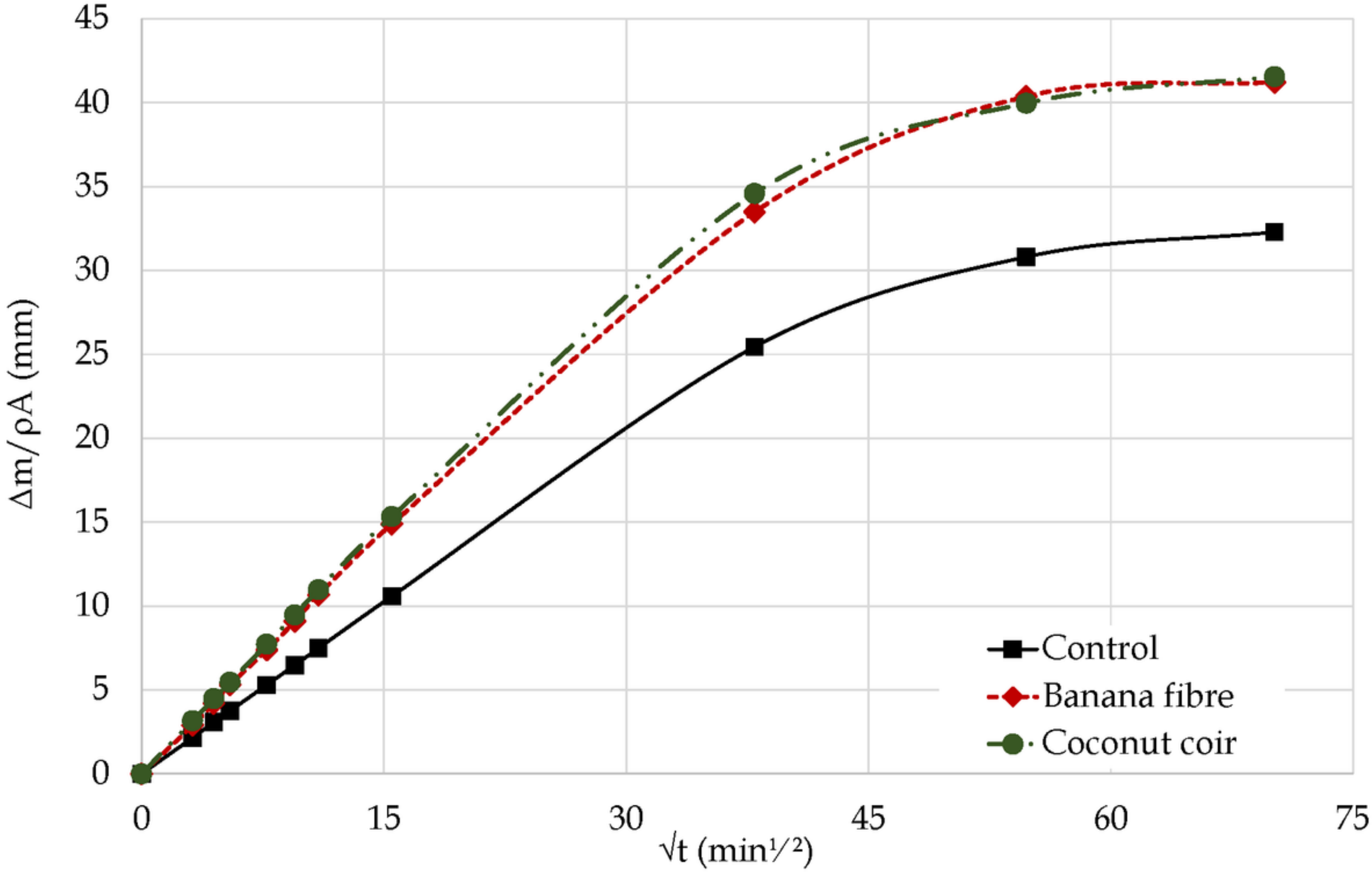

Figure 7

Sorption rate variation of mortars

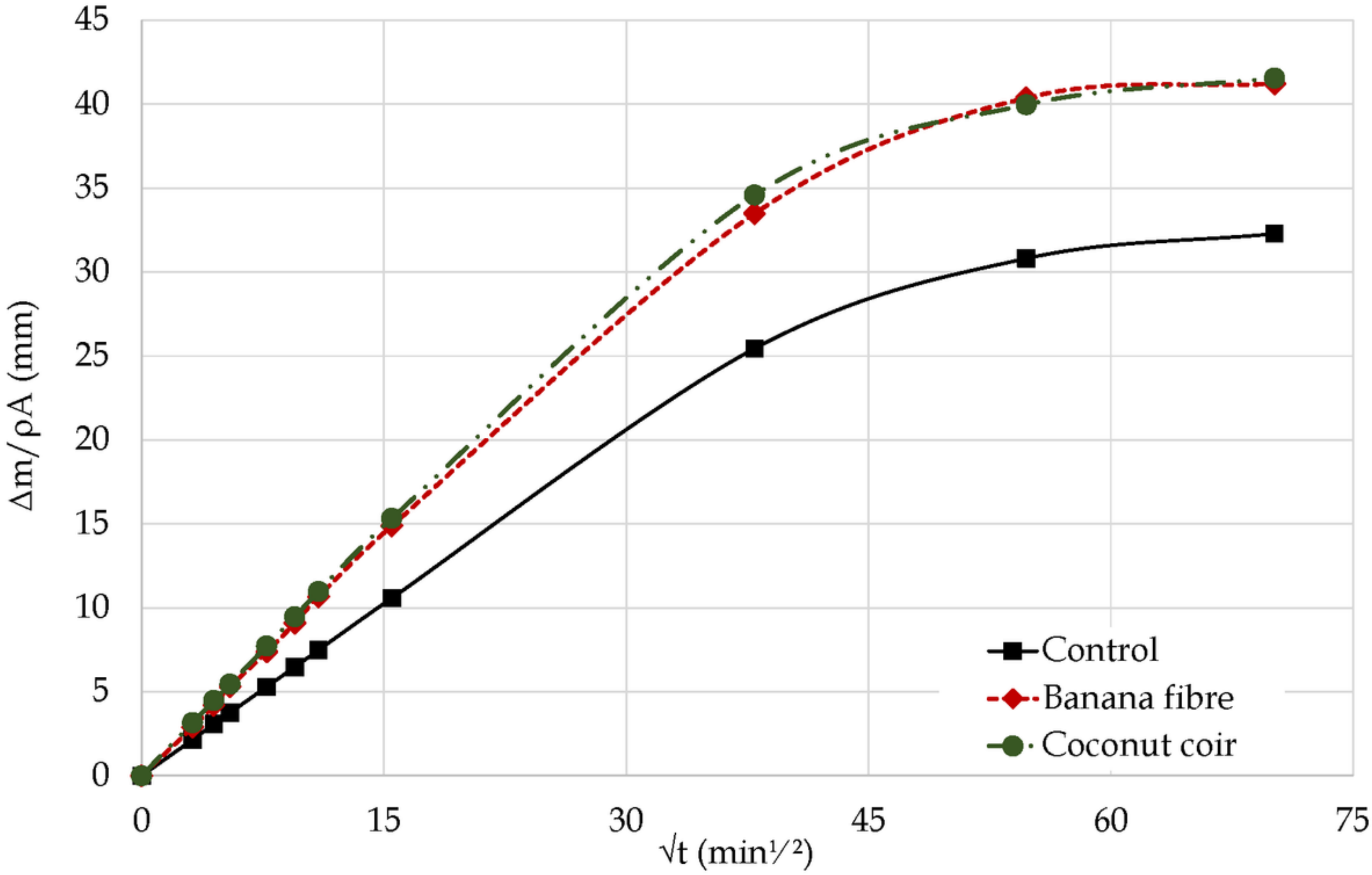

Figure 7

Sorption rate variation of mortars

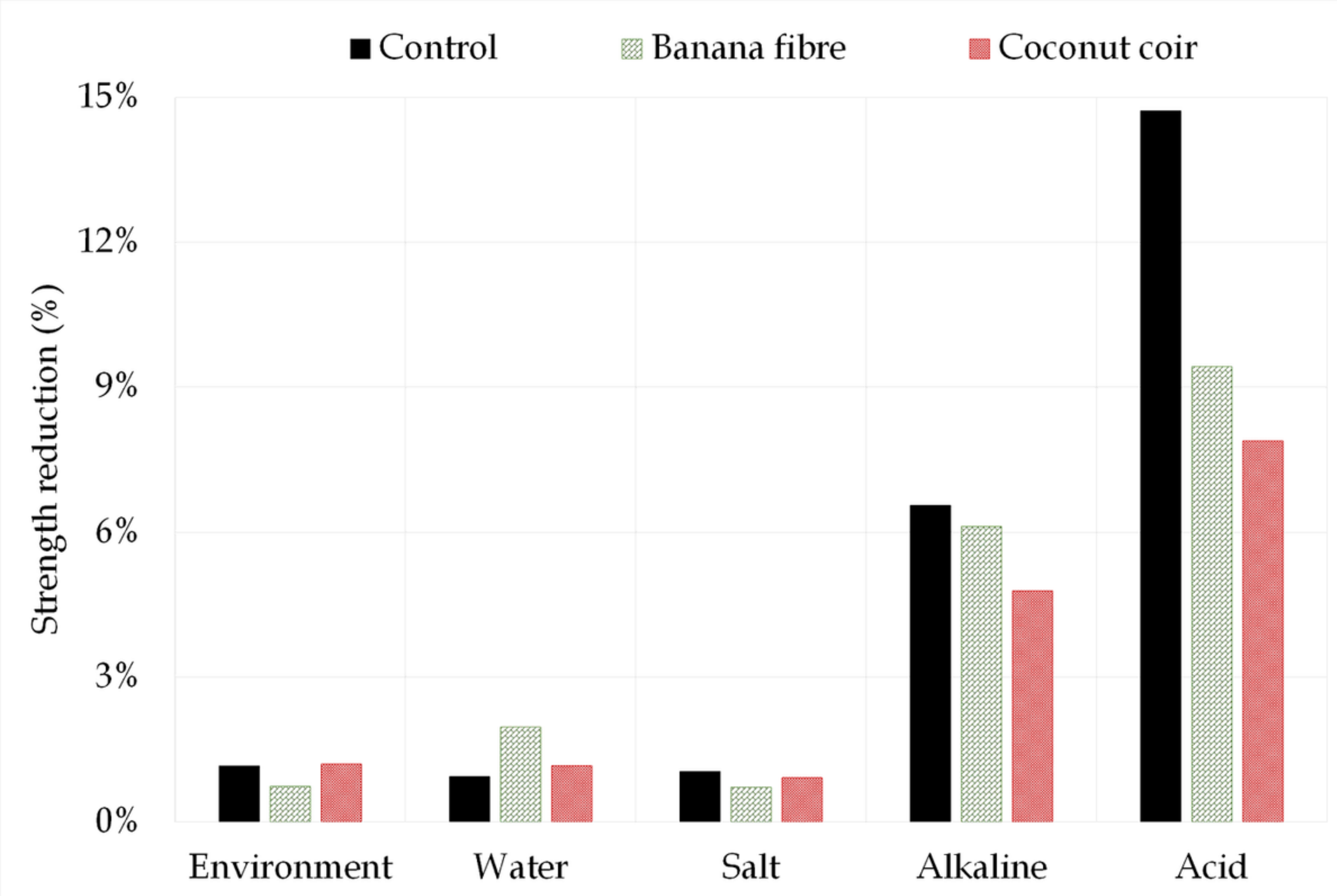

Figure 8

Strength reduction due to chemical attack

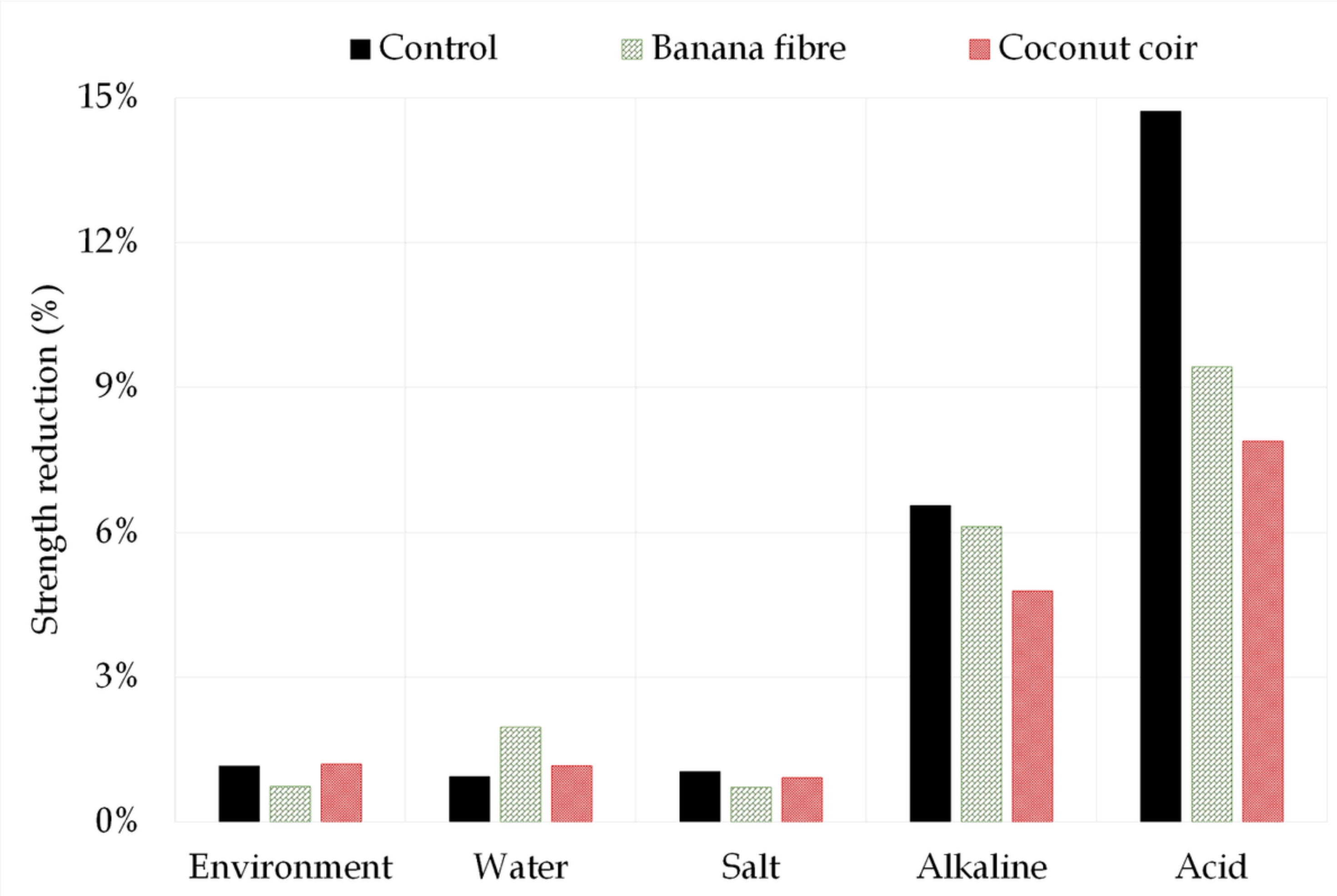

Figure 8

Strength reduction due to chemical attack

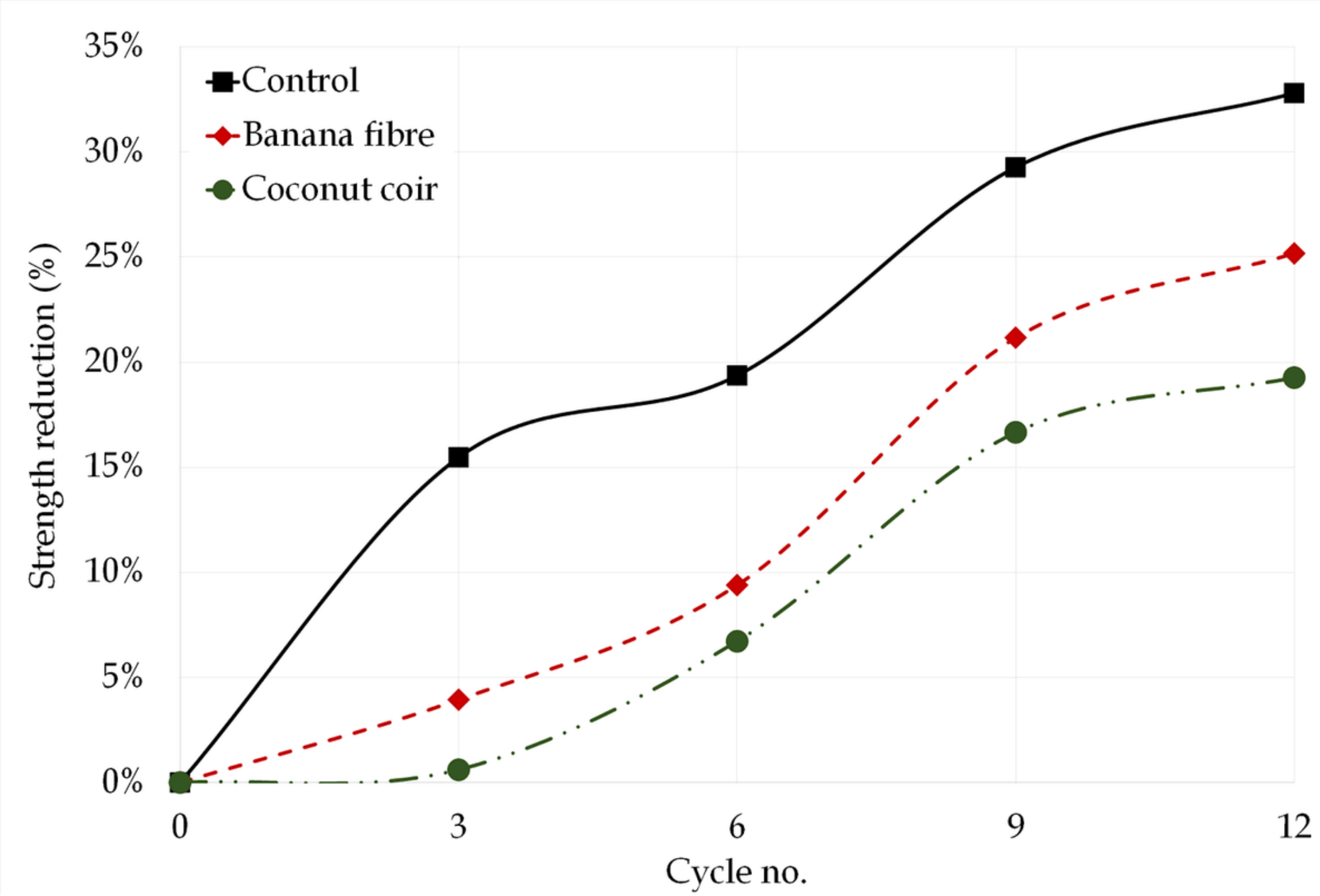

Figure 9

Strength reduction due to freeze and thaw effect

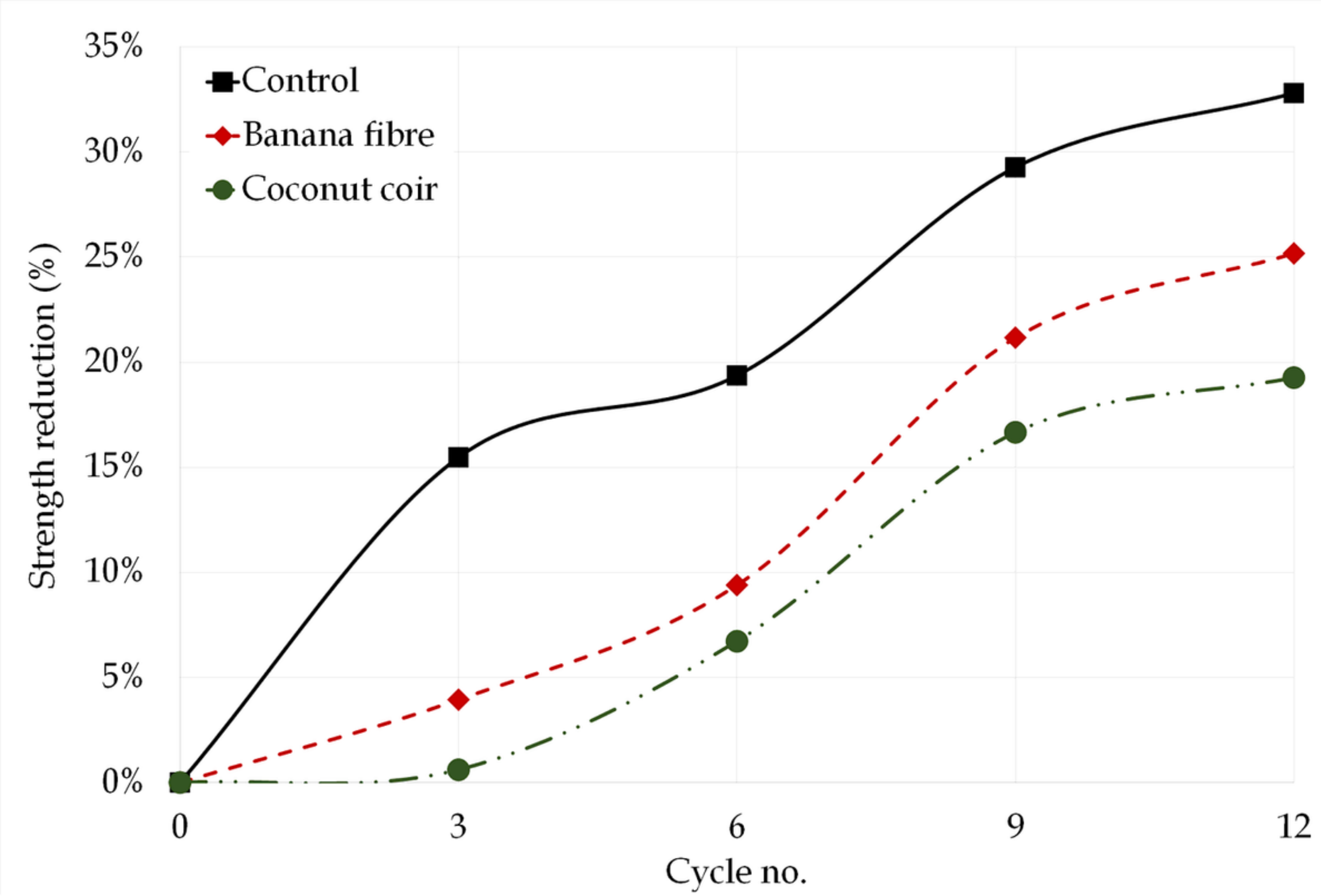

Figure 9

Strength reduction due to freeze and thaw effect

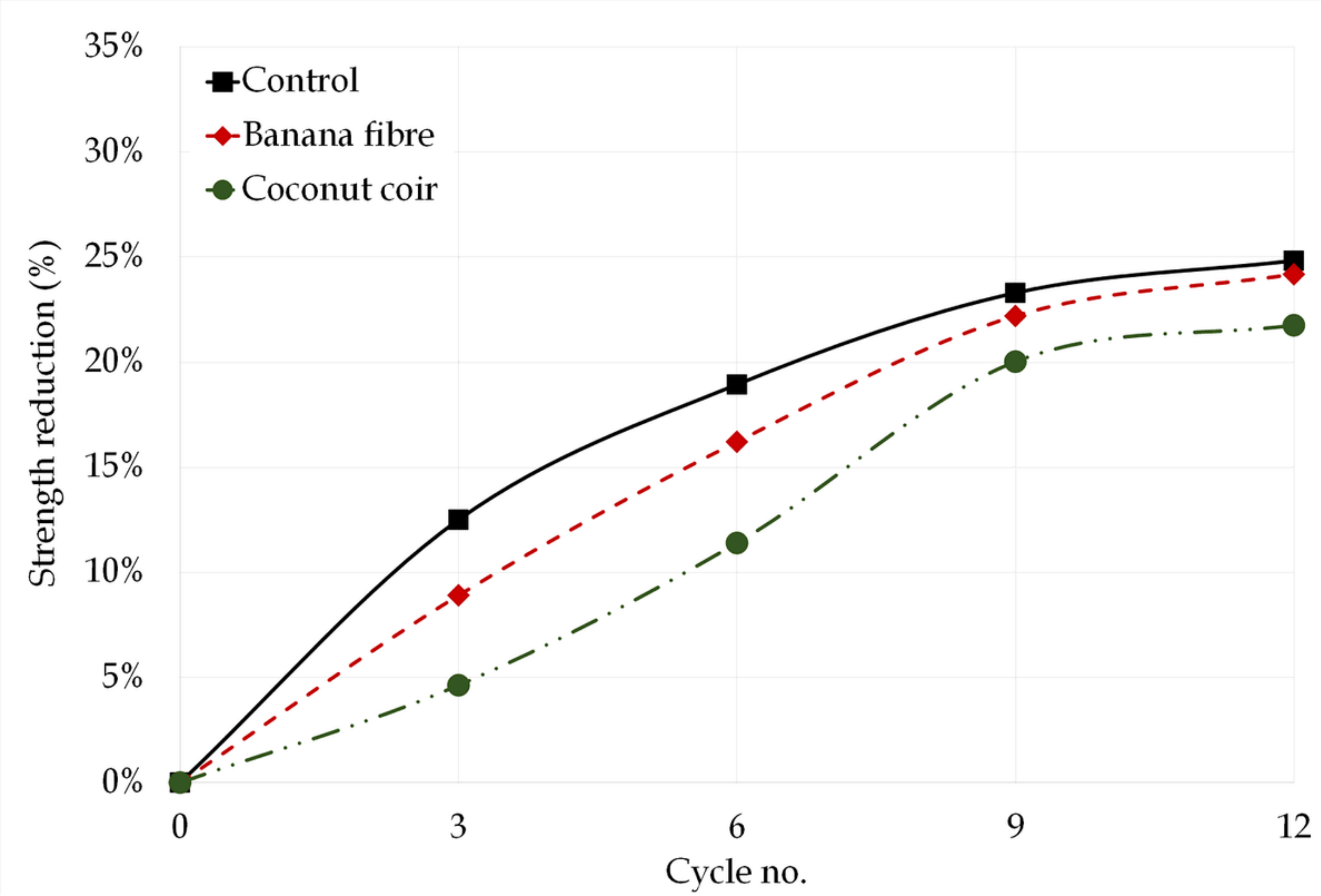

Figure 10

Strength reduction due to wet and dry effect

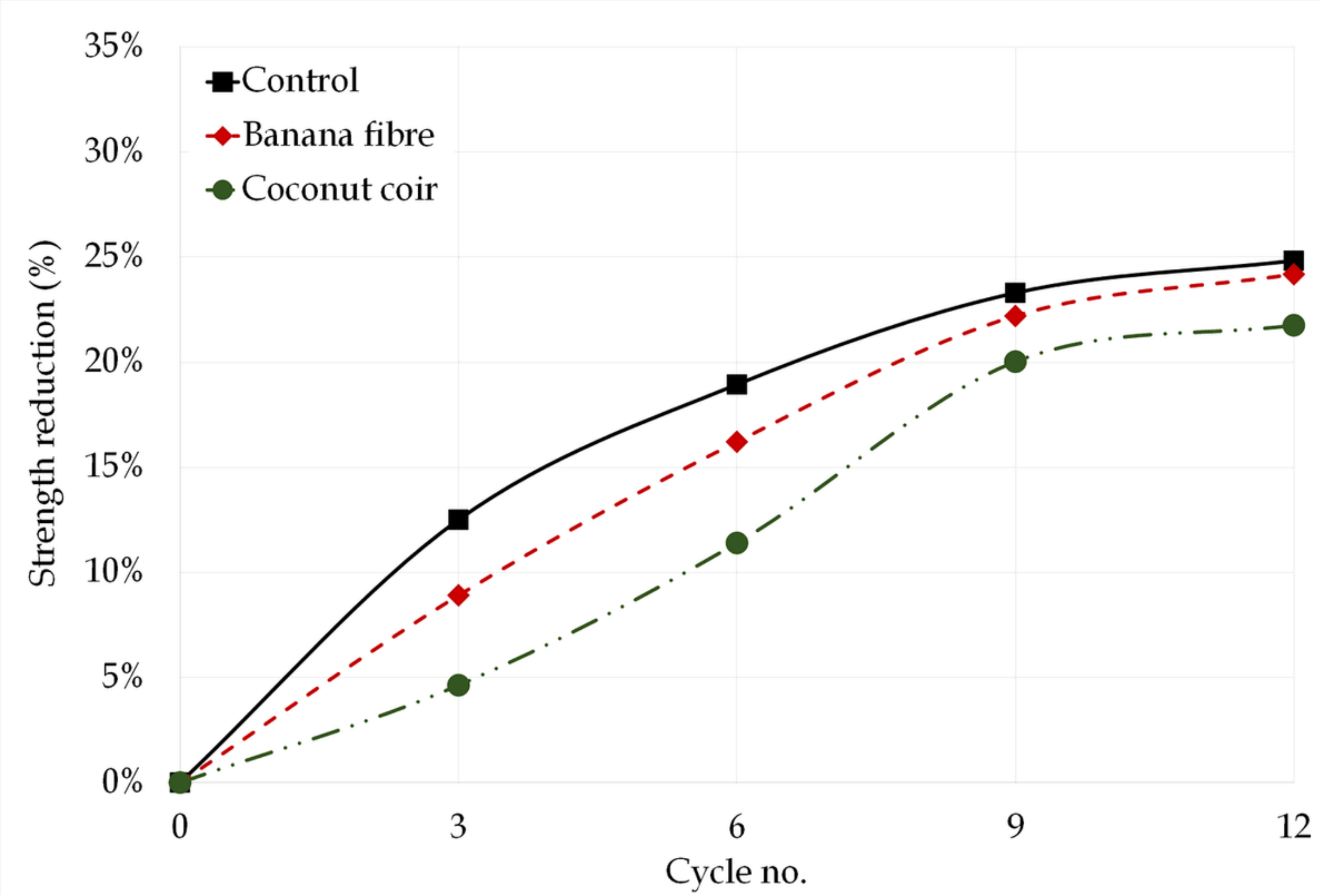

Figure 10

Strength reduction due to wet and dry effect